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GEOMORPHIC AND HYDROLOGIC EFFECTS OF CONSTRUCTING A RESERVOIR ON MBAGATHI RIVER

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ABSTRACT

Building reservoirs along rivers have become a common practice today with the motive being tapping in more water in concentrated demand sites and in flood mitigation towards sustainable management of the resource. However, the practice has transformed the natural flow regime of rivers. This study examines the effects of constructing a reservoir along Mbagathi River, Athi catchment. Using the Water Evaluation and Planning Model (WEAP) and a raster layer for Mbagathi sub-catchment, water supplies and demand data was fed to the model, after which it was ran to model the sustainability of Mbagathi River on constructing a reservoir. Findings show a reduced amount of irrigation water at the expense of increasing domestic site water, a reduced stream flow and unsatisfactory coverage during dry spells thus resource non-sustainability. The area should maximise the benefits of a reservoir by setting flow requirements to retain river flows close to the natural regime.

Keywords: Reservoir, Water Evaluation And Planning model, Hydrology, Geomorphic, Flow regime

BACKGROUND

Sixty years ago Leopold in a book titled, "Man's role in changing the face of the earth" (1956, p.646) forecasted the increase of fabricated reservoirs on many global rivers noting that such modifications would control river flow characteristics. Evenly, such events could result to unsustainable management of the resource compromising other natural resources dependent on water for survival. These predictions have materialised, as dams are a ubiquitous feature in many rivers worldwide making them partly artificial and partly natural fluvial systems. In America, about 75,000 dams impound river catchments with specific rivers having reaches controlled by such reservoirs while 137 large reservoirs, meant to store water regulate the flow in many large streams (Graf, 2005). The installation of these artificial controls coincides with increasing ecological changes in such stream flow systems. Evenly, changes in wildlife and riparian habitats following construction of dams is expected particularly the reduction of endangered and threatened species in such watersheds (Graf, 2006). Reservoirs on one hand regulate peak flow preventing flooding and sediment loading, facilitate hydropower generation and act as water stores while on the other hand, change flow timing, alter annual flow and redistribute discharge ultimately, modifying the river's natural flow.

Several studies applaud reservoirs, as a solution to several ecological changes. Reservoirs control inundation duration and frequencies thus regulate geomorphic characteristics of rivers by reducing their lateral migration and stabilizing their active surfaces through channel shrinking (Shields, Simon & Steffen, 2000). Flooding also controls biological aspects of a river determining its riparian and aquatic system through controlled hydrology-sediment regimes known to influence migration of fish (Benke & Cushing, 2005). Dams play a crucial role in sustainable development towards food security. A report by the International Commission on Large Dams (1999), "*Benefits and concerns about dams*" reported extensive use of such reservoirs in agricultural irrigation projecting an 80% increase in food production by 2025. Reservoirs also regulate water supply especially to governments tasked with energy production and freshwater supply at a time when fossil fuels are reducing and alternative fuels are becoming very important. Hydropower, tapped in such reservoirs is largely renewable, dependable, efficient and clean. In developing countries, dam topography will fill the energy gaps required to realise sustainable development goals. A study by de Georges and Reilly (2006) reported the use of dams in large-scale irrigation on Senegal River contributing to economic development.

