ANTHROPOGENIC GEOMORPHOLOGY OF THE MAGOYE RIVERINE LANDSCAPE , ZAMBIA

ABSTRACT

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. This study was inspired by analytic eclecticism research philosophy and adopted mixed methods, particularly concurrent research design. 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. The results showed that sand mining and brick moulding accounted for almost 68% of human activities in the 11.48 km^2 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). 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 (Chenje, 2000). 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 (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; Zubair, 2006). 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; Lambin *et al*., 2003). 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 Sichingabula, 1988; Poff, 2007).

2. MATERIALS 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, 2007). Figure 1 shows the geographical location of the Magoye sub-catchment.

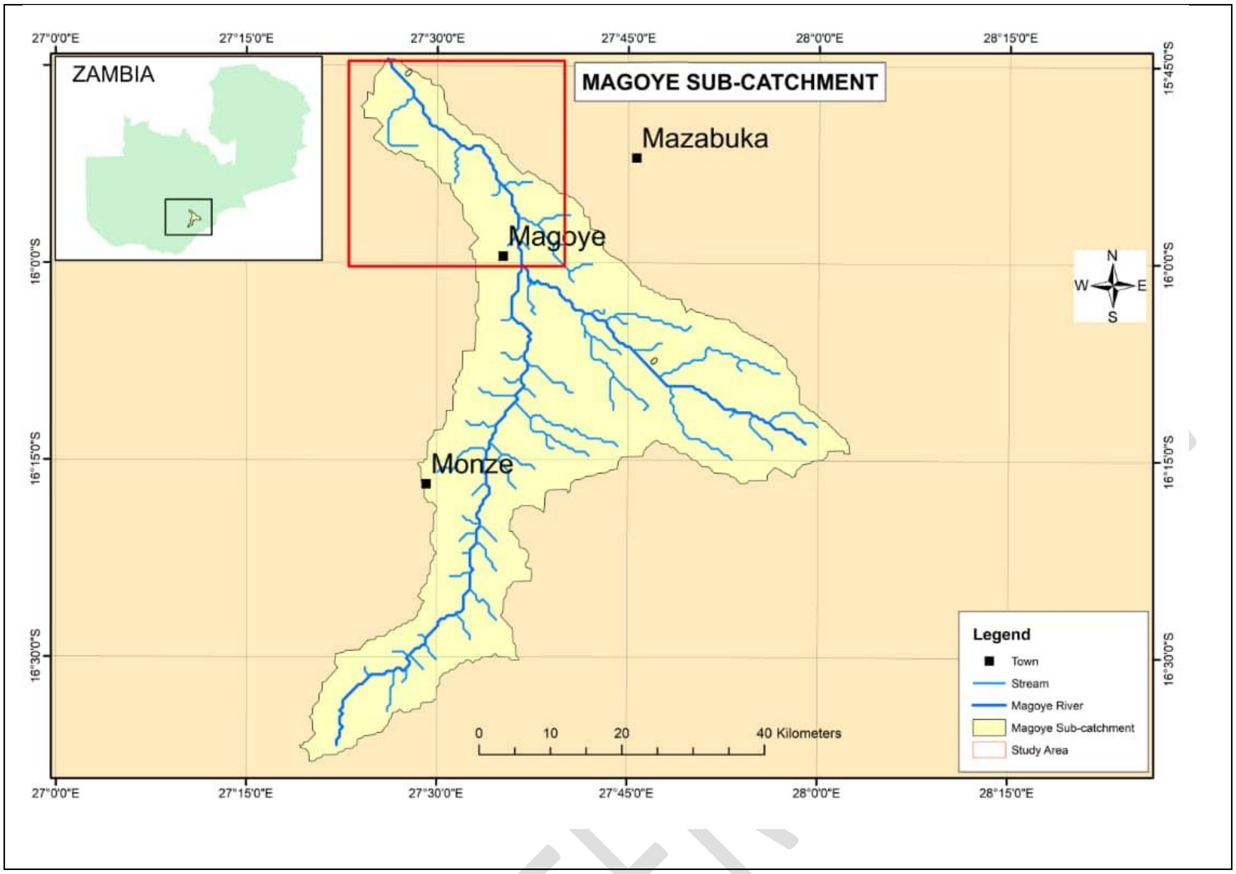

Figure 1: Geographical Location of Magoye sub-Catchment. Source: MWDS (2022)

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 (Zambia Agricultural Research Institute (ZARI), 2015). 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).

