The Impacts of Sand Mining on Water Quality: A South African Perspective

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Keywords: Sand Mining, River, Water Quality, Upstream, Downstream.

Abstract: Sand mining is a common practice in many rivers and flood plains in South Africa. As a result of population growth, economic development, and infrastructural development, the demand of sand continues to rise. The aim of this study was to determine how sand mining affects water quality. The impact of sand mining on water quality was determined by comparing turbidity, pH, electrical conductivity, and temperature in three sampling sites (upstream, adjacent, and downstream). In addition, we determined if sand extracted using the manual method affects the four water parameters the same way they are affected by the tractor-loader-backhoe. These water parameters were measured in five rivers in the Eastern Cape Province (Tsembeyi, Thina, Gaduka, Somerville, and Nomhala). The results showed that sand mining affects turbidity, with greater turbidity in the adjacent sampling sites that the upstream sampling sites. The variation in turbidity can be due to sand extract suspending solid particles in the water column. On the other hand, pH values in adjacent sampling sites increased noticeably. The results revealed that the sand extraction method affects electrical conductivity, with higher electrical conductivity when using the mechanical (tractor-loader-backhoe) method than the manual method. The difference in electrical conductivity can be explained by the fact that generally turbidity and electrical conductivity have a positive correlation. Even though other water parameters such as temperature and pH were not affected by sand mining, results showed that sand mining affects water quality in terms of turbidity and electrical conductivity.

1 INTRODUCTION

Surface water can be found in the form of streams, wetlands, ditches, ponds, or lakes near or at sand mining activities, and Orr and Krumenacher (2015) argue that water from mining sites is likely to seep lower into the groundwater. Ground water, on the other hand, is regarded as a safe source of fresh drinking water. According to Orr and Krumenacher (2015), sand mining has a negative impact on surface water when untreated storm water is released directly into bodies of water. Furthermore, previous studies have demonstrated that sand mining alters sediment deposits in drainage networks, causing turbidity levels to differ among upstream, adjacent to, and downstream of sand mining sites (Lekomo et al. 2021; Okeke et al. 2019). This disparity in turbidity levels could be related to increased riverbed and bank erosion, which raises suspended particles in the water at mining sites and downstream (Lekomo et al. 2021).

The rise in suspended solids has a deleterious influence on flora and fauna (Kale, 2016). Turbidity, for example, is a key cause of biological stress because it is a source of abnormally large amounts of organic material and nutrients (Kale, 2016). Furthermore, the reintroduction of harmful compounds caused by sand mining activities lowers the oxygen levels in water, and therefore increases the demand for oxygen amongst animals (Kale, 2016).

Sand mining affects not just turbidity but also temperature. For example, it has been discovered that when sand mining activities result in soil erosion and deforestation, temperature levels rise (Kale, 2016). Changes in temperature have an impact on photosynthetic activity, gas diffusion rates, and the amount of oxygen that can be dissolved in water (Kale, 2016). According to Kawa et al. (2016) temperature is essential because it affects water chemistry, chemical reactions, for example, tend to accelerate at high temperatures. High water

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Mngeni, A.
The Impacts of Sand Mining on Water Quality: A South African Perspective.
DOI: 10.5220/0011950900003536
In *Proceedings of the 3rd International Symposium on Water, Ecology and Environment (ISWEE 2022)*, pages 156-161
ISBN: 978-989-758-639-2; ISSN: 2975-9439

temperatures can dissolve minerals from rocks, resulting in increased electrical conductivity (Kale, 2016). Furthermore, temperature influences biological activities and growth, as well as the types of organisms that can dwell in water bodies (Kawa et al. 2016)

According to Kale (2016) water temperature is likely to be altered by air temperature, quantity of shadow, and soil erosion, which increases the amount of sediments in a water body. The solubility of dissolved oxygen is affected by water temperature; in cold water, more gases can be dissolved than in warm water. High water temperatures can boost the photosynthetic rate of aquatic plants and algae, resulting in increased plant growth, and algal blooms, which can lead to eutrophication and severely impact water biodiversity (Kale, 2016). Furthermore, Kale (2016) found that extremely cold or extremely warm temperatures in water raise stress levels in aquatic creatures.

Because temperature impacts coagulation, turbidity is similarly tied to temperature. Coagulation efficiency is affected by temperature, and the optimal pH for coagulation decreases, as temperature levels rise (Kale, 2016). Furthermore, corrosion is a function of the dissolved oxygen content in water, as oxygen solubility decreases, temperature levels rise. When compared to the bigger change in corrosion rates, the change in dissolved oxygen with temperature is negligible. Warm water carries less dissolved oxygen than cool water, and aquatic animals may not be able to survive without it (Kale, 2016).