In the east coast, construction of small dams was seen to inhibit migration of diadromous fish, trends also evident in Pacific Northwest and Great Lake Region Rivers (U.S. Fish and Wildlife Service, National Marine Fisheries Service, South Carolina Department of Natural Resources, 2001). Reservoirs are attributed to altered hydrologic regimes of rivers characterised by sediment-choked rivers resulting to reduced flow, extended flow durations and the armouring of channels hence degradation of river profiles (Magilligan, Nislow & Graber, 2003). In Connecticut River Watershed, the construction of reservoirs resulted to a 32% decline in flow replaced with extended flow durations (Magilligan & Nislow, 2005). In Mali, Manatali reservoir construction destroyed over 43,000 ha of its savannah and 120km^2 of its forest, led to aquifer depletion and consequent suppression of the flood cycle, consequences that are anti-development (de Georges & Reilly, 2006). Reservoirs also interfere with flood-dependent ecology, as evident in Nigeria's Kainji dam resulting to 70% reduction in flood resilience downstream and consequently diseases such as malaria, resettlement and dam breakage disasters to affected population (Drijver & Marchand, 1985). As such, the challenge is in optimizing the benefits accruing from reservoir construction while minimizing negating effects to maintain a watershed's sobriety and conditions close to natural flow regimes for water systems as well as enhance sustainable development. The World Commission on Dams (WCD) (2000) agreed with this suggestion after reporting these controversial issues associated with reservoir construction recommending that such projects should subscribe to values of sustainability, efficiency, equity and accountability in use to gain acceptance and maximize their shared benefits towards holistic development. *The purpose of this paper is to model the nature of geomorphic and hydrologic effects of a reservoir using WEAP model, at a sub-catchment level using the case of Mbagathi River.*

MATERIALS AND METHODS

Area of study

The study was carried out at Mbagathi sub-catchment located in 1° 23' 0" South, 36° 46' 0" East. The sub-catchment covers an area of 166km^2 and traverses Ngong, Kikuyu, Kathiani and Lang'ata districts (Krhoda, 2002).

The sub-catchment has an altitude ranging from 1493-1883 meters above sea level and is subdivided into three parts based on the slope: the upper part of Thogoto and Ngong forests with rolling land, the middle part with moderate slopes and mainly urban settlements and lower part with gentle slope to flat land covering the Nairobi National Park. Urbanization, agriculture and forestry are the main land uses in the catchment area. Agriculturally, crop production is diversified where the upper region is mostly subsistence while the lower deals with commercial floriculture and horticulture farming although both parts practice forestry. Figure 2 below shows a map of the sub-catchment.

