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Effects of damming on the ecological condition of urban wastewater polluted rivers

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ABSTRACT

Increasing damming of rivers is a global challenge and many studies have highlighted the ecohydrological effects particularly on migratory fauna. However, there are fewer studies that have explored the effects of the reservoirs on the ecological condition of urban wastewater polluted rivers. Therefore, damming of polluted rivers that drain urban wastewater from the City of Bulawayo, Zimbabwe represents an opportunity to understand the effects of interactions between damming and ecological condition of the affected rivers. Data on environmental variables and macroinvertebrates were collected from twelve sites selected from three rivers: Umzingwane – a river that does not receive wastewater from the city; and Umguza and Khami – both rivers draining urban wastewater from the city. One site each on Khami and Umguza rivers were located before the city whereas the rest of the sites were either located immediately after the city but upstream or downstream of the dams. Sampled sites were assessed for similarity based on macroinvertebrate data and three clusters comprising of (i) less impacted sites, (ii) sites immediately upstream and (iii) those immediately downstream of dams were produced. The assessed environmental variables (ANOVA, $p < 0.05$) and macroinvertebrate community structure (ANOSIM, $p < 0.05$) indicated significantly deteriorated conditions at sites located immediately upstream of the dams and these variables significantly improved soon after the dams. Sites located immediately upstream of the dams were typified by poor water clarity, high nutrients, high sedimentation, dissolved oxygen deficiency, and high levels of COD and BOD plus significantly degraded macroinvertebrate communities. Except for salinity that increased downstream of dams, the present results indicate that dams on urban wastewater polluted rivers improves the ecological condition of the affected rivers. In general, this study suggest that pollutants may be retained within the dams and therefore the utilisation of water from these reservoirs for human consumption, crop and livestock production may be risky as pollutants are likely to be retained within these dams.

1. Introduction

Due to increasing demand for power, high frequency of occurrence of droughts and scarcity of water for municipal use and food production, water harvesting through dam construction is being promoted by most countries (Bates et al., 2008). However, various studies have highlighted the harmful ecohydrological effects of damming of rivers (Watters, 1996; Nilsson and Berggen, 2000; March et al., 2003; Wu et al., 2004). Most of these studies have emphasised the importance of natural flow regimes in sustaining the native biodiversity and ecosystem processes of riverine systems (Watters, 1996; Poff et al., 1997; Nilsson and Berggen, 2000). The effects of dams on riverine fauna include obstructing and constraining the movement of migratory aquatic riverine fauna like fish, shrimps and snails (Nilsson and Berggen, 2000; March et al., 2003). The most negatively affected migratory species being those that cannot migrate across the dams or spillways (Poff et al., 1997; Nilsson and Berggen, 2000). Even those dams with specialised spillways to facilitate the movement of fauna, it has been observed that fish and shrimp abundance is far much reduced upstream of these dams (March et al., 2003). Furthermore, densities of migratory fauna has been observed to concentrate next to downstream of dams and in the process leading to increased mortality due to predation (March et al., 2003). Water abstraction from such areas where migratory fauna tends to concentrate also leads to high mortality. In arid regions, damming of rivers has led to decreased flows or drying-up of these ecosystems (Kingsford and Thomas, 2004). In some cases, damming has been associated with alteration of physicochemical conditions of the affected rivers (March et al., 2003).

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Damming also affect many species of benthic community composition and ecosystem process like decreasing rates of litter processing (March et al., 2003; Mwedzi et al., 2016). Besides these various negative effects, construction of dams has prevailed within the arid regions.

Dams within the arid region are critical to provide water during dry months for drinking, livestock production and irrigating crops. Subsequently, various mitigatory measures have been suggested to minimise the detrimental effects of damming. Some of these mitigatory measures include the provision of specialised ladders on the dams to aid the movement of migratory species, creation of off-stream water storage reservoirs, reduction of water abstraction during times of peak larval drift (Benstead et al., 1999; Laine et al., 2002). Some researchers have suggested the use of artificial lights to attract migratory faunas to cross from one side of the dam to another (Hamano and Honke, 1997). In Zimbabwe, the government has mainly emphasised on maintaining minimum environmental water flows of dammed rivers particularly during dry months so as to protect the biodiversity of the affected rivers.

