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Damming Effect on Downstream Aquatic Ecosystems: A Case Study of Lake Mutirikwi, Masvingo, Zimbabwe

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Abstract- Dams are common in water scarce regions for alleviating water supply problems. However, studies have established that damming has led to the disruption of flow regime, which is the driver of river and floodplain wetland ecosystems. Historical information on the river and data on the fish species was obtained from fisherman and Kyle Recreational Park, Zimbabwe. We that observed reduced stream flow beyond the dam wall has also disrupted seasonal flow, reduced river channel and negatively impacted reproduction, growth and survival of fish and riverine vegetation. This study established the impact of flow regime on sustainable conservation and development.

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I. INTRODUCTION

Knowledge on the interdependence between land and water resources upstream and downstream is critical information for use in potential conflict resolution, resource preservation and development (Luijten et al., 2000). Damming of most streams, for purposes of alleviating water scarcity for agriculture, fishing, domestic use, hydro-electrification and manufacturing has in the process caused changes in the downstream hydrology and geomorphology (Cudennec et al., 2007). As a consequence of damming loss of sediment has been noted downstream, leading to reduced soil fertility thus negatively impacting on quality of aquatic habitats. Change in the flow regime downstream is a factor controlled by both flooding patterns and the possible impact of rainfall changes. Rainfall patterns in the southern African semi-arid region have been generally low, less than 500 mm annually, partly because of climate change factors. However, historical changes in land and water use appear difficult to assess because of limited availability of data.

Studies have shown that water modification and appropriation for human purposes can yield greater costs than benefits and create the risk of irreversible losses of species and ecosystem services (Postel, 2003). Natural river flow is essential for native macro fauna (fishes, shrimps and snails) (March et al., 2003).

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The adults of some fish live and breed in rivers and streams meanwhile their larvae drift downstream into salt water, where they metamorphosis before drifting back upstream into fresh water (Baxter, 1977; March et al., 2003). For example, the eel (*Anguilla* species) live in fresh water, but breed in salt water (March et al., 2003). Regulated rivers disrupt migration and spawning routes of fish (Doremus, 2001; March et al., 2003), hence affecting fish diversity and functional organisation of fish communities. The growth, reproduction and survival of native fishes can be influenced by flow since under natural circumstances downstream biota strives on excess nutrients from upstream.

Flow regime also determines the physical habitat of a stream which in turn influences biotic composition. Flow influences species distribution, abundance, composition and diversity (Bunn and Arthington, 2002). Flow can lead to recruitment failure and loss of biodiversity consequently threatening ecological sustainability. The abundance and distribution of some aquatic plants and animals increase with habitat complexity, depth, water velocity and cover. Habitat of low water velocity can be silted compared to high water velocity which is free from silt. Pools which are not found under normal flow can be formed leading into invasion and success of exotics in rivers (Bunn and Arthington, 2002), hence supporting the notion that aquatic histories evolve in response to natural flow.

Unfortunately, water needs of ecosystems themselves rarely appear on the balance sheets, it is always whatever is left over after agricultural, industrial and urban needs are met (Postel, 2003). Stream flows have been persistently low to levels insufficient to support aquatic life (Doremus, 2001). Disturbance of human communities who depend on the river for domestic use, hunting and fishing is inevitable, and the affected benefit very little from the modified river system (Baxter, 1977). The river downstream from Glen Canyon Dam is probably the most studied river reach in the world; downstream effects noted include erosion, loss of beaches, changes in the riparian distribution and alterations of habitat for endangered native fishes (Graf, 2005).

Ecologists still have difficulties in differentiating the direct effects of modified flow regime from effects

associated with land use change (Bunn and Arthington, 2002). This study assessed the possible impacts that damming had on Mutirikwi River, Masvingo, Zimbabwe. The water in Mutirikwi River was dammed for the purposes of irrigating the Chiredzi and the South Eastern lowveld sugarcane estates. The study established the type of vegetation, fish species and land use patterns along the river. Water flows down the river according to the schedule set by the farming industry some over 200 km downstream. The study intends to add to the existing information advocating that water is a finite resource, therefore, there is need to put a limit to the use and modification of natural freshwater systems.