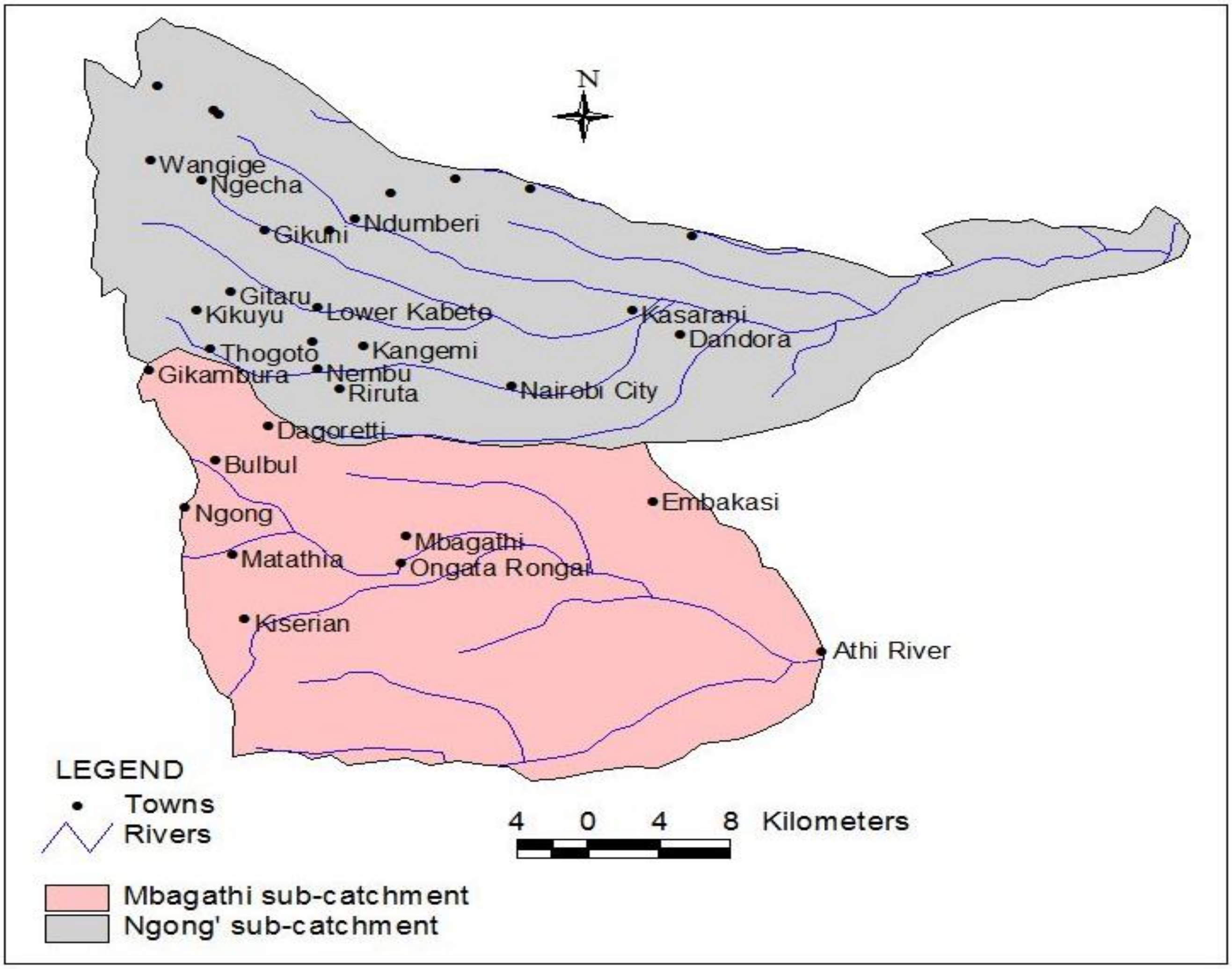

Figure 1: Mbagathi sub-catchment map

WEAP model

Using WEAP's schematic view, climate and socio-economic data was input to generate the current and reference scenarios of Mbagathi sub-catchment with both water supplies and demand sites. This was followed by the creation of a new scenario, city reservoir inherited from the reference scenario. The object the reservoir, positioned on the main river, upstream of the domestic demand site was assigned a demand priority of 99. Data on the start-up year of the reservoir and storage capacity was fed to the model. Afterwards, the model was ran to assess demand coverage changes, sustainability of water resources on construction of the reservoir, effects on downstream river flow and manipulation of operational and flow requirements to mitigate deleterious effects downstream. Changes in water demand in domestic, commercial and subsistence irrigation demand sites and unmet in stream flow requirement was assessed.

RESULTS AND DISCUSSION

Figure 2 shows the effects of introducing a city reservoir in the sub-catchment on domestic, subsistence and commercial irrigation water demand from 2012 to 2020. Domestic water demand increases from 180Mm^3 in 2012 to 248Mm^3 in 2020 owing to an increasing population, rural-urban migration and increased availability of the resource. A study in Nablus City observed that constructing a reservoir in Sabastia increased the demand in the municipality owing to easy accessibility and shifts from other alternative sources (Rahma, 2009). Consequently, economic development occurred though sustainability was impossible owing to compromise of the resource in other development sectors. Commercial water demand reduces from 87Mm^3 in 2012 to 70Mm^3 in 2020, a trend attributed to projected decrease in water flow of Mbagathi river owing to an altered flow regime.

