
Anthropogenic Geomorphology of the Magoye Riverine Landscape, Zambia

ABSTRACT

Aims: This study sought to investigate the role of humans in modification and creation of landforms in river channels with specific focus on the Magoye River. The objectives of this study were to: document geomorphic characteristics of Magoye River, assess anthropogenic activities and landuse/cover change in the buffer zone and, examine key anthropogenic river landforms.

Study design: This study was inspired by analytic eclecticism research philosophy and adopted mixed methods, particularly concurrent research design.

Methodology: The landcover images were analysed using image processing tools in ArcGIS 10.4 for the periods 1990, 2005 and 2020. Descriptive statistics were used to quantitatively visualize the changes in land cover/use. The data was collected using field observation, photography, GPS and a Likert scale tool and, analysed using descriptive statistics, specifically frequency graphs showing mean and standard deviation.

Results: The results showed that sand mining and brick moulding accounted for almost 68% of human activities in the 11.48 km² delineated buffer zone by 2020, compared to 35% in 1990. These punctuated creation of sand conical heaps, stone bunds, pot holes and pools, shallow wells on the river bed, gullies induced by water accessed points, which weakened river banks. Generally, sand mining and brick moulding were the most severe in the buffer zone and they created wide range of deformations riverbanks and beds. The findings further revealed that Magoye River had geomorphologically evolved into Reservoir River covering 80% on the upstream (139.4km) and Sand Bank River accounting 20% on downstream (27.6 km).

Conclusion: The study concludes that, the catchment and buffer zone have undergone degradation propelled by anthropogenic activities, which have punctuated channel morphological degradation. Although the Magoye River channel was highly damaged, it was not beyond regeneration if restoration measures, were collaboratively identified and implemented with the local communities.

Keywords: *Anthropogenic Geomorphology, Buffer zone, Channel Morphology, Magoye River*

1. INTRODUCTION

The scope of anthropogenic geomorphology does not only include the study of artificial landforms, but also the investigation of human-induced surface changes (Chakraborty and Mukhopadhyay, 2015). Anthropogenic river landforms are

alien to the landscape and through establishing new geomorphological conditions humans tend to drastically upset the equilibrium (Chalton and Simm, 2008). Globally, the extent and rate of human-induced geomorphic processes has

become comparable to natural ones and in densely populated areas even exceed the intensity of natural occurring physical processes (Dufour *et al.*, 2015). Before the 1990s, Magoye River used to be perennial (Graf, 2006; GIZ, 2021), but due to human interference especially at catchment and buffer zone scales, the river's perenniality has since the last 40 years been lost. Anthropogenic activities changed the natural state and functions of the Magoye River. Human geomorphic actions may influence environmental changes (Gilvear *et al.*, 2000; WWF, 2016). Magoye River channel is highly vulnerable to impacts associated with human activities and human impacts further do not only influence exogenic processes but even surpasses their efficiency (Mwiinga, 1990; Wassie, 2020). Diverse human activities such as deforestation, intensive agriculture and incidence of fire, stone quarrying and sand mining, building activity and urbanisation especially in riverine buffer zones complement the fluvial processes such as sediment erosion, transportation

and deposition in shaping river channel morphology over time and space (Hickin and Sickingabula, 1988; Poff, 2007).

2. MATERIAL AND METHODS

2.1 Study area

Magoye River is located in the Southern Province of Zambia, and the specific study area is located between 15° 50' S to 15° 58' S and longitude 27°32' E to 27° 37' E. Magoye River is located partly in the District of Pemba, Monze and Mazabuka. The Magoye River flows northbound to the Kafue Flats before reaching the Kafue River, which in turn is a tributary to the major Zambezi River (COWI & SWECO, 2009). The headwaters are located in Pemba around Mookamunga in Muzandu village, Hamaundu chiefdom. The hydrological catchment for Magoye is approximately 2038.2 *km*² while its length is 167 Km (from headwaters to the confluence) (Baumle *et al.*, 2007). Figure 1 shows the geographical location of the Magoye sub-catchment.

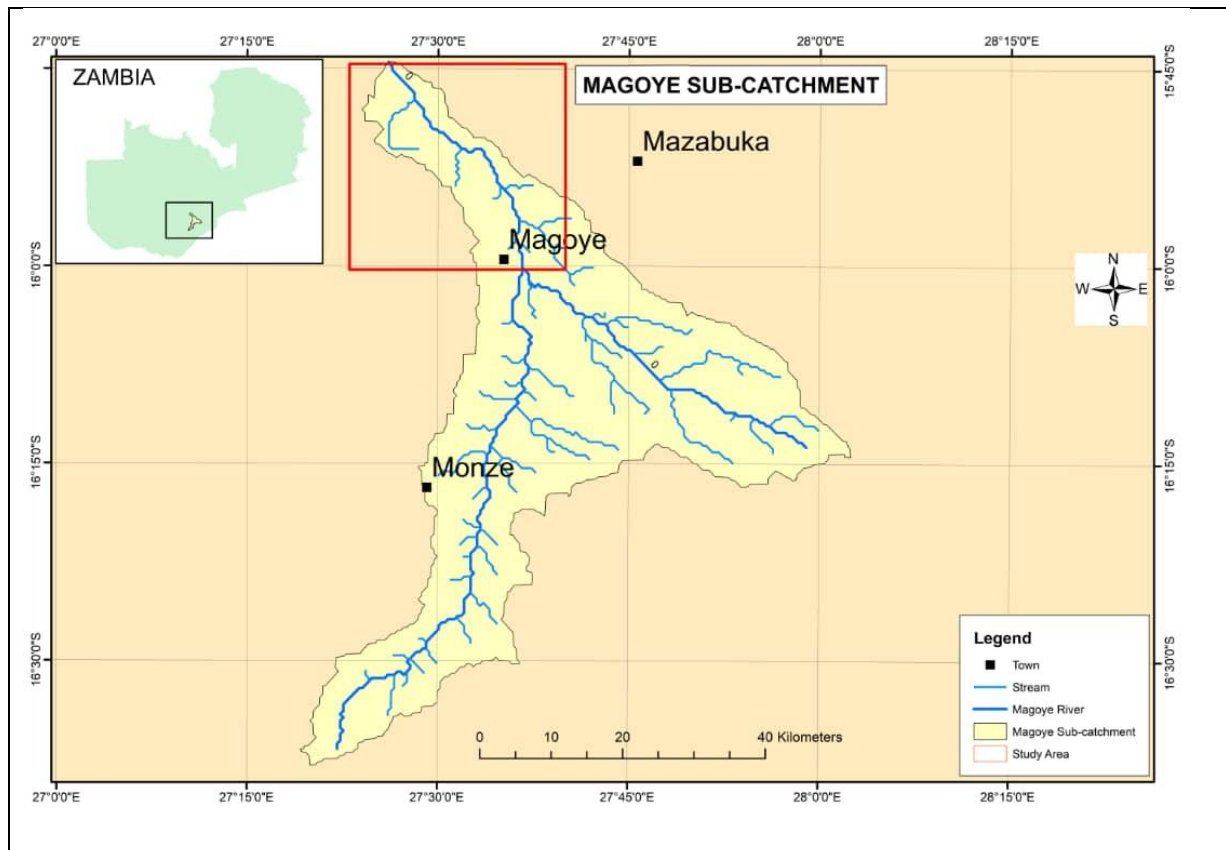


Fig. 1. Geographical Location of Magoye sub-Catchment. Source: MWDS (2022)