Enough dissolved oxygen, relatively low organic content, a pH value around neutral, moderate temperature, and water free of infectious agents, poisonous compounds, and mineral debris are all desirable qualities of water quality (Oluyemi et al. 2010; Singh and Mosley, 2003). Microorganisms that might cause diseases and chemical substances that are hazardous to one's health should not be present in portable water. Previous studies have looked at how sand mining affects variables like turbidity, temperature, pH, turbidity, dissolved oxygen, and electrical conductivity (Mwanzia et al. 2018; Ashraf et al., 2011; Okeke et al., 2019; Lekomo et al., 2021). However, sand mining is practiced using a different method, and there is little that is known about how different methods affect water quality. As a result, the aim of this research was to determine the impacts of sand mining on water quality. The impact of sand mining on water quality was determined by comparing turbidity, pH, electrical conductivity, and temperature in three sampling sites (upstream, adjacent, and downstream). In addition, the study determined if sand extracted using the manual method affects the four water parameters (turbidity, pH, electrical conductivity, and temperature) the same way they are affected by the tractor-loader-backhoe (TLB).

2 MATERIALS AND METHODS

The study was conducted in five sand mining sites (rivers) which are Somerville (Maclear), Thina (Mount Frere), Tsembeyi (Lady Frere), Nomhala (Tsolo), and Gaduka (Mthatha) across the Eastern Cape Province, South Africa. In all the mining sites the area of sand extraction is riverbanks. The chosen mining sites use different methods of extracting sand. At Somerville and Tsembeyi sand is extracted using the manual sand extraction methods, such as, spade, cart and shovel. However, at Thina, Gaduka and Nomhala the sand is extracted using the tractor-loader-backhoe (TLB) sand extraction method.

2.1 Sampling Design

This study adopted quantitative research design. Van der Merwe (1996) defined quantitative research as an approach to study that aims to test hypotheses, establish facts, show correlations between variables, and forecast results. Methods from the natural sciences are used in quantitative research to assure objectivity, generalizability, and reliability. Water samples were collected between May 2018 and October 2018 which is the dry season. This period was chosen given that it is the time when sand extraction is done the most. There is high extraction of sand during this period because of several reasons, such as, the new financial year for the government to issue tenders in the construction industry, low-income people build their houses when it is dry to avoid delays and constant demolishing of structures by heavy rainfall amongst others. A total of 120 samples were drawn from the five different rivers with each river having three sampling sites (upstream of mining sites, adjacent to mining sites and downstream of mining sites). In each sampling site, (upstream, adjacent and downstream) there were eight sub-sites, and a single sample was drawn from each of those sub-sites, making a total of eight samples in each sampling site and 24 samples in each river. All the eight sampling sites were >1 m apart. The upstream of the mining sites, adjacent to mining sites and downstream sites were >200 m apart.

In each subsite, water parameters, including, pH, electrical conductivity and temperature were measured using Hanna Multiprobe parameter whereas turbidity was measured using Hanna Turbidity meter.

2.2 Data Analyses

The effect of sand mining on different water parameters (electrical conductivity, pH, turbidity, and temperature) was analysed in R using the generalized linear mixed models (GLMMs) because data were not normally distributed. The Shapiro-Wilk test was used to test if data were normally distributed or not. The lme4 package (Bates et al. 2015) was used when calculating GLMMs. Analyses were performed for each of the four water parameters. The Poisson distribution was the best fit for electrical conductivity, pH and temperature datasets, the negative binomial distribution was used for the turbidity dataset (Bolker et al. 2009). There were two fixed factors (sampling sites and method of extracting sand) and one random factor (river) in the models. The multcomp package (Horthorn et al. 2008) was used to determine the differences between paired sampling sites (upstream, adjacent to sampling sites and downstream) for water parameters that showed significant differences in the main results.

3 PRESENTATIONS OF RESULTS

Electrical conductivity, pH and temperature did not differ among different sampling sites of the river (Table 1; Figures 1a, b, d). However, there was significantly higher turbidity in the sampling site adjacent to sand mining sites compared to the upstream of sand mining sites ($p = 0.002$; Figure 1c). Although not significantly different, the turbidity in the sampling site adjacent to sand mining sites was slightly higher than that in the downstream sampling site ($p = 0.052$; Figure 1c). Turbidity in the upstream and downstream sampling sites did not differ ($p = 0.55$; Figure 1c).

The method of extracting sand affected the electrical conductivity only, with greater electrical conductivity when using the tractor-loader-backhoe compared to the manual method (Table 1; Figure 2a). Even though, the method of sand extraction did not significantly affect the pH and the turbidity, the tractor-loader-backhoe had slightly higher levels of the pH and turbidity compared to the manual method (Table 1; Figures 2b, c). The temperature was not affected by the method of extracting sand, even though the rivers that used the manual method had slightly higher temperature, than those that use the track-loader-backhoe method (Table 1; Figure 2d).

