Causes and Rate of Reservoir Sedimentation Due to Changes in Catchment Management. A Case of Marah Dam in Masvingo Province of Zimbabwe

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Research Article

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ABSTRACT

The paper sought to analyse the rate of reservoir sedimentation due to changes in catchment management within the catchment area of Marah dam in Masvingo province of Zimbabwe. To do this, the study evaluated the current capacity of the dam based on current sedimentation rate as well as the lifespan of the dam under the current management practices. In order to obtain the rate of sedimentation, the formula (LTD/6) was used. The parameters T and D were measured using an Automatic level, Theodolite and staff. The depth of the reservoir was found to be 16m and the throwback was also found to be 840m. Calculations done pointed to an increase in the rate of sedimentation with a marked increase of 49.9% from 2000 to 2006, giving an average sedimentation rate of 8.3% per annum. The lifespan of the dam was also found to be about 12 years. This meant that the lifespan of the irrigation scheme dependant on the dam had a lifespan less than the 12 years. It was recommended that the Environmental Management Agency be involved and also that the community formulate catchment management strategy so that there is continuity and sustainability of Marah irrigation scheme.

Keywords: Water availability; storage capacity; sedimentation; reservoir; catchment; land-use change.

INTRODUCTION

Small water reservoirs are very important for ensuring water availability and sustenance of livelihoods for rural communities. This is especially so in semi-arid and water scarce areas in Zimbabwe (Sithole and Senzanne, 2006). One of the critical problems in their operation and maintenance is the loss of storage capacity due to continuous deposition of water borne sediments thus reducing the life span of a reservoir (Mavima et al., 2011). The calculated water content at the design stage can be modified significantly by the accumulation of these sediments. Soil erosion which originates in the catchments is transported through the streams and rivers and is deposited in these reservoirs. The seriousness of the depletion in the storage water is dependent upon the rate of sediment accumulation.

Soil erosion and subsequent sedimentation of reservoirs is a complex process dependent upon a number of natural and anthropogenic factors. Chikwanha and Ward (1979) reported soil yields of 30-50 tonnes/km²/annum. Elwell, (1978) measured soil losses due to sheet erosion and it was about 50 tonnes/ha/annum for Zimbabwe. Natural factors that influence soil erosion are geology, climate, landscape features and soil characteristics. Anthropogenic factors are tillage practices, overgrazing, mining and logging. In other words, any form of change in land use disturbs the balance of nature and has catastrophic consequences. Thus, land use changes have been singled out as the main contributing factors to sedimentation of reservoirs (Mavima et al., 2011). The river ecosystems are increasingly subjected to stress due to these induced activities. The identification and solving of this problem of sedimentation has attracted increasing attention over the past half century with ever growing concern worldwide over water resources. Many argue that the driving force for environmental problems and water consumption is population growth (Vlek and Steg, 2007; Wong, 2007; Ehrlich and Ehrlich, 1990). Soil erosion and sedimentation of river systems is currently one of the world’s environmental challenges.

Global sedimentation situation

Soil erosion has been Zimbabwe’s devastating environmental disaster with studies indicating an estimated annual soil loss due to sheet erosion to be as much as 50 tonnes/ha (Elwell, 1987). Some of the eroded material
eventually finds its way into river systems thus contributing to siltation (Nyoni et al, 2012). Siltation is regarded as one of the greatest risks to the failure of small dams especially in communal areas where environmental protection practices are absent or ineffective (RELMA, 2005). Siltation is common to all reservoirs and it is widely recognized that each year up to 1 percent of the world’s reservoir capacity is lost to sedimentation (Howard, 2000). The most extensive survey of siltation in Zimbabwe was undertaken by Agritex in 1983 and results are summarized in Table 1 below.

<table>
<thead>
<tr>
<th>PROVINCE</th>
<th>Number of Dams</th>
<th>Average % siltation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mash East</td>
<td>40</td>
<td>24.8</td>
</tr>
<tr>
<td>Midlands</td>
<td>259</td>
<td>35</td>
</tr>
<tr>
<td>Manicaland</td>
<td>118</td>
<td>54.7</td>
</tr>
<tr>
<td>Mashonaland Central</td>
<td>130</td>
<td>34</td>
</tr>
<tr>
<td>Masvingo</td>
<td>109</td>
<td>61.9</td>
</tr>
</tbody>
</table>

Masvingo had the highest siltation rate according to the above statistics. The report does not however give the methods used to assess the level of siltation in dams. The degree of siltation varies considerably depending on the condition of catchment (Maposa et al, 2010). The study focused on evaluating the current rate of sedimentation of Marah dam. Specifically, it sought to determine the current capacity of the dam based on current sedimentation rate as well as the lifespan of the dam under the current management practices.