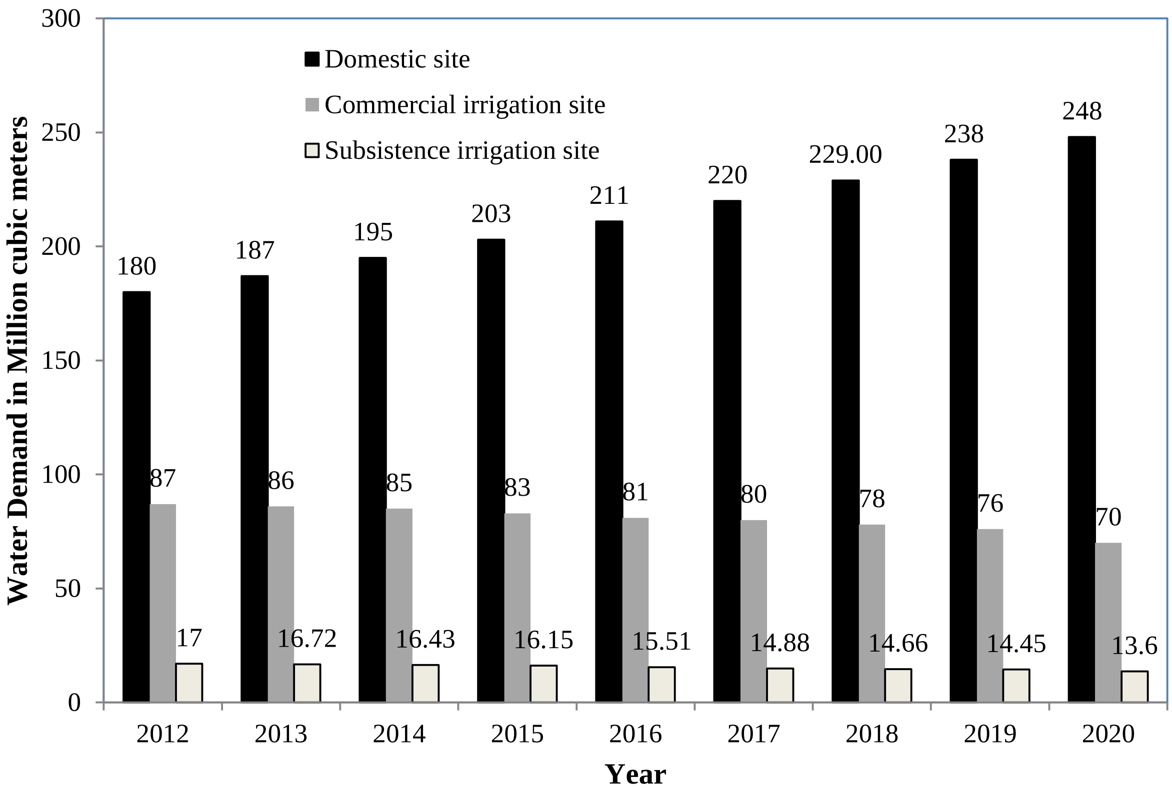

Figure 2: Effects of reservoir construction on water demand in various demand sites

These results differ from a study in western Algerian watersheds showing increase in projected commercial and domestic water demand on constructing reservoirs as both demand sites are of close proximity to the reservoir unlike this study where commercial demand site is located downstream (Hamlat, Errih & Guidoum, 2011). The study reported that choosing an appropriate site of the reservoir determines its benefits, acceptance and sustainability. Subsistence water demand upstream of the catchment reduced from 17Mm^3 in 2012 to 13.6Mm^3 in 2020 owing to land use changes favouring new residential settlements. By constructing the reservoir, excess water is stored during high rainfall to cater for low flow periods and prevent flooding upstream of the sub-catchment in Kiserian and nearby areas. This favours the region considering it is semi-arid and many dams will enable agricultural irrigation even in dry climate facilitating sustainable development amidst uncertainties resulting from climate variability. However, the opportunity cost is an altered hydrological regime explaining the high water availability in the sub-catchment's domestic site and reducing water up- and down-stream the catchment with agricultural practices (Manatunge, Priyadarshana & Nakayama, 2010). Hydrological alterations resulting from reservoir construction benefit the urban region hosting the reservoir at the expense of the remaining sub-catchment areas hence non-sustainable (Nilsson & Berggren, 2000). However, consolidating the loosing and gaining sides is possible through relocation of endangered species, relocation the dam site after re-consideration of its environmental impacts, creating of artificial fish passages to aid migration and comprehensive assessment of water entitlements among users to enable sustainability. The International Institute of Environment and Development (IIED) echoed similar recommendations after highlighting the conflicts that arose in a reservoir construction project in Lesotho (Skinner, Niasse & Haas, 2010).