2.2Data collection

A field observation guide and GPS were used to observe changes in the bed and channel morphology of the riverA 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.

(a) (b) (c)

Figure 2: 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	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

SN	Geomorphic data variable	Tools	Purpose
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 Camera	Record all sections of the channel that were unstable 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

2.2 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 years interval.

3. PRESENTATION OF 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-morphodymic 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 (Figure 3).

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 river[1], which have extensive reservoirs around tributaries and mainstem; and Sandbank river[2], 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).

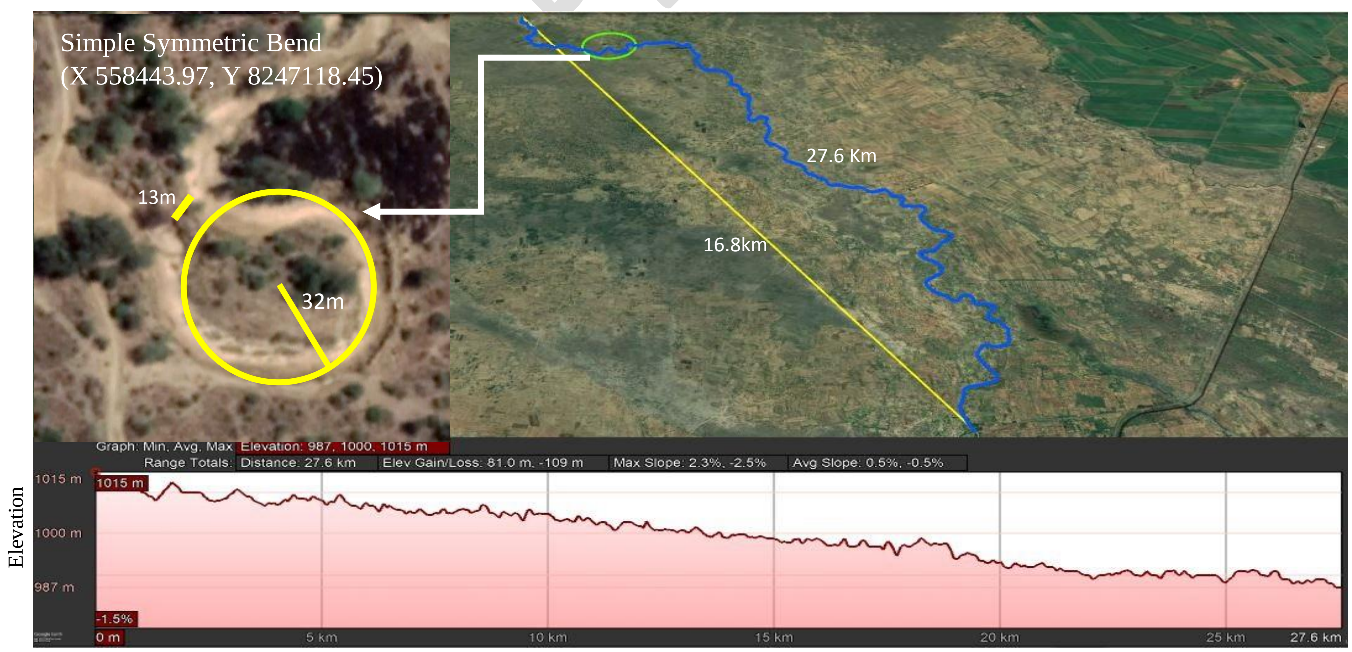

Figure 3: Longitudinal Profile of the Magoye River Channel from Magoye Bridge to the mouth, based on google earth image, 2022.

3.2 Anthropogenic activities and landuse/cover changes within the buffer zone of the Magoye River from 1990 to 2020

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 Km^2 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.