II. MATERIALS AND METHODS

a) Study Area

Mutirikwi and Shagashe rivers are the two major tributaries of Lake Mutirikwi in Masvingo, Zimbabwe. Downstream Mutirikwi river flows past Bangala dam, to the lowveld sugar estates. The dam wall which measures 63 m high was built from 1958-1960. The storage capacity of the dam is $1.4 \times 10^9 \text{ m}^3$, when full its surface area is 9105 ha and the shoreline is 238 km. Lake Mutirikwi (Figure 1), was constructed for the purposes of supplying water to Masvingo city and to the sugar estates in the southern eastern lowveld. The lake lies in agro-region IV which has an average annual rainfall of 650 mm. The area is prone to droughts and it experienced major droughts in 1983/84 and 1992/93.

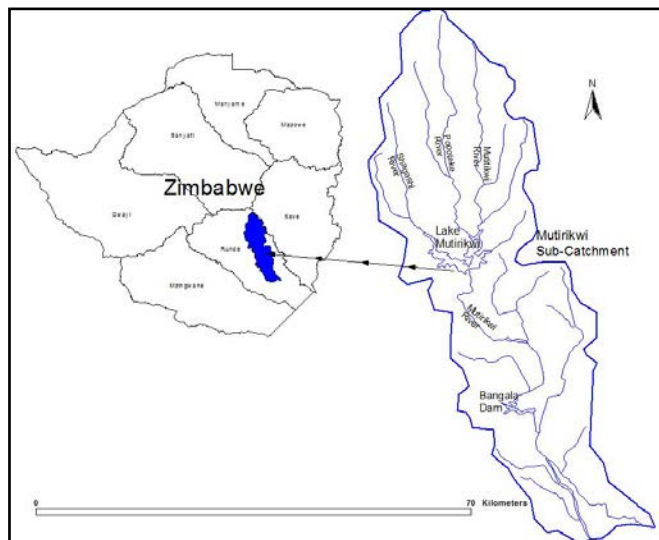


Figure 1 : Location of Lake Mutirikwi, Masvingo, Zimbabwe.

b) Vegetation Assessment

Vegetation was assessed at 5 randomly selected sites using the DNR-random tools in ArcView GIS downstream of Lake Mutirikwi. Two sites upstream site were also selected using the same method (Figure 2). The main objective of this assessment was to determine life forms along Mutirikwi River beyond the

dam wall to as far as Bangala dam as a basis for estimating plant and animal population densities inhabiting this stretch of a river. This stretch is approximately over 100 km and stretches through a gorge between UTM coordinates 7759914, 36K 0294588 at Elevation 1032 m and 77552156, 36K 0292082 at Elevation 867 m then spans on a gentle floodplain from point 77552156, 36K 0292082 and beyond. The assessment entailed identifying the vegetation present after water impoundment in Lake Mutirikwi in 1960. The physiognomic vegetation type on the upper section of the river within approximately 10 km from the dam wall consists basically Miombo woodland type with *Brachystegia glauscescens* dominating whilst the *Brachystegia spiciformis* and *Julbernardia globiflora* are the co-dominant species. Aloe species were recorded at the immediate surrounds to the dam wall commonly on the steep rock outcrops.

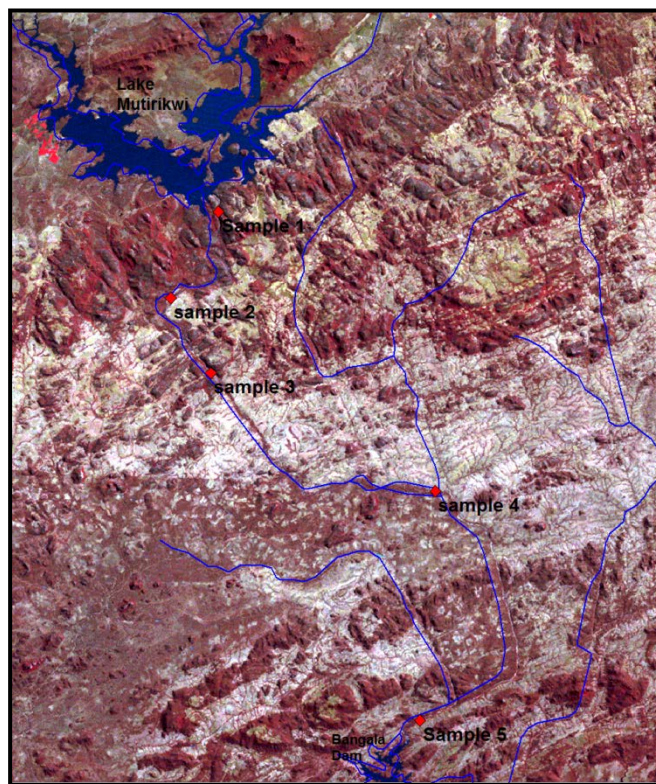


Figure 2 : Landsat Image Showing the Sampled Sites in the Pseudo Natural Colour Composite.

