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Impact of irrigation based sugarcane cultivation on the Chiredzi and Runde Rivers quality, Zimbabwe

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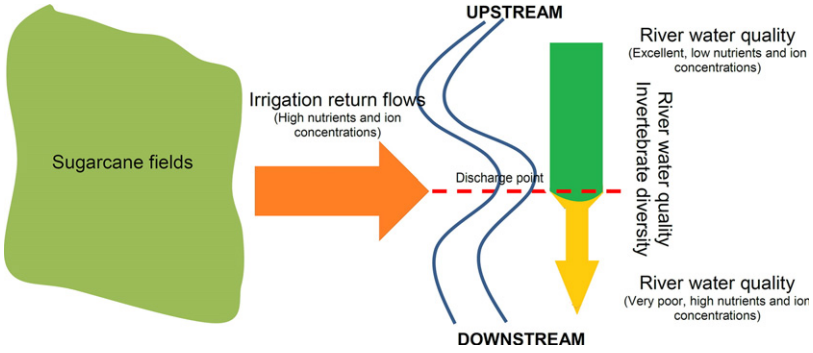
HIGHLIGHTS

- High ion and nutrient concentrations recorded from irrigation return flows.
- Irrigation impacted sites were characterised by pollution tolerant macroinvertebrate taxa.
- Conductivity, salinity and pH were significant in structuring macroinvertebrate communities.

GRAPHICAL ABSTRACT



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ABSTRACT

Agriculture is vital in sustaining human livelihoods. However, agriculture as it is currently practiced, is contributing to the degradation of freshwater ecosystems globally. We investigated impacts of irrigation return flows from sugarcane farming on water quality and health status of the Chiredzi and Runde Rivers, a biodiversity hotspot region in south-eastern Lowveld of Zimbabwe. The water quality at inlets from the crop field into the wetland system; wetland outlets into the river systems; and river sites upstream and downstream of wetland outlets were monitored during the dry and wet seasons. The wetland system formed naturally from excessive drainage from the cane fields but its purifying capacity was unknown to date. An assessment of the water physical-chemical variables (at all sites) and macroinvertebrate communities (at river sites only) was carried out. Results showed that the wetland was deficient in its purifying capacity as it was already saturated by salts and nutrients from high irrigation return flow loads. A significant seasonal variation was observed for conductivity, reactive phosphorus (RP), pH and total phosphorus (TP) concentrations among the inlets to the wetland whereas among the river sites significant seasonal differences were observed for ammonium, dissolved oxygen, nitrate, RP, pH, TP and turbidity concentrations during the dry season. From the macroinvertebrate community data the impact of the irrigation return flows on the river system was apparent, as the good water quality sites were characterised by a high diversity of pollution sensitive macroinvertebrate taxa, while the irrigation impacted sites were characterised and dominated by pollution tolerant taxa. High ion concentration (conductivity and salinity) and pH were found to be important in structuring macroinvertebrate communities as determined using

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multivariate analysis in the river system. In conclusion, the river water quality was significantly impacted by irrigation return flows and this greatly reduced the ecological health as highlighted by low macroinvertebrate diversity and increases in physical-chemical variables.

1. Introduction

The development of irrigation in intensive agricultural areas can have significant impacts on the integrity of river ecosystems in terms of ecological health and water quality (Tafangenyasha and Dube, 2008; Liu et al., 2013). As a result, agricultural pollution has been singled out as the main contributor of river ecosystem degradation worldwide (Novotny et al., 2005; Tanaka et al., 2016). Flood irrigation carried out in sugarcane plantations is of major concern since it leaches off ions from the soil, with most of the leached ions finding their way into river channels (Walker and Skogerboe, 1987; Davis et al., 2013; Oliver et al., 2014; Surendran et al., 2016a, b). Hence, fertilisers and pesticides are major irrigation-induced contaminants in irrigation return flows (Barros et al., 2012).

Flood irrigation is still one of the most popular methods of crop irrigation at large scale commercial farming because it is simple and cheap (Beeks and Evans, 2013). However, the difficulties of water distribution control make it highly inefficient, as only half of the water used actually ends up irrigating the crop and the other half is lost through evaporation and surface runoff processes (Walker and Skogerboe, 1987). In order to meet the high water demands of the sugarcane industry in Zimbabwe, several large reservoirs which include Lake Mutirikwi and Rusape Reservoir were constructed to supply water to the Lowveld (Dube and Van der Zaag, 2003). Irrigation water may cause significant leaching of ions from fertilisers, pesticides and also local geology (i.e. paragneisses of the Beitbridge group forming imbedded series of acid granuliles with schists, marbles and argillaceous rocks) into the groundwater (Cox, 2012). As a result, flood irrigation is linked to a number of problems undermining agricultural productivity and environmental sustainability (Walker and Skogerboe, 1987; Beeks and Evans, 2013; Cox, 2012). Studies elsewhere (e.g. Causapé et al., 2006; Nzima et al., 2009; Barros et al., 2012) indicate that irrigation return flows can have substantial environmental impacts. As there are often problems of determining the optimal timing and duration of irrigation within the fields, farmers have problems in setting the appropriate time for ordering water releases from supply dams (McCauley, 1990). Flow records from canals draining different sugar estates worldwide reveal very high irrigation return flows, with seasonal rivers receiving the water sometimes becoming perennial (Causapé et al., 2006; Nzima et al., 2009).