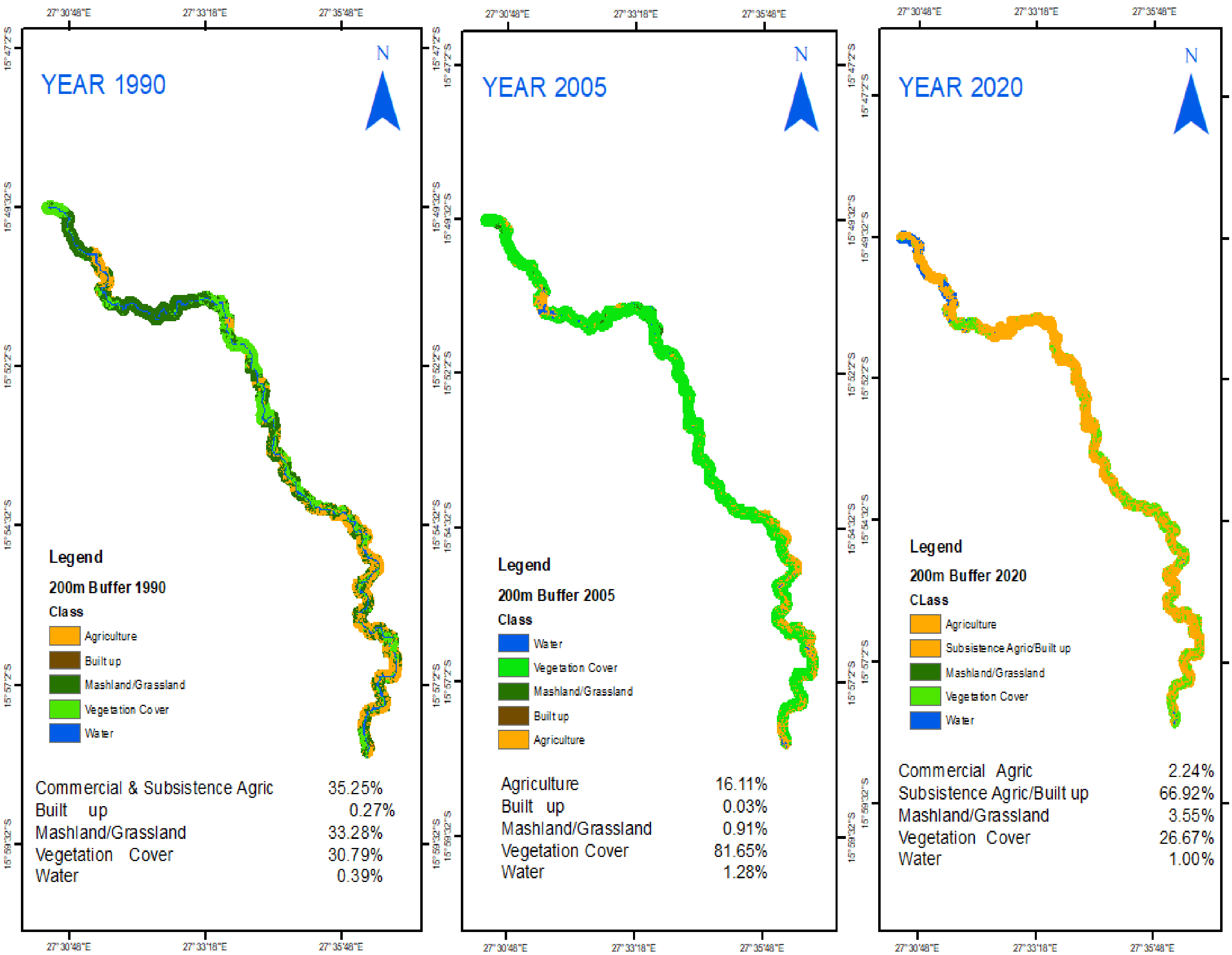

Figure 4: Geospatial progression in the land cover/use change of the downstream of the Magoye River Buffer Zone between 1990 and 2020.

3.3 Anthropogenic-driven river landforms 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 was excessive siltation of the river channel bed leading to drastic loss of flowing water-holding capacity, potential oxbow lakes and floodplains formation. This coupled with sand mining triggered heavy burden of sediment on the riverbed amounting to over 5 million cubic Meters spread across 460, 000m2 of dry surface area. Through field experimental assessment on 31 out of 47 damaged cross sections of the river channel widths from the Magoye River, the study noted other geomorphic features like water access points. Figures 5 below (a) Sand collection (b) Vehicle access roads (c) Sand cone (d) Brick moulding


(a)


(b)


(c)


(d)

Figure 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.