An inventory of tree species composition and density was carried out using the Point Center Quarter Method (PCQM) (Daoudouh-Guebas and Koedam 2006). The technique involves the observer moving in a predetermined direction recording data at predetermined intervals. A purposive random sampling technique was used to pick survey routes and two cross-sectional path lines to the river at selected river segments were mapped approximately 500 m apart and used as transect lines. Along each cross-sectional line a 50 m line transect on both side of the river was

established and each 10 m intervals along these transect lines was treated as a sampling point. At each sampling point the tree nearest to the observation point in each quadrant was recorded together with the distance of that nearest tree (Figure 3). Furthermore, the quadrat method was employed for inventorying grasses along the same path used during the tree inventorying exercise. A square metre quadrat (1 m x 1 m) was used estimating grass species composition and density. A total of forty quadrats were sampled. The observer would stop after every 5 m and place the quadrat along the transect line on alternate sides and record all the species which were within the quadrat.

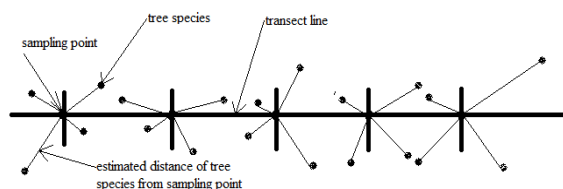


Figure 3 : Illustration of the Point Center Quarter Method.

c) Fish Assessments

Electrofishing was conducted and all depths were less than 50 cm. The average pool sizes were approximately 30 m². Fishing was done through walking along the pool for 10 minutes each with the eletrofisher. Two different sites were sampled for fish.

d) Hydrology and Geomorphology

Remote Sensing and Geographic Information System (GIS) were then used to obtain and classify the two satellite images of the study area. Multispectral image classification was done to enable comparison of the current status of the vegetation and the land use types to those decades ago in this case it was 1976. Classification was done manually by training pixels in a sample set. For both the 1976 and the 2010 images, the August month was selected because it has the best quality images for both time periods. This included limited cloud cover and the best time to differentiate between evergreen forest and deciduous forest that shed their leaves in the dry summer season. The classification of both the 1976 and 2010 images was done in ILWIS GIS using the maximum likelihood classification algorithm. Spot satellite imagery was then used to show the state of the sampled site in 2010. Spot imagery were chosen because of a convenient downloading policy and also their high spatial resolution of 2.5 m x 2.5 m. Informal interviews were also held with 10 community members from each site to gather information relating to the history of the river.

e) Data Analysis

The following formulae were used to estimate the vegetation density and at the same time relative density of different species.

$$i. d = \frac{D}{\text{Total number of quarters}}$$

Where d is the mean distance (m) and D is total of all distances.

ii. $MA = d^2$ where MA is the mean area per individual tree

iii. $\text{Density} = \frac{1}{MA}$ and relative density $\frac{d}{D} \times \text{density (trees /hectare)}$

Species diversity was calculated using the Shannon-Weiner diversity index: $-\sum p_i \ln p_i$; where p_i is the probability of encountering a given species and \ln is the natural logarithm.

III. RESULTS

a) Land Cover/Land Use Changes

Figure 4 shows a comparison of landcover/landuse maps of the the Mutirikwi sub-catchment in August 1976 and August 2010. It is evident from figure 4 that landcover/landuse has changed in the area. In between 1976 and 2010, it was mainly the evergreen and the deciduous forests that have been seriously reduced. Cropland and grasslands now dominate the landscape with an increase from 36% to over 60%. Deciduous forests have gone down from close to 35% to less than 27%. It is the evergreen forests however that have suffered the highest magnitude of decline from close to 20% in 1976 to less than 5% in 2010 (Figure 5).