In addition to the impact on the hydrology of the scarce water resources in the region, intensive sugar cane cultivation also requires the application of fertilisers and pesticides, which with recharge and/or water run off impact ground water and surface waters, respectively (Tafangenyasha et al., 2010). Taking into account the ecological and touristic value of the region as a biodiversity hotspot this inevitably results in a conflict for resources with potential degradation of the water quality of water bodies in the catchment. Moreover, land that was traditionally set aside for grazing is now interrupted by massive fields of intensive sugarcane agriculture, which also causes a social conflict between farmers and pastoralists. So far, a few studies such as Tafangenyasha and Dzinomwa (2005) and Tafangenyasha and Dube (2008) have assessed agricultural pollution in the Lowveld region of Zimbabwe, with no known study that has directly assessed agricultural irrigation return inflow impact from the sugarcane fields on river ecosystems.

The most direct way to assess environmental impacts on water quality is to measure physical and chemical variables and adopt biological monitoring (biomonitoring) techniques to assess the health-status of river systems (Dallas, 2000, 2004; Dallas and Day, 2007; Mwedzi et al., 2016; Tanaka et al., 2016). Among the potential biotic components available for biomonitoring, macroinvertebrates are the most widely used (Dallas, 2000; Dallas and Day, 2007; Bere and Nyamupingidza, 2014; Bere et al., 2016; Mwedzi et al., 2016). This is because they rank highly as pollution-sensitive biota of river ecosystems, with the additional advantages of being relatively ubiquitous and their ease of identification (Metcalfe-Smith, 2009; Dickens and Graham, 2002).

In the Zimbabwean south-eastern Lowveld, the total sugarcane area under Hippo Valley and Triangle is estimated at 44519 ha, with an average yield of 100 t hectare^{-1} annum^{-1}. In the same region some national and private game parks are located (e.g. Gonarezhou, Save Conservancy) which make the area a biodiversity hotspot due to high species diversity in terms of both fauna and flora (Nhiwatiwa et al., 2009, 2011; Wolmer, 2007; Tuytens et al., 2015) and therefore of great conservation importance. The aim of the study was to assess impact of sugarcane plantation irrigation return flows on physical-chemical and biological river surface water quality in the south-eastern Lowveld of Zimbabwe. With most of the dryland rivers currently being subjected to extreme seasonal fluctuations in water levels, we aimed to assess the effects of runoff from the fields on the river water quality both in the dry and in the wet season. Due to high volume return flow, we hypothesized that the ion concentration will be higher from the sugarcane fields and will show significant seasonal variation. Thus, the impact of sugarcane plantation irrigation return flows on the river water quality will vary significantly among the seasons and would likely have a negative impact on river health.

2. Materials and methods

2.1. Study area

The study was carried out in the south-eastern Lowveld of Zimbabwe on the Chiredzi and Runde Rivers, where most of the sugarcane plantations (e.g. Hippo Valley Estates, Triangle) are located (Runde catchment; Fig. 1). The intensive sugarcane production is based on flood irrigation, facilitated by the use of canals. The Runde catchment is ~41,000 km^2 and strongly influences the southeast Lowveld economic development (Tafangenyasha et al., 2010). The area is semi-arid with an annual rainfall of <450 mm. The hot–wet season lasts from late–November to April, the cool–dry season from May to August and the hot–dry season from September to mid–November. High daily maximum temperatures of >32 °C throughout the year are mostly recorded and peak temperatures of >45 °C during hot spells in the summer make the region water stressed and unfavourable for mainstream cropping activities.

2.2. Sugar cane cultivation

In Zimbabwe, commercial sugarcane cultivation is considered a young industry (80–90 years) compared to other sugarcane growing regions of the world (Mlambo and Pangeti, 1996; Nzima et al., 2009). It is largely confined to the semi-arid south-eastern Lowveld which is an agro-ecological zone 5 characterised by a very erratic rainfall with mean annual rainfall of <450 mm and warm temperatures all year round. As water accounts for more than two-thirds of sugarcane's weight, it is a high water requirement crop and about 250–300 t of water are needed to produce 1 t of sugarcane (DSD, 2013). Sugarcane is a high labour intensive crop especially for weeding and harvesting and it is an important user of agro-chemicals like fertilisers and herbicides. The main fertilisers applied for sugar cane cultivation are