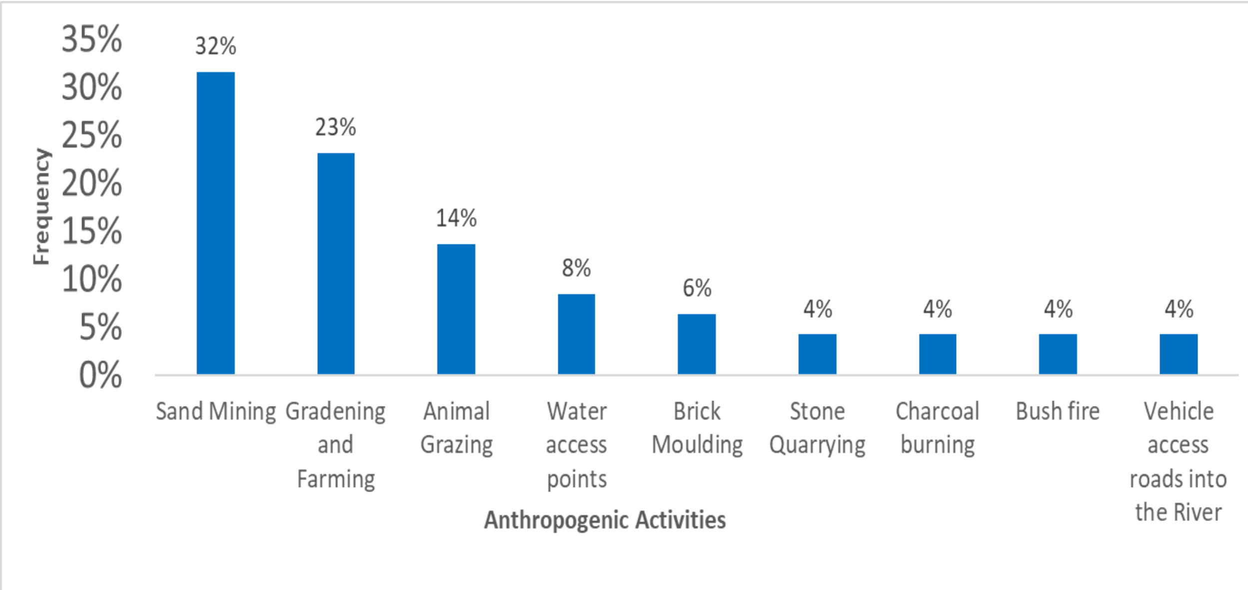

Figure 6: Frequency of occurrence of anthropogenic activities within the buffer zone, downstream of the river channel. Source: (field Data, 2022)

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 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: 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

Source: Field data (2022)

The visual evidence of some of the observed destructive human activities in the buffer zone are qualified in Figure 7, 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 8 (a) Reservoir on the riverbed (b) Sand open-pit

(a) (b)