Magoye area soils fall into two main divisions, the plateau group of light textured soils and the upper valley group of medium to heavy textured soils (COWI and SWECO, 2009). The average annual flow amounts 47-58 m³/s. The mean annual rainfall extends from mid- November to the end of March and temperature range between 650 mm to 800 mm and between 12°C - 26°C respectively (WARMA, 2019). The estimated population of households in the catchment is about 115,462, of which 80% depend on pastoral and sand mining (CSO, 2018; World Bank, 2010).

2.2 Data collection

A field observation guide and GPS were used to observe changes in the bed and channel morphology of the river. A Likert scale tool was used where participants were requested to state the most frequently occurring human activities and thereafter rank the severity of each identified human activity where rank 1 meant low severity, rank 2 moderate severity and rank 3, high severity. This was done to compare the ranked data with the insitu observations by the researcher. In addition, samples of degraded channel sections were selected using field observation guides with the aid of handheld GPS. Each section was measured for initial channel width and current channel

width simultaneously. In selected sections, the initial river channel widths were detected using remote sensing from Google Earth. The total number of assessed sections of

the channel width were 31. Below is figure 2. (a)-(b)-(c) that show data collection on the channel and bed morphology of the Magoye River.



Fig 2: (a-b) Field measurements of sediment depth and (c) Degraded channel and bed morphology of the Magoye River.

In order to assess selected geomorphic features downstream of the Magoye River channel from Magoye Bridge to the mouth

around the Kafue Flats, different methods and tools were used as summarised in Table 1.

Table 1. Tools and materials employed to collect channel geomorphic Data

SN	Geomorphic data variable	Tools	Purpose
1	Sand pit dugs and Sand heaps ⁴	Sediment angle bars	Sediment sizes from the dry riverbed cross section
		GPS Campus Measuring Tool App	Determine distance from the Bridge for each sampling point
		GPS	Record sampling coordinates
2	Water and vehicle access roads	Camera	Capturing the geomorphic feature observed
		GPS	Record coordinates
		Field Notes Sheet	Record keeping
3	Meander bends/ Oxbow lakes	Camera	Capture visual impression
		GPS Campus Measuring Tool App	Measure Curvature length
		Measuring tape	Measure the neck between meander bends
		Google earth Engine	Remote confirmation of the beds and their type
4	Stone ridges, Rills/ Gorges and Sinkholes	GPS Campus Measuring Tool App Measuring tape	Measure and record location of features
		Satellite Imagery in Google Earth	Provide evidence
5	Bank caves/ cracks and Weir	Observations & Bank stability analysis sheet	Record all sections of the channel that were unstable
		Camera	Provide visual evidence
6	Channel Bed Profile and Shallow wells on the riverbed	Profile Tool in GPS Campus App and google earth	Real time measuring of bed Profile.
7	Pools/ponds and sand bars and cones	GPS Field recording Sheet	Determine coordinates
			Record keeping of features

2.3 Data Analysis

The data that was collected using the Likert Scale tool was analysed by means of descriptive statistics showing frequency of occurrence of selected anthropogenic activities and standard deviation of the ranks from the mean rank mapped using Excel Spreadsheet. ArcGIS 10.4 was

partly used visualize the geospatial location of human activities. The anthropogenic activities and landuse/cover change were analysed by Image processing tool in ArcGIS 10.4 at 15 year interval.

3. RESULTS

3.1 Geomorphometric characteristics of the Magoye River Channel between the Magoye Bridge and the mouth around Kafue flats

There were diverse geomorphometric characteristics of a river channel, but only selected ones were parameters considered for the study based on the financial budgetary allocation. The Magoye River was found to have morphed from a single river it used to be before the 1980s into two classification, namely, Reservoir River on the upstream amounting to 70% and Sandbank River amounting to 20% on the downstream creating an hydro-morphodynamic

disequilibrium. Due to rampant human sand mining, stone quarrying and farming number of meanders have emerged; simple symmetric, simple asymmetric and compound asymmetric meander beds especially on the downstream. Magoye River just on the downstream had 27 meanders of different types along 276km stretch, implying that, on average, every 1km, had a meander, hence the high deposition rate. The downstream was highly meandering with low slope gradient, which partly explains why there was high sediment deposition due to reduced flow velocities as shown in (Table 2).

Table 2. Selected geomorphometric characteristics of the Downstream of Magoye River Channel

Geomorphometric Features	Measure	
Length	27.6 Km	
Sinuosity Index	1.65	
Number of Meander Bends	Simple Symmetric	10
	Simple Asymmetric	10
	Compound Asymmetric	7
Number of Sand bars	23	
Gradient	0.04 (1:27)	
Downstream bed perimeter	55 Km	
Type of River	Upstream: Reservoir River ¹	
	Downstream: Sandbank River ²	

Upstream reservoir river¹, which have extensive reservoirs around tributaries and mainstem; and Sandbank river², where there are extremes of annual fluctuation in water level from severe flood during wet season to complete dry bed during dry season (FAO, 2022).

The longitudinal profile of the Magoye River channel from the

Magoye Bridge to the Mouth is shown in Figure 3.