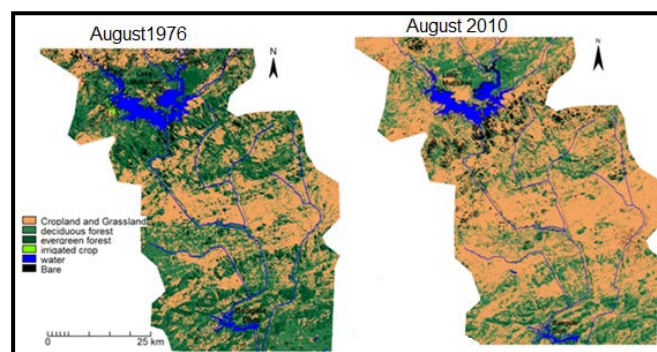


Figure 4 : Comparison between the land Cover/Land use Maps of 1976 and 2010 Derived from Landsat Images of the Mutirikwi Sub-Catchment from Lake Mutirikwi to Bangala dam.

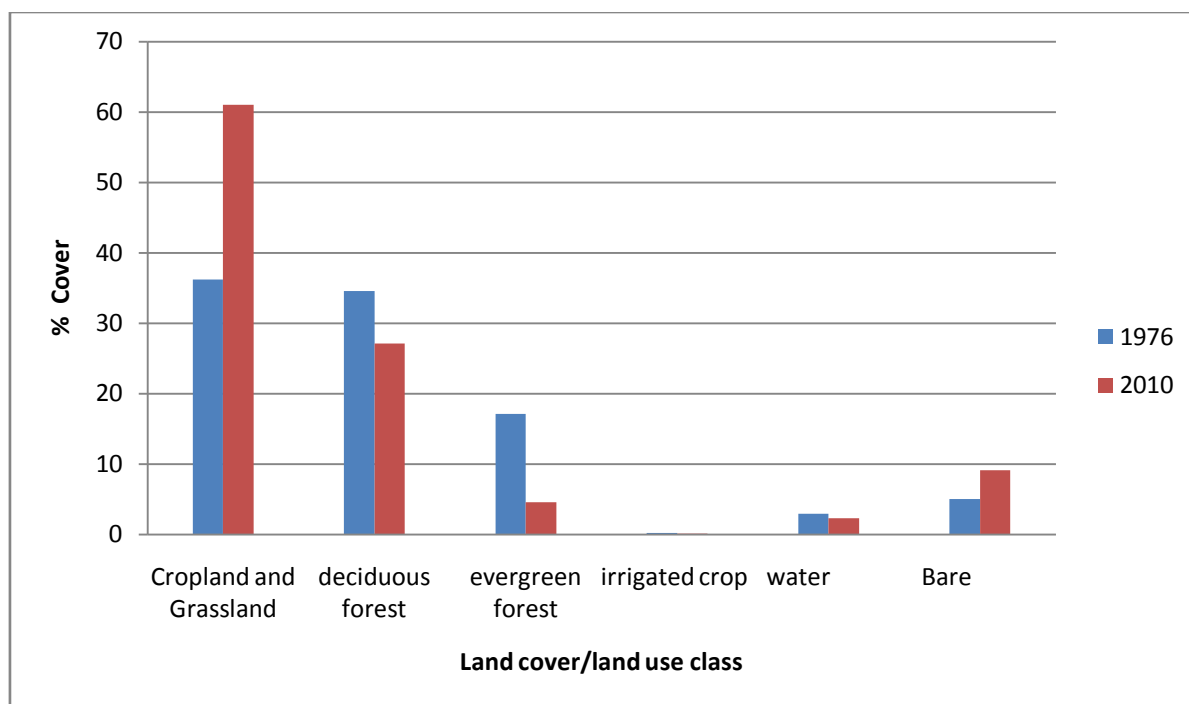


Figure 5 : Comparison of Land Cover/Land Use Classes in 1976 and 2010.

b) Woody Plant Diversity

A total of 11 species were identified (Table 1) with a diversity of 1.67 (Shannon-Weiner Index). The overall mean woody plant density for the sampled area was 383 woody plants per ha.

Table 1 : Relative Density of Tree Species.