Figure 3 shows the effect of adding a reservoir on the flow requirement coverage in the sub-catchment. Results show 100% coverage during precipitation peak periods of the year while least coverage at 52.45% occurs during the driest month. *Results attest to a sediment-hungry river characterised by reduced deposition and increased erosion resulting to eroded riverbed and shores.* Ultimately, sustainable development is impossible owing to a reduction in wildlife support, ecosystem variability and coastal delta/ plains sediment as evident in Three Gorger Dam in China (Dai & Liu, 2013). Reservoir introduction interferes with natural flow of Mbagathi River by eliminating the annual discharge usually governed by climate factors while reducing and increasing the peak river flows and low flows, respectively. McCully (2001) shared similar opinions claiming that 139 largest rivers in the use have been fragmented owing to dam construction and water regulation during reservoir operation, irrigation and inter-basin diversion.

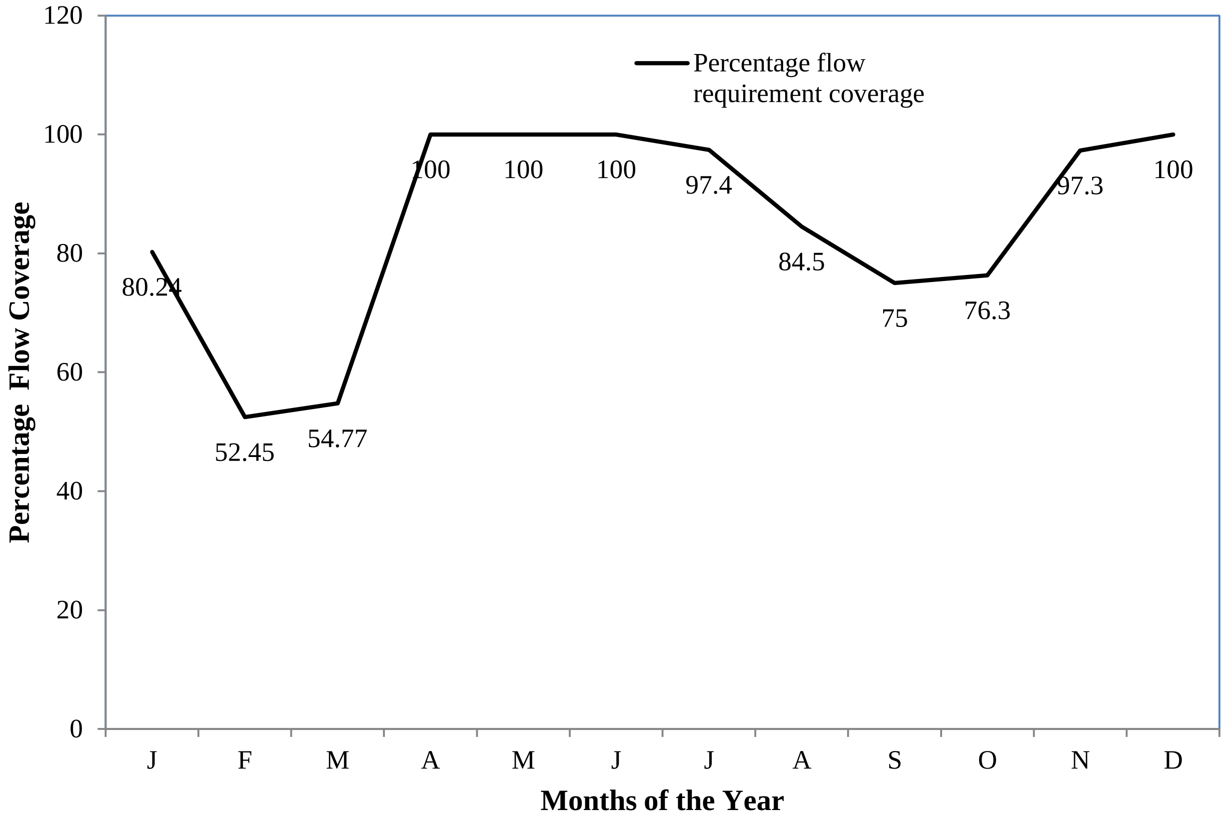

Figure 3: Effect of reservoir construction on flow requirement coverage

Reservoir construction promotes the growth natural and artificial vegetation since there is reduced overland flow that causes soil and nutrient erosion, which promotes agricultural support and economic development. In South Tobacco Creek catchment, Manitoba, reduced sediment, nitrogen and phosphorous loadings was evident following construction of small reservoirs during high flow. Additionally, reduced crop destruction by floods was evident resulting to improved food security (Tiessen, Elliott, Stainton, Yarotski & Lobb, 2011).