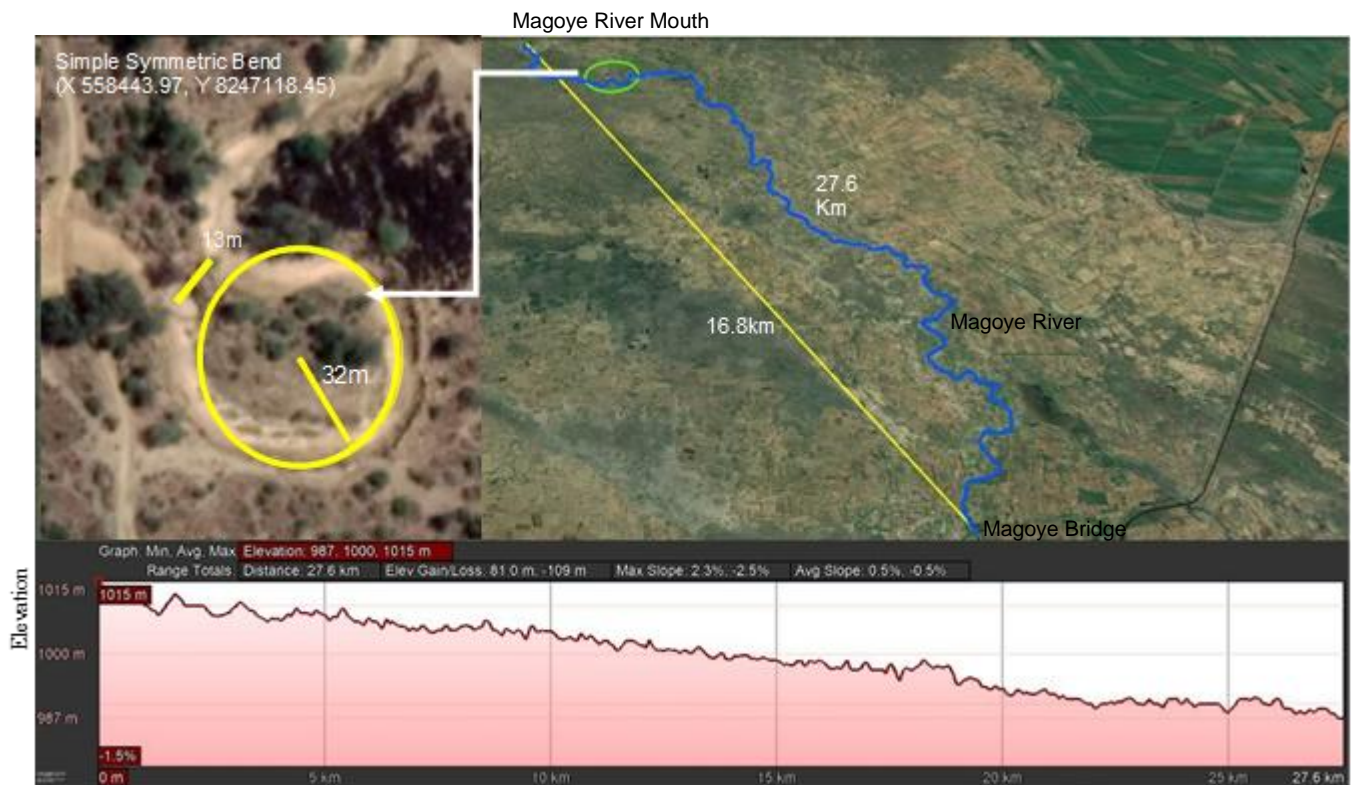


Fig. 3. Longitudinal Profile of the Magoye River Channel from Magoye Bridge to the mouth, based on google earth image, 2022.

3.2 Anthropogenic activities and landuse/cover changes within the buffer zone

Landcover/use change is a significant factor in the management of the geomorphic equilibrium of river channels. Based on the assessment of land cover/use change in the broader landscape of the Magoye Catchment and river downstream buffer zone, the study noted a geospatial and temporal heterogeneity in the land cover/use changes as can be seen in Figure 4. The findings are suggesting that cropland (both rain-fed and irrigated) were significantly taking up much of the vegetation cover in the entire catchment. However, the immediate geospatial analysis of the buffer of the downstream indicated a ubiquity of mixed cover/use exemplified through agriculture, sand mining and brick moulding, which accounted for almost 68% of the 11.48 Km² delineated buffer by 2022, from about 35% in 1990. Results suggest that, there is no buffer zone protection because the changes from a wider geospatial context seem to relate with changes in the buffer zone. Moreover, expansion in agricultural activities widely reduce the vegetation coverage not only at buffer scale, but also at catchment scale. This inherently suggests, need for effective enforcement of SI 1 of 2000 and forestry conservation.

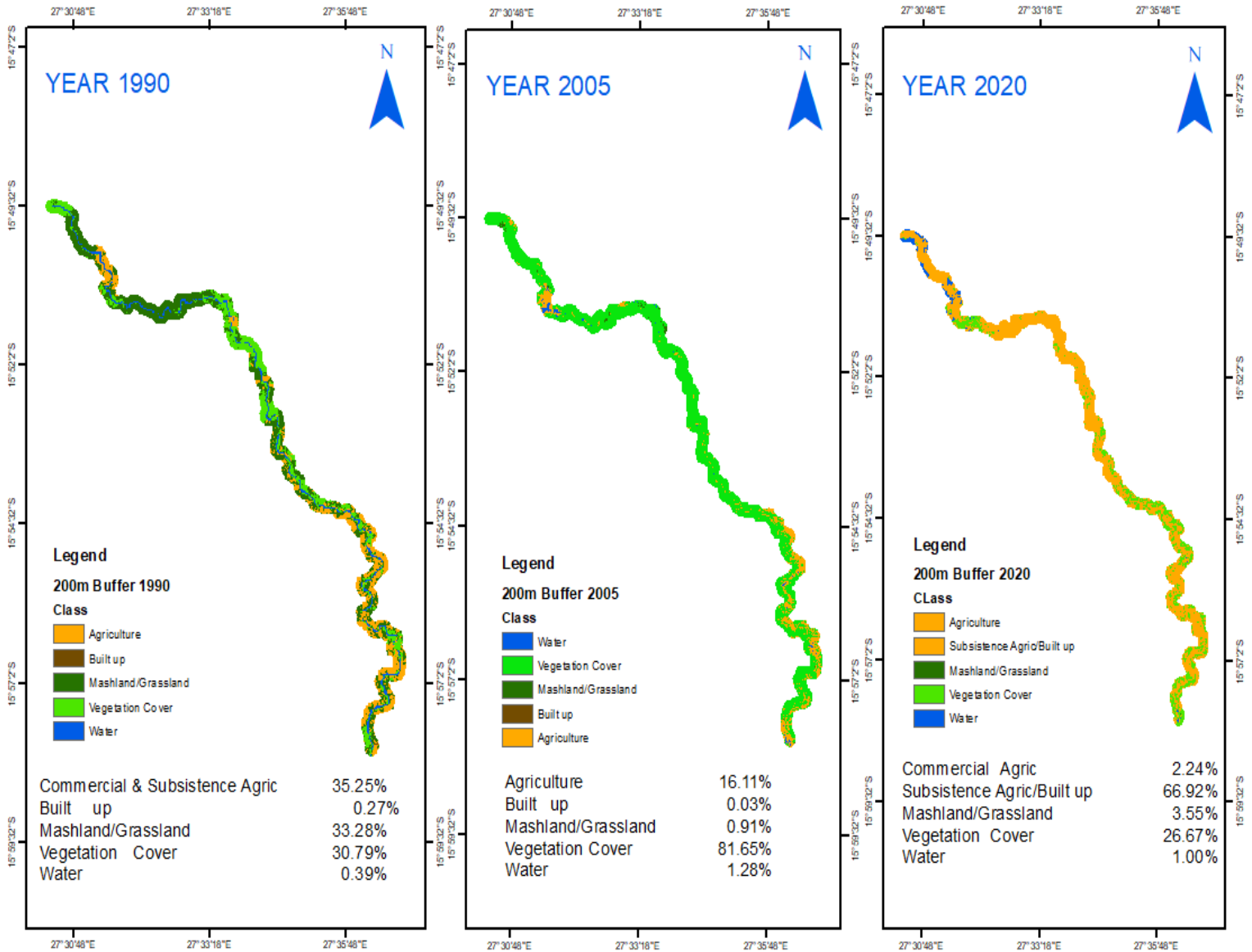


Fig. 4. Geospatial progression in the land cover/use change of the downstream of the Magoye River Buffer Zone between 1990 and 2020