Bulawayo region of Zimbabwe is increasingly becoming arid due to high frequency of occurrence of severe droughts. The city of Bulawayo is located on the watershed and thus most of the main rivers in this region originate in close proximity of this city. Hence, discharge of pollutants from the city to surrounding rivers is likely to have widespread effects. Khami and Umguza are the main rivers that drain wastewater from the city of Bulawayo whereas on the other side of the watershed, Umzingwane and Mtshabezi are the main rivers that drain the runoff that is not affected by the wastewater from the City. All these rivers are critical in the provision of water either to the already water stressed City, farming communities or surrounding rural communities and as a result all these rivers are dammed. Of late there are increasing concerns on the degradation of both Khami and Umguza Rivers due to poor quality of urban wastewater that is discharged by the City of Bulawayo (Naik et al., 2013; Basopo et al., 2014). Deteriorating water quality of Khami and Umguza rivers and their tributaries may be attributed to Bulawayo's rapidly growing population coupled with dilapidating and inadequate sewage infrastructure. This has forced the City to stop pumping municipal water from the nearby urban-wastewater affected dams like the Khami dam. In contrast, rural communities and farmers of this region still heavily depend on water from these polluted rivers.

Although the detrimental effects of dams have received considerable research effort, there are still large gabs in the knowledge of interactions between reservoirs and other anthropogenic disturbances like pollution. Degradation of rivers draining urban wastewater is one of the key anthropogenic disturbances that have affected most of the rivers and streams of the world. This study hypothesised that the dams on polluted rivers are likely to serve as sinks for pollutants discharged with urban effluents; and this in turn will improve the ecological condition of rivers downstream of the dams. To test this hypothesis, this study assessed environmental variables and macroinvertebrate communities immediately upstream and downstream of selected dams on rivers draining wastewater from the City of Bulawayo. This study provides an important understanding on the effects of damming on the ecological condition of urban wastewater impacted rivers.

2. Materials and methods

Three field excursions were conducted between February and July 2015. Sampling was conducted on three rivers: Umzingwane – with no history of receiving wastewater from the city of Bulawayo and Khami and Umguza Rivers – that are draining wastewater from the City. On these three rivers sampling sites were selected so that they were either immediately upstream or downstream of dams: Mzingwane, Khami and Umguza dams (Fig. 1). Both upstream and downstream sites were randomly selected within distances ranging from 500 m to 3 km from the dams. Umzingwane Dam was included in this study to serve as a control since this river does not receive wastewater from the City of Bulawayo. Additionally, more less impacted sites were selected, one site each on Umguza and Khami Rivers, before the City. These less impacted sites upstream of the City on both Umguza and Khami Rivers served as reference sites. In total, twelve sites (Fig. 1) from the same ecoregion were sampled and assessed for environmental variables and macroinvertebrate community structure.

2.1. Measurement of environmental variables

On each selected site, a suite of physicochemical parameters were measured. Physical water parameters that were measured in *situ* included: temperature and dissolved oxygen (DO) (measured using a *MI 605, Portable Dissolved Oxygen Meter, Martini Instruments*), electrical conductivity (EC), total dissolved solids (TDS) and pH (*MW801, Milwaukee*), Turbidity (*Turbidity meter MI415, Martini Instruments, USA*). Percentage of embeddedness by fine sediments at each sampling site was estimated following procedures by Platts et al. (1983) and Simonson et al. (1994). A scale of Simonson et al. (1994) was used as follows: *100% embeddedness* = cobbles are completely surrounded and covered by fine sediments (<4 mm); *75% embeddedness* = cobbles are completely surrounded and half covered by fine sediments; *50% embeddedness* = cobbles are completely surrounded by sediment but are not covered by sediment; *25% embeddedness* = cobbles are half surrounded by sediment and are not covered by sediment; and 0% *embeddedness* = no fine sediments on substrate.

At each selected site, water samples measuring 2 l were collected for nutrient (Total Nitrogen – TN and Total Phosphorus – TP) and Oxygen Demand (Chemical and Biological) analysis in the laboratory. Water samples were analysed for TP following a described procedure (APHA, 2012). TN was determined by oxidising nitrogenous compounds to nitrate by heating with alkaline per sulphate solution (Koroleff, 1972). Chemical oxygen demand (COD) and Biological oxygen demand (BOD) were determined by oxidation of potassium dichromate in an acid medium following procedure by Jirka and Carter (1975).

2.2. Macroinvertebrate sampling

A hand held net with mesh size of 1 mm was used to collect macroinvertebrates following the South African Scoring System version 5 protocol (SASS5; Dickens and Graham, 2002). At each site, samples of macroinvertebrates were sampled from any available microhabitats of marginal vegetation, stones, gravel, sand, mud, silt and clay as outlined by Dickens and Graham (2002). Three replicate samples were collected at each site. Trapped macroinvertebrates were identified to the lowest level possible using taxonomic keys of Gerber and Gabriel (2002). Macroinvertebrates that were identified and enumerated in the field were returned into the river. Those macroinvertebrates that could not be classified or counted in the field were preserved in 10% formalin in polythene bottles and later transferred into 70% alcohol for later identification and abundance counting.

2.3. Data analysis

Dendrogram based cluster analysis using Bray–Curtis dissimilarity matrix was employed to assess similarity of the 12 sampled sites based on macroinvertebrate community data. Three clusters were produced comprising of (i) less impacted sites, (ii) sites