Figure 7: Shows the Reservoir on Riverbed and Sand open.- pit

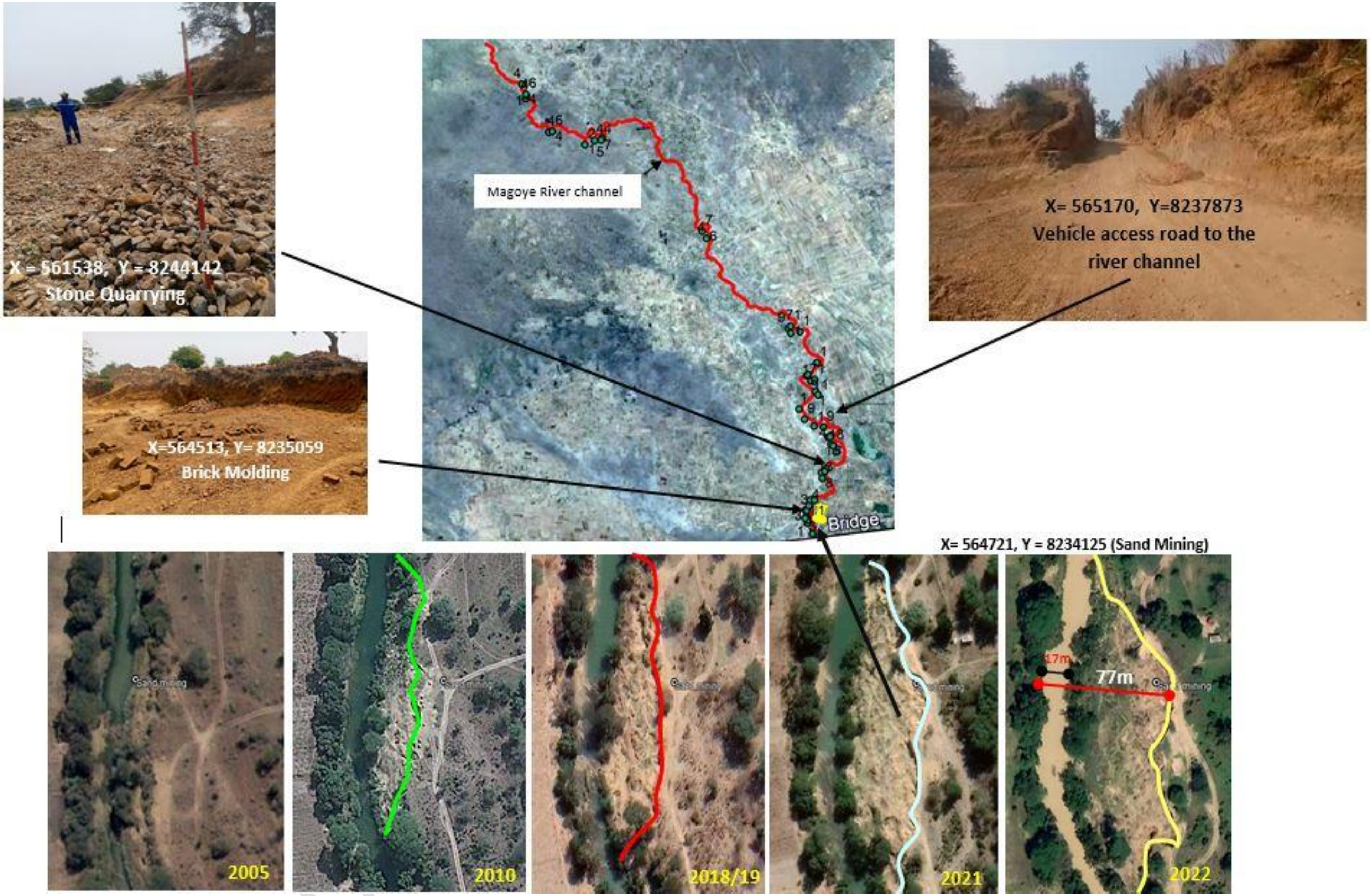

Figure 8: Visual impressions of human activities in the Magoye River Buffer Zone. (1: Sand mining, 2: Stone Quarrying, 3: Brick moulding, 4: Livestock grazing, 5: Farming and Gardening, 6: Charcoal-burning Source: (Field data, google earth, 2022)

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, (2021); Chomba *et al*. (2021), Sichingabula (2021) 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 phenomenonwhich, 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 (Hickin and Sichingabula, 1988)

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 tandemwith Wilcock *et al*. (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.

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 (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. Wohl (2019) 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 (Clark and Wilcork, 2000). 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 alters 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 (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 and Sichingabula, 2016). 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 *et al*., 2022). 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 (James and Lecce, 2013). 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 (James and Lecce, 2013; Sichingabula *etal*., 2021; Tejpal *et al*., 2015).

Unlike earlier studies that simply reflected on the general landcover/use changes (Monde *et al*., 2023; Chisola *et al*., 2022; Ministry of Water Development and Sanitation, 2021; Muchanga, 2017; Okello *et al*., 2017; Wohl, 2015; Tucker *et al*., 2010). 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 thatincrease 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). 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 *et al*., 2014). 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 steam 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). This partially explains the imposing loss of perenniality of the whole river. FAO (2022) 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 *et al*., 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 (Sichingabula, 2021; 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 such as the one shown in Figure 9 were highly incised in their naturesuch 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, 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 (Sichingabula, 2021; Wohl, 2015).

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.

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