3.3 Anthropogenic-driven river landform on the Magoye River

In a broader sense, anthropogenic activities have manifold influences on the environment, modify natural process, and in a long run create geomorphic features. The subject of anthropogenic geomorphology is

the description of the wide and ever widening range of surface landforms, extremely diverse in origin and in purpose created by the operation of humans. It is worth noting that, landforms produced by human actions are often more difficult to recognize, because they tend to involve the

acceleration of natural processes rather than the operation of new ones. They result from environmental changes brought about inadvertently by human actions. The rightful judgement that humans are the victims of an environment created by themselves is also

true for the geomorphic action of humans. Below is table 3, showing the observed anthropogenic River landforms location, description of features and there drivers along the river channel on the downstream.

Table 3. Characteristics of Anthropogenic River landforms

Sample Location		Anthropogenic River landform	Description of feature	Driver
X	Y			
564721	8234125	Sand and soil pits	Shallow depression filled with soft sand	Sand mining
565170	8237873	Vehicle Access roads to the river	Light trucks entry points in riverbanks	Sand mining
565082	8236596	Sand cones	Cone-shaped heaps of fine sand	Mining and quarrying
557874	8246988	Riverbed Potholes/pools	Depression/hollow in riverbed	Stone/ brick moulding
565458	8237603	Riverbed pothole and pools	Depressions in the riverbed	Sand quarrying
564522	8234965	Stones ridges/bunds	Long, narrow elevated crest on banks	Quarrying and mining
558441	8247201	Bank caves	Caves/holes on riverbanks	Sand mining
556829	8247404	Shallow well	About 3m depth on the riverbed	Livestock farming
564522	8234965	Water access points	Points on the riverbed for livestock	Livestock farming/ Irrigation
561538	8244142	Small weir	Stone-barrier across width of the river.	Livestock arming
564513	8235059	Gullies	Deep channels or Ravine on riverine.	Cultivation Bush fires
564672	8234636	River channel migration	River channel widened	Brick moulding
565082	8236596	Sand bars/ Slurry reservoirs	Area of sand, gravel	Sand mining
558400	8247131	Sinkholes	A bit deep holes on riverbed	Stone quarrying
561618	8244061	Floodplains/ Slag deposition sites	Lowland/flat areas on the downstream	Farming
565112	8235798	Rills and gorges	Narrow valley with steep rocky walls	Mining and quarrying

The findings further reveal that, the most imposing 1000m² of dry surface area. Through field was excessive siltation of the river channel bed experimental assessment on 31 out of 47 damaged leading to drastic loss of flowing water-holding cross sections of the river channel widths from the capacity, potential oxbow lakes and floodplains. In Magoye River, the study noted other geomorphic formation. This coupled with sand mining triggered features like water access points, sand collection, heavy burden of sediment on the riverbed amounting to over 5 million cubic Meters spread across 46 (Figure 5).



a



b



c



d

Fig 5. Showing (a) Sand collection (b) Vehicle access roads (c) Sand cone (d) Brick moulding

This enhanced sediment inflows into the river especially during rainy season eventually disturbing the stability of the riverbanks. **The frequency of occurrence of anthropogenic**

activities within the buffer zone of Magoye River channel on the downstream as shown in Figure 6 below.

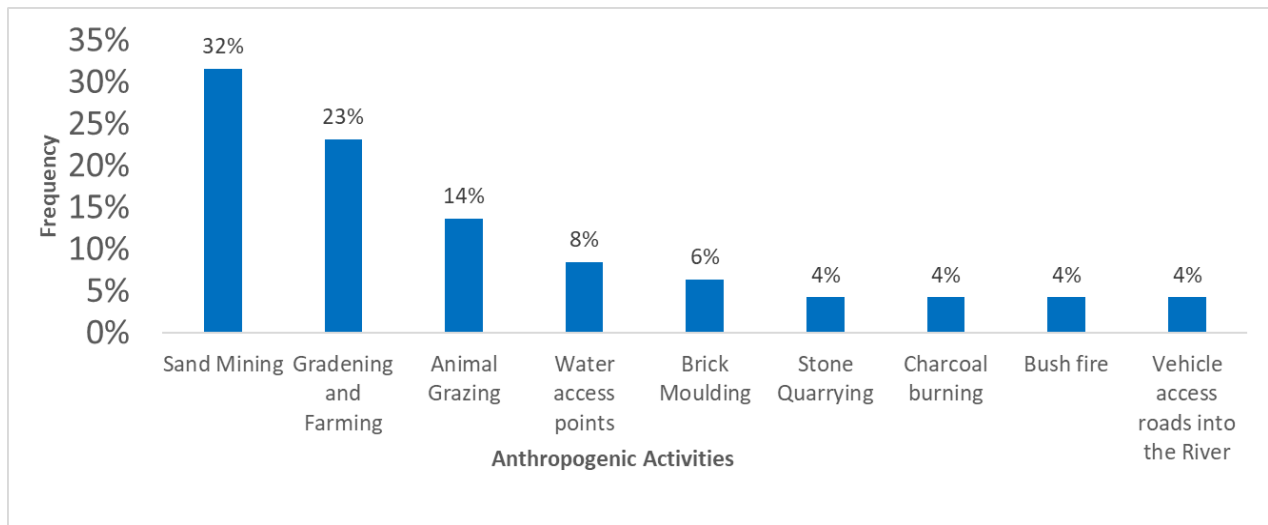


Fig. 6. Frequency of occurrence of anthropogenic activities within the buffer zone, downstream of the river channel.

Over 108 sand conical heaps observed at different sections of the channel bed were associated with degradational effects such as pools and sinkholes and in some cases, and shallow wells (3 m) deep on the riverbed especially halfway towards the mouth. Remote sensed images from google earth confirmed that, most of these changes happened after 2005 when human activities in the buffer zone and beyond has also significantly increased taking up almost 70% of the total areas at catchment and buffer zone scale. The sand mining, brick molding and stone

quarrying on the buffer zone may have promoted occurrence of instability of the riverbed and formation of pools and ponds, sand pit dugs on the riverbed and banks and shallow wells. This has disturbed Microphytes and Micro/Macro invertebrates in the buffer zone ecosystem. Table 4 shows the severity analysis of human activities in the buffer zone of the downstream of the Magoye River channel. It was noted that sand mining and brick moulding were the most severe.