**METHODOLOGY**

Location of study

![Figure 2: Map showing Marah dam and its catchment area](image)

The study was carried out at Marah dam agro-ecological region 3 in the hydrological zone ES4 about 70km from the city of Masvingo along Mutare-Masvingo high way in the Victoria east ICA on Marah Ranch. Marah Dam was built in 1970 along Mangezi river with an initial capacity of 667,000 m$^3$. Its main purpose is to provide irrigation water to Marah irrigation scheme. The catchment size is 16100 hectares in extent. Before land redistribution, the greater part of the catchment area was under the control of two white farmers. Altitudes range from 900 to 1200 meters above sea level and mean summer temperatures range from 7.5°C to 20°C. This region experiences fairly...
low total rainfall and is subject to periodic seasonal droughts and severe dry spells during the growing season. Rainfall statistics of the study range from 475 to 1250 mm per year predominantly from October to March. The soils are mainly moderately, greyish brown coarse grains throughout the profile.

The slope ranges from 3 to 8%. The catchment is drained by Mungezi and its two tributaries Chunyamangwana and Chengezana. Valleys tend to be v-shaped at the top of the catchment and become broad and flat as from the middle part of the catchment to the bottom. Dominant trees are Brachystegia speciformis and Julbernadia globiflora are on the mountains with the undergrowth of Sporobolous and degitara. Hyperparania spp is found in grazing area and heteropogony is found in contour ridges. The above topographical characteristics reduce available arable land. Excessive sheet and real erosion is evident throughout the catchment and this is intensified by the degree of hill; top and hill face cultivation. Poor mechanical and biological conservation works result in increased run off (due to low infiltration rates) being highly erosive. Very active gully erosion is evident in three wards (Chief Makore and Chief Chiwara in Gutu) which are part of the catchment area of Marah dam.

Determination of annual rate of sedimentation

To come up with the annual rate of sedimentation entering the reservoir, the following method was used. The current dam capacity at full supply level was estimated using the rough estimation formula

\[ Q = \frac{LTD}{6} \]  

Where parameters:
L is the length of the embankment in metres.
T is the throw back of the water in the reservoir
D is the maximum depth of the dam in metres.

The throw back of the water and the length of the embankment were measured using a measuring staff, theodolite and an automatic level machine. Variable D was obtained by measuring wall height up to supply level at equal intervals. Choice of intervals was ten metres and the deepest point noted. The readings were taken from an established bench mark. Data used were for the following periods: 1970 (on completion of dam), 1977-78, 1978-79, 1979-80, 1980-93, 1993-2000 and 2000-2006. The dam’s lifespan is going to be regarded as the number of years before 100% siltation.

RESULT AND DISCUSSION

During the first seven seasons of Marah dam’s life, it silted at a rate of 1.77% per season, reducing its capacity from 6.67*10^5 m^3 to 6.55*10^5 m^3. At this rate, the life span of the dam was considered to be 57 years (See figures 3 and 4 below). Soil erosion was considered to be low due to proper conservation practices being practiced by the white owners of land. A sharp rise in sedimentation was experienced by the dam from 1977/78 season to 1979/80 season. The sedimentation rate rose from 1.77% to 15%. The dam’s lifespan dropped from 56.5 years to 7 years during the same period as shown in figure 5. This meant that if the rate would remain at 15%, the dam would come to 100% sedimentation in 7 years time.

This increase in the rate of sedimentation was possibly as a result of activities like stream bank cultivation in the three wards of Gutu which also form part of the dam’s catchment. This was possibly due to the unanimous
boycott by the black peasants to construct contour ridges in their fields. Sufficeth to say that this was at the time when the liberation war (Second Chimurenga) was at its peak in the then Southern Rhodesia. For the periods between 1979/80 and 1980/1993, sedimentation rate dropped from 15% to 0.09% as shown in figure 3 above. As a result, the lifespan of the dam rose to 1123.59 years.

![Figure 4: Marah dam capacity from 1970 to 2006](image)

![Figure 5: Marah dam's lifespan](image)

During this period, silt trap dams were constructed upstream of Marah dam (See figure 1). This resulted in the siltation rate dropping from 15% to 1.5% in 1993. The decrease was as a result of the sedimentation being trapped in the silt traps and very little passing into the dam. There was also a change in attitude towards soil conservation among the people dwelling within Marah catchment.