4 DISCUSSIONS

Effect of sand mining on electrical conductivity focusing on sampling sites.

When electrical conductivity of sampling sites adjacent to the sand mining site was compared to that in the upstream and downstream sampling sites, there were no statistically significant differences. These results agree with previous studies (Mwanzia et al. 2018; Mwanzia, 2019; Obot et al. 2019; Yen and Rohasliney, 2013). Similarities in electrical conductivity across sampling sites could be since electrical conductivity is a measure of total dissolved substitution in water, which varies with geological structure, rainfall, and temperature (Bai et al, 2013; Yilmaz and Koc, 2014). The fact that the study was done during dry season, when there was no rainfall, may explain the observed similarities in electrical conductivity of upstream, adjacent to sand mining sites, and downstream sampling sites. However, other studies discovered that electrical conductivity vary dramatically from upstream to downstream (Bhattacharya, 2018; Lekomo et al. 2021; Okeke et al. 2019). Furthermore, these studies suggested differences in electrical conductivity between upstream and downstream sampling sites are since sand extraction is a source of dissolved ion precipitation in the water (Bhattacharya, 2018; Lekomo et al. 2021; Okeke et al. 2019). However, it is worth noting that the afore mentioned authors conducted their studies during different seasons, including the rainy season (Bhattacharya, 2018; Lekomo et al. 2021; Okeke et al. 2019). As such, the contrast between our study and these previous studies could be since our study was conducted during the dry season, therefore the capacity of rainfall to affect electrical conductivity was not considered.

Effect of sand mining on pH focusing on sampling sites

The pH of water is used to determine the amount of hydrogen present, which is controlled by chemical reactions and the ion balance (Viera et al. 2020). This study supports previous studies, which found similarities of the pH values among the adjacent, upstream, and downstream sampling sites (Mwanzia, 2019; Mwanzia et al. 2018; Obot et al. 2019; Yen and Rahasliney, 2013). The identical pH levels between adjacent, upstream, and downstream sampling sites could be explained by the lack of harmful pollutants. According to Singh and Gupta (2016) pollution from diffuse sources is a non-point source of pollution. Agricultural or storm water runoff, as well as debris blown into waterways from land, are examples. There was no obvious contamination (point sources) near the sand mining sites. Wastewater, also known as effluent, released legally or illegally by a company, oil refinery, or water treatment facility, as well as contamination from leaking septic systems, chemical and oil spills, and illegal dumping, are all common point sources of pollution in rivers (Singh and Gupta, 2016). The pH of water in a stream, river, lake, or underground flow changes depending on the source of the water, the kind of soil, bedrock, and contaminants encountered along the route (Kale, 2016). Even though, the study found no statistically significant differences between the sampling sites, there is a slight increase in pH values at adjacent sampling sites (Figure 1b), indicating that sand mining has the potential of increasing the pH. On the other hand, the study findings, contradict those of (Gebreyohannes et al. 2015; Okeke et al. 2019) who reported significant results among upstream, adjacent, and downstream sampling sites. The differences could be explained by the number of reasons such as oil leak from the TLB used for sand extraction which possess oil as a determining factor for pH as alluded by (Singh and Gupta, 2016).

Effect of sand mining on temperature focusing on sampling sites

Temperature oscillations in natural water bodies are induced by a range of activities that cause daily and seasonal changes in surface water. For example, turbidity usually causes a rise in water temperature due to heat absorption produced by suspended particles (Kumar, 2015). Additionally, during mechanical mining, equipment, such as, tractor-loader-backhoe (TLB) heats up, resulting in higher water temperatures. Furthermore, the magnitude and time spent by TLB on the water column can be linked to the lack of variance in water temperature. In addition, previous studies have indicated significant differences in temperature between upstream and downstream mining sites and these differences in temperature were because of heating up of mining equipment (Okeke et al. 2019; Koehnken and Rintoul, 2018). However, in our study the temperature did not differ among the three sampling sites (upstream, adjacent to and downstream of sand mining site), supporting previous studies (Mwanzia, 2019; Mwanzia et al. 2018; Obot et al. 2019; Yen and Rohaslineys, 2013).

Effect of sand mining on turbidity focusing on sampling sites

The study found that the adjacent sampling sites, which is near where sand mining is taking place, had higher turbidity than the upstream sampling site, which is upstream of sand mining. Increased turbidity is normally caused by resuspension of sediment, sedimentation due to stockpiling and dumping of excess mining material (Ashraf et al. 2011). These higher levels of turbidity in the adjacent sampling sites were expected as these sampling sites are very close to where sand mining occurs. The study findings are consistent with previous studies, which found that adjacent sampling site produced statistically significant turbidity results when compared to upstream sampling site (Bhattacharya, 2018; Bhattacharya et al. 2019; Koehnken and Rintoul, 2018; Mwanzia et al. 2018; Okeke et al. 2019; Yen and Rohasliney, 2014).