Table 4. Severity analysis of human activities in the buffer zone of the downstream of the channel

Human activities	Participants ranking of Severity of the impact land uses on the degradation of the river channel				Standard Deviation of each rank from the Mean			Interpretation of Severity based on standard deviations
	Low (1)	Moderate (3)	Severe (5)	Mean rank	Rank 1	Rank 3	Rank 5	
	Frequency of rankings							
Sand Mining	3	7	50	4.6	2.55	1.13	0.28	Severe
Gardening and Farming	20	34	6	2.5	1.06	0.35	1.77	Moderate
Animal Grazing	32	21	7	2.2	0.85	0.57	1.98	Moderate
Water access points	15	12	33	3.6	1.84	0.42	0.99	Moderate
Brick Moulding	12	1	47	4.2	2.26	0.85	0.57	Severe
Stone Quarrying	16	33	11	2.8	1.27	0.14	1.56	Moderate
Charcoal burning	42	11	7	1.8	0.57	0.85	2.26	Low
Bush fire	48	9	3	1.5	0.35	1.06	2.47	Low
Vehicle access roads into the river channel	13	27	20	3.2	1.56	0.14	1.27	Moderate

The visual evidence of some of the observed destructive human activities in the buffer zone are qualified in Figure 8, which depicts negative impact of stone quarrying on the river bed and

microphytes and micro invertible organisms, river bank cutting to create road access into the river, brick moulding and sand mining. Figure 7 (a) Reservoir on the riverbed (b) Sand open-pit.

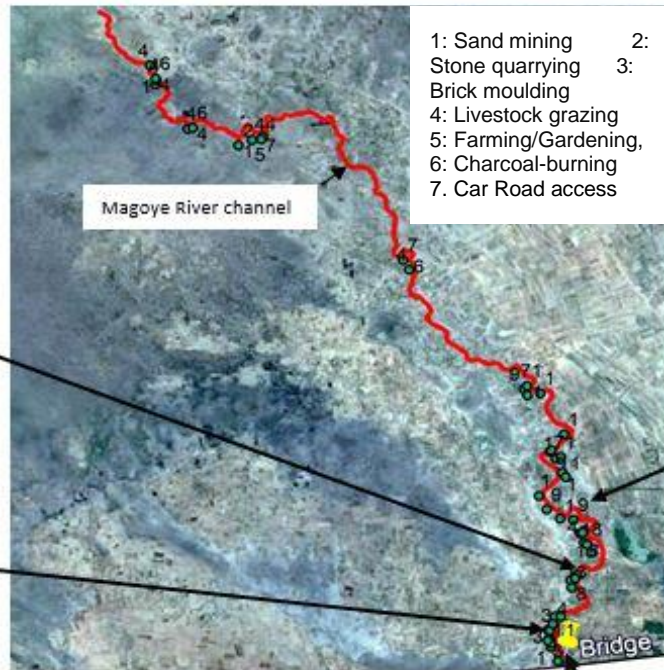
(a)



(b)



Fig. 7. One of the water pools (a) on Riverbed and a Riverbank cave (b)



X= 564721, Y = 8234125 (Sand Mining)



Fig. 8. Visual impressions of human activities in the Magoye River Buffer Zone.

4. DISCUSSION OF RESULTS

4.1 Geomorphometric characteristics of the Magoye River channel between Magoye Bridge and mouth of the Magoye River

Earlier studies by scholars such as GRZ, (2019, 2021); Chomba *et al.* (2021), Sichingabula (1999) confirm the findings of the current study that such high magnitudes of siltation are usually a function of destructive activities (especially agriculture and sand mining) happening in the entire catchment and buffer zone as indicated in the earlier section. However, the current study further noted one unique phenomenon which, was not documented in earlier studies where it was observed that people involved in sand mining and stone quarrying had to cut through the riverbanks at several sections of the river to create roads to the riverbed to transport stones and sand, which were mined during dry season. This could not only damage the riverbank stability, also created wide conduits through which sediment would cascade into the riverbed and hence, the observed heavy laden of sediments on the riverbed (Mzyecee and Muchanga, 2023).

Studies in and outside Africa also confirm similar patterns, which show the geospatially distributed nature of the impact of anthropogenic activities on river system (Knox, 2001; Fryirs and Brierley 2013; Swali, 2022; Chisola and Kuraz, 2016). The findings are also in tandem with Wilcock and Clark (2000) who found that landuse change affected channel morphology in the Northern Puerto Rico. Through field experimental assessment on 31 out of 47 damaged cross sections

of the river channel widths from the Magoye Bridge to the mouth of the Magoye River, it was noted that, the river channel widths had significantly changed within the first 10 Km from the bridge and moderate changed in the last 10 Km towards the mouth. On average, the river width among selected sections had significantly migrated from the initial width. Remote sensed images from google earth engine confirmed that, most of these changes happened after 2005 during, which human activities in the buffer zone and beyond had also significantly increased taking up almost 70% of the total areas at catchment and buffer zone scales (Walling and Collins, 2006).

Sand mining, brick moulding and stone quarrying observed at different sections of the river channel were associated with degradational effects such as pools/ponds and sinkholes and in some cases, and shallow wells (3 meters deep) on the riverbed especially half way towards the mouth. These features were not unique to the Magoye System, but were also observed by Singubi *et al.* (2023) in the Lusitu Catchment; Chisola *et al.* (2022) in the Kaleya Catchment; Simweene and Muchanga (2021) in the upper reach of Magoye Basin; Hamatuli and Muchanga (2021) in Central Province of Zambia; Muchanga (2017) in Njola area, east of Monze. Thus, showing how spatially distributed the practice was across water stressed catchments in Southern Zambia and beyond.

4.2 Anthropogenic activities and landuse/cover changes within the catchment of Magoye River

The extent to which human beings modify fluvial systems through changes in landuse is complex to estimate (Clark and Wilcork, 2000). Based on the assessment of land cover/use change in the broader landscape of the Magoye Catchment and downstream river buffer zone, the study noted that, the catchment landcover generally underwent significant changes with agriculture being the main driver of reduction on vegetative cover. In the buffer zone, the degradations were mainly driven by a mix of human activities (especially crop farming, sand mining, stone quarrying and brick moulding), both at catchment scale and buffer zone scale, vegetation was only about a quarter of the respective total areas meaning that, about 75% was taken up by other land covers and uses. UNESCO (2011) Muchanga (2013) explained that landuse change influences discharge, sediment erosion, transportation and deposition of materials into water bodies and can change water quality, aquatic habitat, as well as channel and floodplain morphology over short to intermediate spatial-temporal scales. Hence, such landcover changes as observed in the Magoye Catchment and the target buffer zone could destabilise infiltration, suppress groundwater recharge, and amplify runoff generation and flood magnitudes as also experienced during the 2022/2023 rainy season on the low-lying areas of the Magoye catchment

(Zambia Meteorological Department, 2023). Disaster Management Mitigation Unit (DMMU) (2023) classified Magoye Catchment as one of the severely affected by flooding of the 2022/2023, this could be linked to the degradation of vegetation cover on a larger scale rendering surface runoff more violent than it would be if there was sufficient vegetation cover.