There was a reduction in rate of sedimentation until 2000 when land ownership was changed. During the year 2000, the land reform programme resettled farmers in the catchment area of the three commercial farms. 150 self contained units with an average of 85 hectares per farmer were allocated to new farmers. An additional number of 350 farmers also benefited from the villagised A1 model within the same decade. The three farms that used to be under the control of two white farmers were now controlled by 500 black owners. These farmers started the moulding of bricks to build housing units. They also cut down trees to build pole and dagger huts. There was also opening of new land for cultivation and gold panning in other farms. More cattle were brought by the new farmers thus increasing the stocking rate. There was a general degradation of the land due to reduced infiltration rate, increased runoff and the cutting down of trees. On average, the siltation rate increased to 8.2%. This change in system of land tenure is the major cause of the drop in the dam’s lifespan from 64.9 years to 12 years. The rate of sedimentation of the dam during this period rose from 1.54% to 8.32% and its capacity dropped from 447,000 m$^3$ to 224,000 m$^3$. The three farms used to belong to two white commercial farmers but after the land reform program, they were placed into the hands of five hundred farmers with different land management systems resulting in an increased rate of soil erosion leading to siltation of the dam.

The degree of siltation varies considerably depending on the condition of the catchment area (Maposa et al, 2010). The system of land tenure has changed from commercial to communal with no catchment management strategy in place and with no policies to protect the environment. According to Whitlow and Campbell (1989), soil
erosion tends to be severe and widespread in communal lands where population density is high. New lands were opened as agricultural activities intensified in the catchment area of Marah dam. This led to the breakdown of biochemical and biogeochemical processes which are known to be vital for the sustenance of the soil fertility. Consequently, the capacity of soil to withstand erosion in the catchment area has been critically reduced resulting in increased rate of siltation of the dam.

Whitlow and Campbell (1989) estimated that 25 per cent of the communal areas were severely eroded compared to 2 per cent in the commercial areas. Whitlow (1987) found that soil erosion was prevalent in all agro ecological zones, but more pronounced in zones III, IV and V. Zones IV and V are characterized by unreliable rainfall and poor soils susceptible to erosion. As was stated earlier on, Marah dam is in agro ecological region III, but its catchment area is spread between agro ecological regions III and IV (See figure 6).

Figure 6: Map showing agro ecological zones of Zimbabwe

All these soil losses are reducing the life span of the dam because of the system of the land tenures. However, Elwell (1987) stated that the average loss is about 50 tonnes / hectare / yr and the soils in communal areas will not be able to sustain yields in 35 to 50 years. The result is thus more lands are to be opened for cultivation in the near future. These activities will only aggravate siltation of the dam which now has a lifespan of six years and thus the existence of irrigation scheme. Land degradation is widespread in the catchment area; consequently water storage will be limited due to siltation of the dam. Sediment from the deforested and overgrazed areas as well as the eroded farm lands and the loosened alluvial deposits in gold panning areas reduced the lifespan of the dam and thus the existence of the irrigation scheme.

There are several direct and indirect causes of degradation in this particular catchment leading to rapid siltation of the dam. Among the direct causes of overgrazing, excessive wood cutting, improper soil and water management, land disturbance and cropping lands that are too erodible. Indirect causes include increase in human and livestock populations, refusal to believe that a problem exists, absence of environmental awareness, lack of knowledge on how to control and prevent land degradation, government policies and greed. Improper soil and water management and cropping are the most important causes in this particular catchment.

Similar studies elsewhere have also been conducted with similar results. Shiyang Reservoir in China had its capacity reduced after 43 % of woodland areas within its catchment were turned into agricultural land (Zhou, 2002 in Mavima et al, 2011). In Ghana a similar study to assess the impact of land use changes on the Burekese catchment was conducted and the results showed a loss in reservoir storage capacity of 45 % due to siltation over a period of six years. The causes for the siltation of the reservoir were attributed to deforestation, population growth and lack of proper education of the communities in catchment management (Adjei et al, 2008 in Mavima et al, 2011).
CONCLUSIONS AND RECOMMENDATIONS

With the current rate of sedimentation standing at 8.2% and about 12 years before complete siltation, a strategic catchment rehabilitation program should be put in place. The research program has come up with the expected life span of the dam. The research has also predicted the life span of the dam and hence the existence of the irrigation scheme. Results obtained will help the community to formulate catchment management strategy so that there is continuity and sustainability of Marah irrigation scheme. Proper catchment management has got to be implemented as a matter of urgency if siltation rate is to be retarded. In other words, preventative and curative measures can be adopted to minimise siltation of the dam. The project is a people’s project and its success depends on the very people. Participatory approach can best help the situation. This could be achieved through community involvement and active participation.

Stream bank and stream bed cultivation which promote soil loss must cease within the catchment area of Marah dam. All arable land must have mechanical conservation works which must be planned, designed and constructed to specifications. Re-afforestation must be introduced within the catchment area of Marah dam as a matter of urgency. This tends to increase filtration of rainfall water and reduce surface runoff which subsequently reduces erosion within the catchment. In order to achieve these recommendations, the national environmental agency (EMA) should be tasked to make sure these targets are realised. The recommendations made are not an easy task to carry. They require dedications and a strategic management plan.

REFERENCES