Tree species	Relative density (woody plants/ha)
<i>Brachystegia glaucescens</i>	0.44
<i>Brachystegia boehmii</i>	0.07
<i>Brachystegia spiciiformis</i>	0.17
<i>Faurea saligna</i>	0.03
<i>Securinega virosa</i>	0.07
<i>Pterocarpus rotundifolius</i>	0.01
<i>Bauhinia pertesiana</i>	0.01
<i>Rhus lancea</i>	0.02
<i>Julbernardia globiflora</i>	0.12
<i>Zizphus mucronata</i>	0.01
<i>Bolusanthus speciosus</i>	0.03

c) Grass Composition

The overall grass Shannon-Wiener Index of diversity was 2.19. *Hyperthaenia filipendula* was the dominant grass species on the upper section of the stretch around the dam wall site (Table 2) and was clustered around well-developed soil substrate. Other co-dominant species included *Rhynchethrium repens* and *Eragrostis aspera* which were found in distinctive stands on disturbed areas around the immediate area to the dam wall. The least abundant grass was

Cymbopogon pardus which was only noted on the margins of the cross-section.

Table 2 : Grasses Species in the Surveyed Quarry Site and the Immediate Surrounding Area.

Name of species	Relative abundance (%)
<i>Hyperthaenia filipendula</i>	0.23
<i>Eragrostis aspera</i>	0.14
<i>Rhynchethrium repens</i>	0.12
<i>Heteropogon contortus</i>	0.11
<i>Hyperthaenia rufa</i>	0.09
<i>Hyperthaenia cymbaria</i>	0.08
<i>Cynodon dactylon</i>	0.07
<i>Loudetia simplex</i>	0.06
<i>Pogonathria squarrosa</i>	0.05
<i>Cymbopogon pardus</i>	0.05

d) Fish Composition

Five fish species were found downstream on site 3 and 4, i.e., *Barbus atromaculatus* three spotted minnow, *Tilapia rendalli* red breasted bream, *Clarius gariepinus* catfish, *Oreochromis niloticus* and *Micropterus salmoides* bass (Figure 6). *Barbus trimaculatus* and *T. rendalli* were the only fish species caught in greater numbers (more than 6 per 10 minute sampling). All fish sampled were less the 10 g in weight and the average standard length was less than 10cm except for the catfish and bass which had a standard length of between 10 and 13cm. Bass and *O. niloticus* are exotic species which are also found in the dam and downstream. Results from electrofishing conducted in

Lake Mutirikwi showed similar fish species except for two species (*O. macrochir* and *S. robustus*), species in the dam include *T. rendalli*, *O. niloticus*, *O. macrochir*,

Seranochromis robustus, *C. gariepinus* and *M. salmoides*.