Consequently, quality and quantity of water downstream deteriorates owing to increased sedimentation, riverbed scouring and the drying up of most rivers as evident in the sub-catchment. With incomplete coverage in majority of the year, up- and down-stream linkages will be cut encouraging water conflicts hence the need to consider the tradeoffs in reservoir construction. The ultimate effect is felt when coverage is low and no allocation for environmental flow is made as observed in the Marromeu complex, Zambezi Delta (Beilfuss & Brown, 2006). Mbagathi sub-catchment should retain reservoirs owing to their role in flood control and agricultural irrigation for economic development but link up- and down-stream users to enhance water use efficient practices amidst climate change uncertainties. This will minimise negative impacts of upstream developments on downstream aquatic ecosystems, as reservoirs will adopt operation rules that restore natural flow regimes during high and low flows (Ronco, Fasolato, Nones & Di Silvo, 2010). Ultimately, sustainability is achievable by pre-determining maximum and minimum low flow in drier seasons and minimum high flow during wet seasons to set operation rules of reservoirs as evident in Zambezi Delta (Tilmant, Beevers & Muyunda, 2010).

Figure 4 shows the effects of introducing a reservoir on unmet in stream flow requirement in Mbagathi sub-catchment. Results indicate that during high rainfall incidence, unmet in stream flow is zero while during drier months the deficiency increases to its peak at 121.15Mm^3 in March for all seasons. The lack of fulfilling in stream flow most of the year depicts rainfall fluctuations and poor surface- and ground-water replenishment as well as overexploitation of water resources.