The consequence of sand mining and stone quarrying is the destruction of the biota and most of the soil on the riverbed and riverbank (Ajith, 2006; Gorczyca *et al.*, 2020). Although, some kinds of landscape restoration are usually done after construction, this “new biota” cannot be compared to natural ecosystems in biodiversity and in their capability for adjustment. Agricultural and forest management practices also greatly alter surface runoff, extensive clear-cuts may result in rapid erosion as the amount of precipitation retained by vegetation may drop abruptly. Hydrological interventions for floods control influence morphologic processes both directly and indirectly (Leopold and Maddock, 1952; Gyamfi *et al.*, 2016). The create new landforms as well as modify the process of channel erosion and even that of sediment accumulation forming pits and slag deposition sites. In extreme cases, soil is eroded to bedrock and becomes unsuitable for agriculture. The extension of arable lands is reduced by the evolution of erosion features, and gradually increase in size and depth and finally group into a gully system of several metres in depth (Lambin *et al.*, 2003).

The scenario in the Magoye System inherently signalled lack of enforcement of SI 1 of 2000 and forestry conservation. Between 1990 and 2020, high magnitude of land cover change was evident and, the general message is that, Magoye Catchment in general and, Magoye River buffer zone in particular experienced significant changes and variations in land cover/use between 1990 and 2020. Buffer zones play an important role in river system restoration (Chomba *et al.*, 2021). However, many buffer zones in the world especially where water related policies are weak, disturbed by increased land uses with them. Changes in land use and cover in river catchment areas and buffer zones increases sediment generation, transportation and deposition in river channels (Chisola and Kuraz, 2016). Any modification done on land cover in a buffer zone has an implication on river channel. Buffer zone geo-physical processes operate naturally and have a mechanism of restoring the altered landscape as long as there is minimum anthropogenic interference (Chisanga *et al.*, 2022). However, demand of certain buffer zone commodities such as proximity to water source, building sand and fertile soil along riverbanks by humans have brought land use/cover changes. Most buffer zones making human-induced changes to alluvial stratigraphy and channel adjustments greater than those left by climate change (Sichingabula, 2000; GLL, 2013).

Unlike earlier studies that simply reflected on the general landcover/use changes (Masayi *et al.*, 2017; Chisola *et al.*, 2022;

Ministry of Water Development and Sanitation, 2021; Muchanga, 2017; Wohl, 2015). These studies provided further insights, on how changes in the larger landscape of a catchment could actually influence change in the channel system buffer zone if the buffer zone remained unregulated by law. Meaning that, not only the immediate buffer zone of the river channel needs protection, but also the wide landscape of the catchments. Moreover, the study noted that, spatial coverage of a particular land use is not necessary a factor in terms of the impact on the channel degradation. This is in line with the finding that, sand mining and brick moulding did not cover very wider space as compared to agricultural activities, yet wherever they occurred, the damage was high. This therefore calls for detailed analysis of the drivers of channel change before interventions are proposed.

4.3 Key anthropogenic river landforms formed on the downstream of the Magoye River channels

According to Tena *et al.* (2021), rivers are dynamic landscape features, altered by human activities, making it difficult to disentangle human impact on geomorphic change from natural river dynamics. In this study, it was noted that increase in erosion along the river channel and riverbanks due to increased water velocity, river abrasion and attrition generally produced geomorphic features like gullies, gorges, rills, sinuosity, oxbow lakes, floodplains, and episodic erosion and longitudinal connectivity (Wohl, 2015; Suresh and Krishnan, 2022). However, by

the year 2005, several reservoirs were constructed especially on the tributary channels of the main channel on the upstream as indicated by an increase in water surface coverage to 2.1% of land surface. Whereas the upstream of the Magoye River was getting clustered with reservoirs, the downstream was becoming drier and sandier (silted) due to lack of outlet valves on most of the reservoirs on the upper catchment (Sichingabula, 2000; Muchanga *et al.*, 2023). The current study noted that between 1990 and 2005 and beyond, the river had geomorphologically evolved into two types namely, Reservoir River covering about 80% of about 167km of the main stream on the upstream and Sandbank River on the downstream accounting for about 20% within a stretch of 27.6 Km.

Overpopulation of animal stocks in the Catchment significantly damage the watering holes by trapping and soil compaction as observed (Zumbair, 2006). The tracts leading to watering holes are the sites where erosion starts and can often lead to remarkable sediment accumulation along the lower reaches of the river. Another, most spectacular environmental changes caused by human activities results from forest clearing. This implies that water retaining capacity of vegetation cover reduced by forest will create waste-valleys, river channel instability, delta expansion, sheet flow, and rapid gullying, cellar collapses (Sharma, 2017).

According to Food Agriculture Organization (FAO) (2022), a reservoir

river is that, which has extensive reservoirs, swamps or pools normally resulting in the gradual release of floodwaters and permanent flow on the downstream. On the contrary, this was not the case for Magoye as most if not all reservoirs did not have outlet valves which could allow environmental flows on the downstream (MWDS, 2021, Muchanga 2020). This partially explains the imposing loss of perenniality of the whole river. FAO (2022); ZMD (2016) further says that, a sandbank river is a river where there are two extremes of annual fluctuation in water level from severe flood overtopping the banks and cutting them during rainy season to little or no flow, except heavy laden of sediment during dry seasons. Quarry walls are normally subvertical and usually surrounded in walls on sides. As materials accumulates in debris cones, they may form a continuous debris apron. The quarry floor is an approximately flat ground surface surrounded by walls and debris aprons, including a range of features like quarry heaps, rock counterforts, pillars and out-weathered quarry columns (Baker and Miller, 2013; Chakraborty and Mukhopadhyay, 2015).

The downstream of the Magoye River is highly meandered with Sinuosity Index (SI) at 1.67. According to Leopold and Wolman (1957); Mueller (1968); SI above 1.5 tends to reduce stream power because of too many bends and sediment load in suspension or on bed. For example, Magoye River just downstream had 27 meanders of different types along the 27.6 Km stretch, implying that, on

average, every 1 Km, had a meander, hence the high deposition of sediment observed. The 27 meanders were classified into three namely, simple asymmetric, simple symmetric and compound asymmetric. Leopold and Wolman (1957) define a simple symmetric bend meander as that which can almost symmetrically fold perfectly once vertically divided into two (Figure 9) and whose amplitude and sinuosity increase gradually and the point sediment bar grows laterally towards the outer bank. Sand bars inundated with heavy sediment. The simple asymmetric bend represents the exact opposite of the former (Leopold and Wolman, 1957)). Meanwhile, compound symmetric meanders are channel bends with multiple parts of maximum curvature, which can almost perfectly align symmetrically and vice versa for compound asymmetric meanders (Muchanga *et al.*, 2019; Addor *et al.*, 2022). These findings imply that the downstream of the Magoye River is likely to have some oxbow lakes in the near future given that, selected meander bends were highly incised in their nature such that, they can completely be cut by running waters.