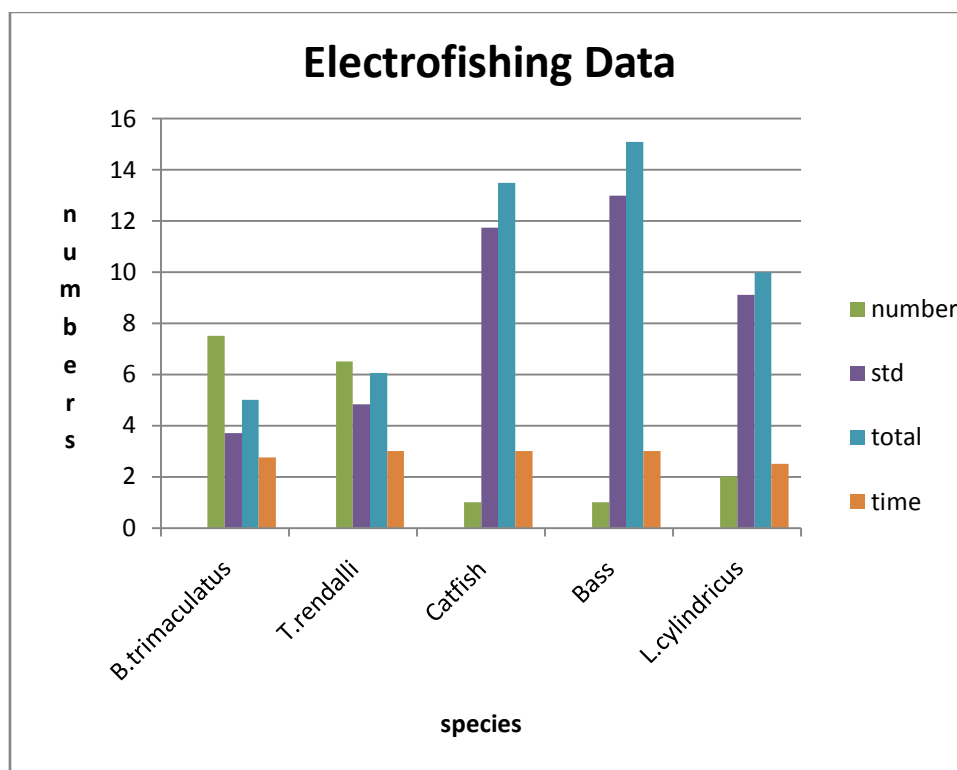


Figure 6 : Summary of Electrofishing Findings, Showing Standard Length, Total Length and Number of Fish Caught.

e) Hydrology and Geomorphology

i. Site 1

Situated downstream soon after the dam wall was characterized by continuous steep rock slopes with a single narrow river channel at the bottom of the slopes. There was no evidence of any soil substrate (Figure 7). In addition, there was a great reduction from a thick evergreen forest in 1976 to an almost bare surface with fragmented tree cover.



Figure 7 : Spot Image of Sample Site 1 on 30 October 2012.

ii. Site 2

Downstream the river had split into two channels and Sand Island of 819.45 m² separated the river (Figure 8). Maize fields were less than 50 cm from the stream bank. The water level was shallow and

villagers were crossing on foot. The river bottom was sandy. The width of the two streams varied between 2 and 3m. Compared with the situation in 1976 the island had not yet formed. There was a reduction of vegetation cover from a relatively thick deciduous forest to just scattered trees and shrubs. Close by landuse is now dominated by crop cultivation and grazing fields as compared to what it was in 1976.



Figure 8 : Spot image of Sample Site 2 on 30 October 2012.

iii. Site 3

Downstream was characterized by crystalline basement rocks, large boulders with clear water pools scattered within the boulders greater than 40 cm in diameter. The river width was 80 m (Figure 9). There was no evidence of farming along the river bank. Vegetation cover has not changed much from its de-vegetated

state in 1976 and the current land use practices characterised by croplands, bare rocks and grasslands.



Figure 9 : Spot Image of Sample Site 3 on 30 October 2012.

iv. Site 4

Downstream the river had again reduced into a small stream with sandy patches with rock out crops (Figure 10). Gardens were also along the river bank.



Figure 10 : Spot Image of Sample Site 4 on 30 October 2012.

v. Site 5

Downstream the river was wide, about 120m. The substrate was all sand (Picture 1). The water in the river appeared in patches gently flowing both above and below the sand beds. The site was not very far from Bangala dam mouth (Figure 11). Vegetable gardens were along the river bank in positions which indicated the past high water mark. The water was clear with some deposits of organic matter at the base. There was a change in vegetation cover from a deciduous forest in 1976 to mainly crop cultivation fields and vegetable gardens. These land use patterns have continued to encroach the river and are now almost on the river bed.



Figure 11a above : Part of the River Bed at Site 5 and

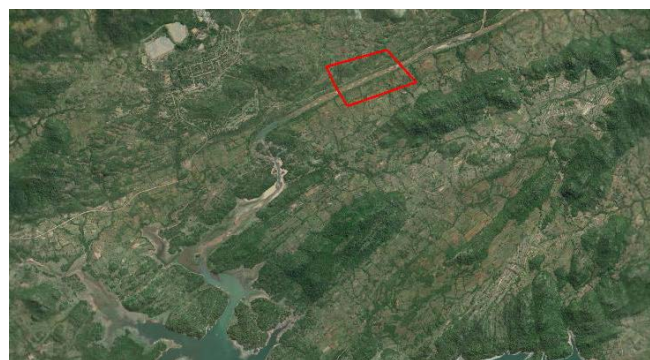


Figure 11b below : Spot Image of Sample Site on 5 May 25 2010.

Both Picture 1 and Figure 11 depict the same site 5. In the picture 1 there are women further down washing their laundry.