Although not statistically significant, the turbidity was slightly greater in the adjacent sampling sites than in the downstream sampling site. This is most likely owing to the river's natural desire to clean itself, causing solid particles to settle, thus the low turbidity in the downstream sampling sites. Furthermore, Ashraf et al. (2011) reported that turbidity decreases with distance downstream. In addition, Okeke et al. (2019) found that turbidity differs significantly between adjacent and downstream sampling site.

Even though the downstream sampling site had slightly higher values than the upstream sampling site (Figure 1c), the analysis found no significant differences. The slightly higher turbidity values in downstream sampling site than upstream sampling sites could be attributed to sand mining after-effects. These findings are in contrast with those of Okeke et al. (2019), who discovered significant differences in turbidity between upstream and downstream sampling sites.

Effect of the method of extracting sand on water quality

According to Padmalal and Maya (2014) mining for river sand is done both manually and mechanically. Manual mining is less harmful to the environment, and the amount of mining is often low. In manual mining, a simple equipment, such as, spades, shovels, and carts are utilized, whereas in mechanical mining, heavy machines, such as, power jet pumps and tractor-loader-backhoe (TLB) are used. When comparing mechanical (TLB) and manual extraction methods, the study found that TLB had a significantly electrical conductivity than manual extraction. This may be due to the elevated turbidity values in the adjacent sampling site (Figure 1c). According to Aris et al. (2014), electrical conductivity has a positive correlation with turbidity (r = 0.765). It is worth noting that using TLB in sand extraction raises solid particles, which raises turbidity. However, the turbidity together with pH and temperature were not significantly influenced by the method of sand extraction methods. Similarities between the manual and machinery methods are contrary to our expectations where temperature was expected to be influenced using TLB given that TLB heats up and result in higher water temperature. The amount of time the TLB spends in the water column, the velocity of the stream, and the amount of water in the rivers could all explain the lack of higher water temperatures.

Table 1: Effect of the sand mining on water parameters.

	Electrical Conductivity			pH		
	χ2	df	p	χ2	df	P
Sampling sites	0.06	2	0.97	1.04	4	0.59
Method of extraction	10.09	1	0.001	2.80	1	0.09
	Turbidity			**Temperature**		
	χ2	df	P	χ2	df	P
Sampling sites	11.93	2	0.003	0.42	2	0.81
Method of extraction	1.57	1	0.21	0.15	1	0.69

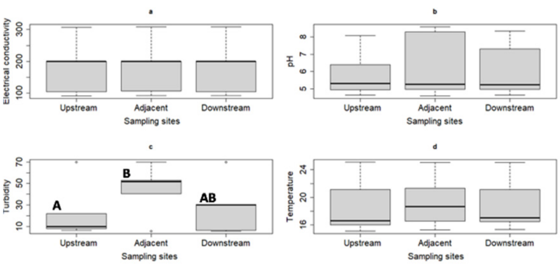

Figure 1: Effect of sand mining on water parameters (a - electrical conductivity, b - pH, c - turbidity and d - temperature) in three sampling sites; upstream of the mining site, adjacent to the mining site and downstream of the mining site. Letters above boxplots in turbidity indicate significant differences ($p < 0.05$) among sampling sites.

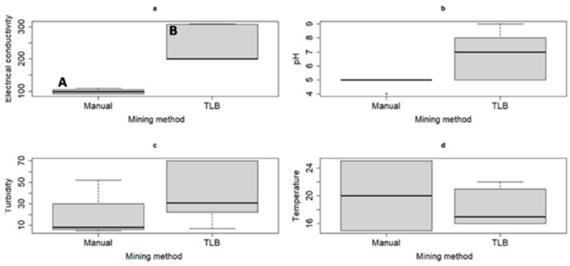

Figure 2: Effect of the method of extracting sand on a) electrical conductivity, b) pH, c) turbidity and d) temperature. Letters above and inside boxplots in electrical conductivity indicate significant differences ($p < 0.05$) between the methods.

5 CONCLUSIONS

This study showed that the impact of sand mining is dependent on the water parameter measured. For example, sand mining across the sampling sites in the five rivers in the Eastern Cape Province influenced water turbidity, while not affecting the electrical conductivity, pH and temperature. On the other hand, the electrical conductivity was significantly influenced by the sand extraction method, while pH, temperature and turbidity were not affected. If sand extraction continues without proper control, sand extraction might lead to irreversible destruction of the ecosystem and subsequent biodiversity loss. Lastly, it is important to encourage sustainable resource use, law enforcement, regulation of sand mining activity and adopt negative impact minimisation strategies.

ACKNOWLEDGEMENTS

I would also like to thank National Research Foundation for financing the study.

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