The 27 meanders of different types combined with low average slope of -0.5 to 0.5% indirectly contributed to heavy sedimentation and formation of over 20 sand bars on along the 27.6km stretch of the downstream. Generally, the downstream of Magoye River channel was characterized by different anthropogenic river landforms; sand cones, bank caves and sinkholes.

Meanders of different types with some having potential to evolve into oxbow lakes, very low gradient and slope percentage punctuating high settling of sediment of different type and size with sandy sediment as the most commonly distributed (Wohl, 2015; Sickingabula and Muchanga, 2021).

5. CONCLUSION

The study observed a number of geomorphometric characteristics such as high magnitudes of siltation which was a function of destructive human activities happening in the entire catchment and buffer zone. The overall morphological integrity is significantly threatened by the effects of unchecked anthropogenic influences, such as deforestation, urbanization, sand mining, stone quarrying, brick moulding, among others. The study conclusively notes that diverse anthropogenic activities in the catchment and buffer zone negatively affect the optimality of ecosystem goods and services offered by rivers. The study recommends adoption of a holistic approach to managing the river basin that takes socioeconomic, hydrological, and ecological factors into account. Furthermore, implementing erosion control measures to mitigate the impact of sedimentation resulting from human activities may be key. This may involve reforestation efforts, terracing, and the establishment of riparian buffers. To this end, there is urgent need for educational campaigns to raise awareness among local communities about the importance of responsible land and water resource management especially that humans are

at the centre of river morphological degradation.

CONSENT

Consent before interviewed. The information to be confidential and only used for academic purpose.

ETHICAL APPROVAL

The paper was submitted for clearance sanctioned to the University of Zambia, Natural and Applied Sciences Research Ethics committee (UNZA-NASREC).

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Ajith, A.V. Bathymetric survey to study the sediment deposit in reservoir of Peechi Dam. *IOSR Journal of Mechanical and Civil Engineering*. 2016; 3(1): 34-38.
2. Addor, S.O., Yidana, M.S, Oforu, A.E, Koffi, M.J. and Kabo, A.T. Modelling current and future groundwater demands in the White Volta River basin. *Journal of Hydrology: Regional studies*. Kumasi. 2022..
3. Baker, T.J. and Miller, S.N. . Using the Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources in an East African watershed. *Journal of Hydrology*. 2013; 486, 100–111.
4. Baumle, R., Neukum, C., Nkhoma, J. and Silembo, O. *The Groundwater resources of southern province, Zambia (phase 1)*, No.1 – Technical Report, Lusaka: MWDS. 2007..
5. Central Statistical Office. Census of population and housing: Southern Province Analytic Report, Central Statistical Office, Lusaka. 2018.
6. Chakraborty, S. and Mukhopadhyay, S. Riverbank Erosion and Channel Width Adjustments across a Meandering Channel of North Bengal, India. *Earth Science India*, eISSN: 0974 – 8350 Volume 8 (III), 2015; pp. 61-78
7. Charlton, R. and Simm, D. (2008). *Fundamentals of fluvial geomorphology*. London
8. Chenje, M. The state of the environment in the Zambezi Basin- SADC/IUCN/ZRA, Maseru, Lusaka,Harare; 2000.
9. Chomba I.C., Banda, K.E., winsemius, H.C., Chomba, M.J., Mataa. M., Ngwenya, V., Sichingabula, H.M., Nyambe, I.A., and Ellend B.,. A Review of

- Coupled Hydrologic-Hydraulic Models for floodplain Assessments in Africa: Opportunities and challenges for Floodplain Wetland Management. *Hydrology* 2021, 8, 44. <https://doi.org/10.3390/hydrology8010044>. 2021.
10. Chisanga, C., Mubanga, K., Sichingabula, H.M., Banda, K., Muchanga, M. Modelling climatic trends for the Zambezi and Orange River Basins: Implications on water security. *Journal of Water and Climate Change*. Vol. 13.No. 3.,pp 2022; 1275-1296.
 11. Chisola, M. and Kuraz, M. A landscape hydrology approach to inform sustainable water resource management. Chongwe Catchment, Lusaka. 2016.
 12. Chisola, M., Sichingabula, H.M., Muchanga, M., Sikazwe, M. and Chomba, I. Kaleya River Catchment regional estimation of Reservoir capacities using Solar and GIS Approaches. *Journal of Natural and Applied Sciences*. 2022; 6(1), 1-13
 13. Clark, J. J. and Wilcock, P. R. Effects of land-use change on channel morphology in North-eastern Puerto Rico, *Geological Society of America Bulletin*., Volume. 112 No. 2000; 12, pp. 1763-1777
 14. COWI and SWECO International AB (a). "Availability of water resources for sugar cane production expansion in Zambia in the context of competing hydropower and other users Contract number". 2009: SUCRE/2009/169-446.
 15. CSO Projected total population and number of eligible voters in the year 2018. Central Statistical Office. Lusaka. 2000
 16. DMMU. Report states widespread damage of farmlands, river channels, due to floods. Issued on January 27 .2023, Lusaka.
 17. Dufour, S., Rinaldi, M., Piegay, H. and Michalon, A. Landscape and urban planning: How do River dynamics and human influences affect the landscape pattern of fluvial corridor? Lessons from the Magra River, Central-Northern Italy. 2015.
 18. FAO. Manual on Small earth dams: A guide to siting, design and construction, irrigation and drainage. Rome. 2022.
 19. Fryirs, K. A. and Brierley, G. J. Geomorphic analysis of river systems: An approach to reading the landscape. Hoboken: Wiley-Blackwell. 2013.
 20. Gilvear, D., Winterbottom, S. and Sichingabula, M.H. (2000). Character of channel planform change and meander development: Luangwa River, Zambia. *Earth surf. Process. Landforms* 25, 421-436
 21. Golden Lay Limited. Environmental and Social Impact Statement for the Development of