IV. DISCUSSION

Based on the interviews held with the communities living adjacent to the Mutirikwi River it is suggested that the river flow regime has changed. The river used to flow more often, was a source of large fish such as *Seranochromis robustus*, eel (*Anguilla* species) which were not recorded during this present study because it has been long ago when they last saw these fish species. The eel migrates between freshwater and salt water during its life cycle (March et al., 2003) and therefore, disappears when flow is disrupted. Wild animals also used to drink from the river but are no more, supporting the observation by Gandiwa et al. (2012) that damming of major rivers affects the availability of water for wildlife as recorded in Gonarezhou National Park, southeast Zimbabwe. Moreover, the older villagers living along the river claimed they would harvest riverine fruits from the riparian vegetation but these have gone almost extinct (Graf, 2005). According to them what used to be a perennial large river has now turned into a narrow channel (Graf, 2005) which only flows when the floodgates are opened for irrigation. The villagers

complained that when the floodgates were open and they coincided with a natural rain storm, their lives are put in danger as the river floods everything downstream. Lives of both livestock and humans were sometimes lost due to these floods. The loss of continuous flow has presented problems for watering livestock. Ploughing and gardens are now within the old high water mark levels as the villagers keep searching for water into the stream bed. At one site there was evidence of shallow holes dug within the sand in the river bed used as sources of clean drinking water.

The communities were of the opinion that the construction of the dam wall was of no benefit to them, instead a disadvantage (Baxter, 1977; Richter et al., 2010; Gwazani et al., 2012). The effect of the dam wall has extended hundreds of kilometres downstream (Williams and Wolman, 1984) as Bangala dam is over one hundred of kilometres down from Lake Mutirikwi. In support of the findings in this study, Kingsford (2000) states in Australia damming caused changes in aquatic vegetation, reduced vegetation health, led to decline in water-birds, decline in native fish and invertebrate populations.

The historic migration of eel was no longer evident as supported by their disappearance from the stream. The very small sized fish could not be caught by rod and line; therefore, the villagers had resorted to poisoning them. The clear water downstream (implying limited nutrients for fish) results from the trapping of sediments in the reservoir (Graf, 2005). The disruption in seasonal flow has interfered with sediment loading (Doremus, 2001) and river channel patterns hence decreasing habitat suitability for fish growth and breeding (Cudennec et al., 2007). The presence of isolated pools characterized by minimal flow promotes the success of exotic species in rivers (Bunn and Arthington, 2002) in this case *O. niloticus* and *Micropterus salmoides*, black bass.

The villagers thought the loss of natural large water pools was also the cause for the reduced rains as no more natural evapotranspiration processes were occurring. Rainfall variation due to likely climate change and loss of large pools is likely to have affected the occurrence of hippopotamus (*Hippopotamus amphibius*) (Gandiwa et al., 2012) which the elders said used to reside in the river.

The presence of gardens and fields along the river bank has also contributed to the heavy siltation, river bank erosion and flooding (Pradip et al., 2011). The usual recommendation that no farming was permitted within 30 m of the river bank was no longer being observed. The dependence on primary productivity for food increased the rate of degradation along the river bank as poverty demands were taking precedence over the river bank preservation.

The activities in the river of washing clothes and bathing has long term implications on sustainability of a

healthy river ecosystem as the nitrogen and phosphorus loads that are contained in household detergents gradually increase (Mapira, 2011). Nitrogen and phosphorus can lead to eutrophication, i.e., nutrient enrichment of the river system which can accelerate plant growth at the expense of fish and other aquatic organisms. O'Connor (2001) established that tree die back increased with the distance of riparian woodland from the river as also observed in this study. Regulated rivers led to reduced river complexity with a shrunken and simplified ecosystem offering reduced habitat for aquatic and riparian vegetation (Graf, 2006).

Downstream changes in hydrology and geomorphology result from at least the influence of land use and hydro-climatic changes but these are difficult to separate (Graf, 2006). The GIS information has shown a 10-15% reduction in vegetation and over 20% increase in cropland, supporting the increases of settlements along the river bank and deforestation in response to demand for cultivation land (Pradip et al., 2011). There was a general observation of spatially smaller, less diverse ecosystem compared to the upstream reaches of river Mutirikwi (Graf, 2006). The challenge of the researcher is to reverse the impacts of damming through stream restoration. More studies are required to further investigate the ecological impacts of management practices of river flows and basin management in Zimbabwe, since more dams are being continually constructed. For such findings to be relevant there is need for actions to harmonize water use and management in order to achieve water security for all by advocating for commitment from policy makers, managers, communities and all stakeholders (Postel, 2003).

V. ACKNOWLEDGEMENTS

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