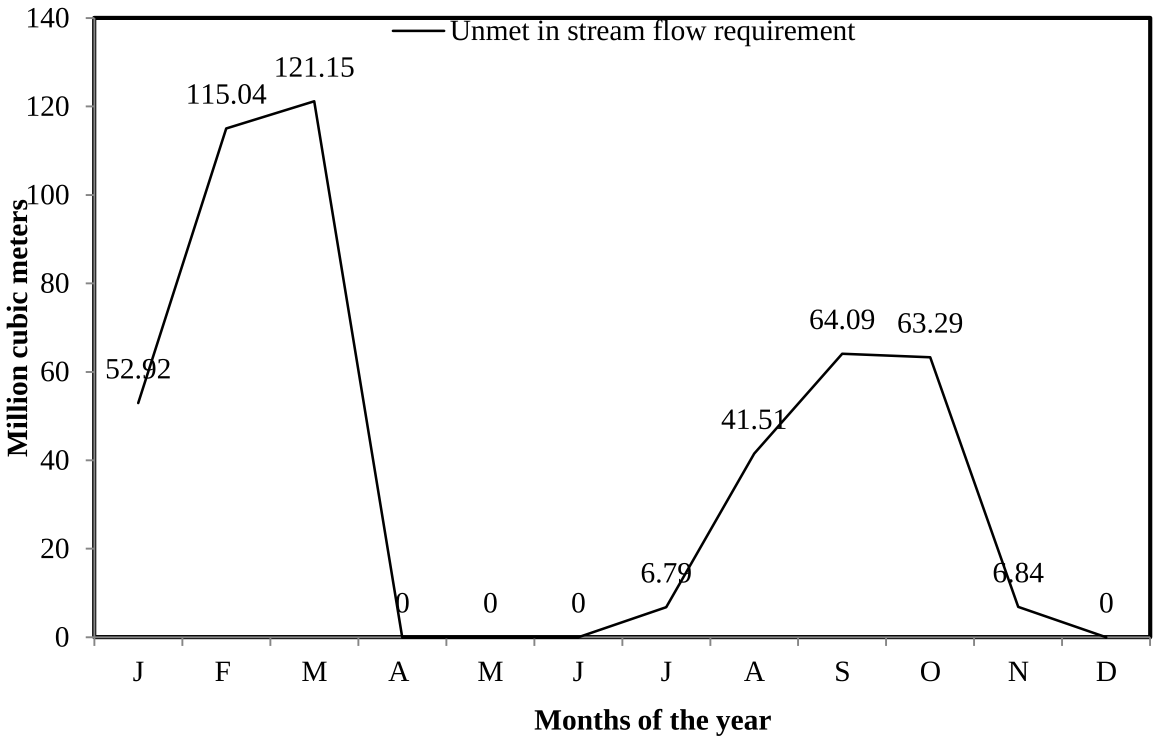

Figure 4: Effects of introducing a reservoir on in stream flow requirement

With such climate and water resources variability, agricultural practices are unpredictable and bound to fail in most cases, as replicated in the unstable economy of the region. The trend threatens the sustenance of the sub-catchment's aquatic ecology through altered channel hydraulics ground roughness, reduced flow and low habitat support, which limits transportation of sediment and lowers water quality (Baker, Bledsoe, Albano & Poff, 2011). To maintain high in stream flow, setting high demand priorities for highly valued demand sites, environmental flows and flow requirements is essential, as they will ensure effective use of the resource for the ranked economic and environmental demands of the region. Evenly, the use of return flows to replenish Mbagathi sub-catchment would ease the unmet flows and demands without compromising important off-stream abstractions as indicated by Carmo Vaz and Van Der Zaag, (2003) in their study on sharing Incomati waters between South Africa and Mozambique. The Southwest region of US has increased its national water supply by 27% following reuse of return flow resulting to better efficiency in water management (Kusanto, 2013).

CONCLUSION

The study established that constructing a reservoir in Mbagathi River has advantages and disadvantages towards sustainable development of the sub-catchment. Dams will promote development through better food security by promoting agricultural irrigation as evident by a reducing water demand in subsistence and commercial irrigation sites. Dams will also ease the region's energy crises through hydroelectric power generation, which is largely unexploited, ease water scarcity in dry spells, promote vegetative amendments upstream and control flooding downstream. However, such reservoirs will alter the natural flow of the river causing unsatisfactory flow requirement coverage and stream flow especially in dry climate resulting to asymmetry in up- and down-stream water availability. Similarly, it will reduce the area's biological diversity, increase sedimentation shock hence destroy Mbagathi riverbed, reduce its flow and extend its flow periods, effects that are negating to sustainable development of the area's economy and environment. These effects depend on the location of the dam in the sub-catchment. As such, solutions should focus on best site selection for reservoirs to reduce their resultant environmental damage. *Evenly, better planning and consultation during reservoir construction projects is mandatory to assess its environmental and economic importance, enhance its acceptance among water users and define its entitlement among sharing users in sharing rivers. Maintenance through setting priority users and demands, pre-determining maximum and minimum low flow in drier seasons and minimum high flow during wet seasons and adopting operation rules that restore natural flow regimes during high and low flows will enforce sustainable, efficient and effective use of such reservoirs. Such initiatives require close monitoring and evaluation to enforce compliance in the long-term*. The proposed reservoir should be constructed to meet the sub-catchment's domestic needs without creating unequal up- and down-stream water supplies and reduced environmental flows to induce holistic and sustainable development.

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