- Kafubu Farm. Greenline Environmental Solutions Limited, Lusaka. 2013
22. GIZ. Implementation report on the Catchment protection measures in Mutama-Bwengwa and Magoye Catchments. Lower Kafue Sub-Catchment, Southern Zambia. 2021.
 23. Gorczyca, E., Krzemien, K. and Jaryna, K. Can beaver impact promote river denaturalization? The example of the Raba River, southern Poland. *Sci. Total Environ.* 2018; 615, 1048–1060.
 24. Graf, W.L. Downstream Hydrologic and Geomorphic Effects of Large Dams on American Rivers. *Geomorphology*, 79(3-4), 336-360. doi:10.1016/j.geomorph.2006.06.022
 25. GRZ, Land degradation Neutrality National Report. Ministry of water development, sanitation and environmental protection. Lusaka. 2019.
 26. Gyamfi, C., Ndambuki, J. and Salim, R. Hydrological Responses to Land Use/Cover Changes in the Olifants Basin, South Africa. *Water*. 2016; 8. 588. 10.3390/w8120588.
 27. Hamatuli, M. and Muchanga, M. Social Perspectives on the Effects of Buffer Zone Anthropogenic Activities on Mashili Reservoir of Shibuyunji District, Central Province, Zambia. *International Journal of Humanities Social Sciences and Education*. Vol. 8. No. 11. P 2021. 102-109.
 28. Hickin, E.J. and Sickingabula, H.M. The geomorphic impact of the catastrophic October 1984 flood on the planform of Squamish River, Southwestern British Columbia. *Canadian Journal of Earth Sciences*. 25. 1988; 1078-1087.
 29. Knox, J.C. Agricultural influence on landscape sensitivity in the Upper Mississippi River Valley. *Catena* 42, 2001: 193–224
 30. Lambin, E.F., Geist, H.J. and Lepers, E. Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environmental Resources*. 2003. 28:205–41.
 31. Leopold, L.B. and Maddock Jr. *The Hydraulic Geometry of Stream Channels and Some Physiographic Implications*. U.S. Geological Survey, Washington DC, Professional Paper. 1952; p 252.
 32. Leopold, L.B. and Wolman, M.G. *River Channel Patterns: Braided, Meandering, and Straight*. U.S. Geological Survey, Washington DC, Professional Paper. 1957; 52 282-B.
 33. Masayi, N. N., Omondi, P. and Tsingalia, M. Assessment of landuse and landcover changes in Kenya's Mount Elgon Forest ecosystem. 2017; 10. 1111 *aje*. 12886.
 34. Muchanga, M. Learning for Climate Change Adaptation among selected Communities of Lusaka Province in Zambia.

- Southern African Journal of Environmental Education. 2013: p. 94-114.
35. Muchanga, M. Understanding Sedimentation Process in the Makoye Reservoir of Southern, Zambia. *Journal of Geography and Earth Science*. 2017.
 36. Muchanga, M., Obando, J. and Sichingabula, M.H. (2019). Bathymetric of Makoye reservoir and its implications on water security for livestock within the catchment. Southern Zambia, *Journal of Geography*, 5(1): 77-96. Available at: <https://doi.org/10.15640/jges.v5n1.a6>
 37. Muchanga, M. Determination of Sediment, Water Quantity and Quality for SWAT Modelling of Sedimentation in the Makoye Reservoir, Southern Province, Zambia, 2020, University of Zambia.
 38. Muchanga M., Sichingabula, H.M., Wankie, R., Banda, K. and Chisanga, C.. Impact of sedimentation and bathymetry of selected small reservoirs on the priority water-linked sectors in the Zambezi River Basin. *Journal of geography and geology*. 2023; 15(1).
 39. Mueller, A.J. Kappa-Affected parametia Development community, Eastern-United Kingdom. 1968. 41(2).
 40. MWDS, Report on Economic Transformation through green growth. Lusaka, Zambia.t, Lusaka. 2021.
 41. Mwiinga, C. Pollution in Kafue River on the Copperbelt. N.C.S.R WRRU/TR, Lusaka (1990).
 42. Mzyecee, B. and Muchanga, M. Economic Effects of the Failure of Kandesha Dam on Local Communities in Mumbwa District, Zambia. *American Journal of Environmental Economics* 1 (1). 2023. 1-10.
 43. Poff, N. L. Homogenization of regional river dynamics by dams and global biodiversity implications, *Proc. Natl. Acad. Sci. U. S. A.*, 104(14). 2007; 5,732–5,737, <https://doi.org/10.1073/pnas.0609812104>.
 44. Sharma, S. Effects of urbanization on water resources-facts and figures. *International Journal of Scientific and Engineering Research*. 2017; 8. 433.
 45. Sichingabula, H.M. Magnitude-frequency characteristics of effective discharge for suspended sediment transport, Fraser River. Columbia Press.1999.
 46. Sichingabula, H.M. Character of Channel planform change and meander development: Earth surface processes and Landforms. Luangwa River, Zambia. 2000; Pp 15-19..
 47. Sichingabula, H.M. and Muchanga, M. Spatial and seasonal dynamics of total suspended sediment Total Dissolved Solids and Turbidity of a lacustrine Reservoir in the

- Magoye Catchment. Southern Zambia 2021.
48. Simweene, E. and Muchanga, M. Socio-hydrological learning for Integrated Siltation Control and Water Resources Management in a Small Reservoir of Southern Zambia. *American Journal of Humanities and Social Science*. 2021; 29, 24-32.
 49. Suresh, S. and Krishnan, P. Morphometric Analysis on Vanniyar Basin in Dharmapuri, Southern India, Using Geo-Spatial Techniques. *Front. Remote Sens.* 3:845705. doi: 10.3389/frsen.2022.845705
 50. Swali, A. Effects of landuse change on the planform of the Kafubu River channel (1993-2015). Ndola Zambia 2022.
 51. Tena, T.M., Mudenda, F., Mwaanga, P., Gathenya, M.J. and Nguvulu, A. Analysis of River tributaries streamflow contribution using WEAP Model: A case of the Ngwerere and Kanakatapa tributaries to the Chongwe River, Zambia. *Sustainability*, 2021; 6415.
 52. UNESCO, Sediment issues and sediment management in larger river basins. Interim case study synthesis report. International Sediment initiative Technical Document in Hydrology. UNESCO, Beijing and IRTCES.2011.
 53. Walling, D.E. and Collins, A.L. The Catchment sediment budget as a Management tool. *Environmental Science and Policy*. Europe. 2006; 136-143.
 54. WARMA, Lower Kafue River Basin. Report card. Lusaka. 2019
 55. Wassie, B.S. Natural resource degradation tendencies in Ethiopia: A review. *Environmental Systems Research*. 2020; 33(2020).
 56. Wilcock, P.R. and Clark, J. Effects of landuse on channel morphology in Northern Puerto Rico. *Geological Society of American Bulletin*. 112(22): 2000; 1763-1777.
 57. Wohl, E. The natural sediment regime in rivers: Broadening the foundation for ecosystem management, *Bioscience*, 65(4), 2015; 358–371, <https://doi.org/10.1093/biosci/biv002>.
 58. World Bank. The Zambezi River Basin. A Multi-Sector Investment Opportunities Analysis. Volume 3 State of the Basin. Washington. 2010
 59. World Wide Fund for Nature (WWF), (2016). Water in the Zambian economy: Exploring shared risks and opportunities in the Kafue Flats. WWF Zambia.
 60. Zambia Meteorological Department (ZMD), National weather data sheet. Lusaka. 2016.
 61. Zubair, A.O. Change detection in land use and Land cover using remote sensing data and GIS (A case study of Ilorin and its environs in Kwara State), MSc Thesis, University of Ibadan, Nigeria; 2006.