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An analysis of physico-chemical parameters of effluent from a gold mine processing plant: an environmental pollution indicator.

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ABSTRACT

, There has been notable pollution impact on tailings dams and surrounding areas at gold mines in . Zimbabwe. Nevertheless, there is little information on the levels of pollution and the prescription of the correct environmental remediation techniques. This study aimed to investigate the physico-chemical properties of effluent water from gold mine operations. The level of physico-chemical properties is an indicator of the level of pollutants contained in the effluent water. Pulp and water samples were collected from a gold mine's active slimes dam and its surroundings. Physico-chemical parameters examined on water samples comprised; electrical conductivity (EC), total dissolved solids (TDS), pH, dissolved oxygen (DO), chemical oxygen demand (COD) and turbidity. . It was noted with concern that three sites had electrical conductivity (EC) values in the red band of EMA limits; the process effluent (6010µS/cm), see-page water (5810µS/cm) and down-stream water (5030 µS/cm).Total dissolved solids (TDS) in process effluent (4250mg/L), seepage water (4060mg/L) and down-stream water (3440mg/L) are in the red band of the local environmental management agency (EMA) standards. Additionally, process effluent pH was at 13.69, which is too high and falls in the red band of EMA standards. However, COD levels were within the required limits in most of the water samples.

Key words: pollution, physico-chemical parameters, tailings dam, environmental pollutants.

1. INTRODUCTION

Environmental Conscious Manufacturing (ECM) requires that industrial players must strive to maintain the natural state of the environment. This research seeks to explore ways of minimizing environmental impacts of tailings dams in gold operations utilising the cyanidation route. Gold extraction using cyanidation involves the use of chemical reagents to dissolve the gold minerals into solution. However, the dissolution process is not selective, resulting in other elements dissolving together with the gold. The solution and ground solid ore mixture, after separating the gold, is then discarded into the tailings dam. On setting up a tailings impoundment, there is an upset of the natural ecosystem since there is ground excavation on a vast area. Pollutants from mine operations result in costly environmental and socio-economic impacts. It is common practice for most operations to re-vegetate the slimes dam areas in an effort to minimise effects such as dust and pollution of water streams. There have been attempts to try and grow plants on tailings dams at most gold mines with little success. Tailings dams cause a lot of environmental pollution in terms of acid mine drainage (AMD), heavy metals and cyanide species contamination of the soils, surface and ground water. Lack of vegetation would also aid to air pollution as dust would be generated from the walls of the dam.

After the extraction of gold, there is need to dispose of the tailings residue in an environmentally friendly way. Tailings from gold cyanidation plants contain cyanide and heavy metal ions species which have serious environmental risks because of their highly toxic nature (Keskinen, 2013). According to Acheampong & Lens (2011), many industrial players discharge their effluents without sufficient characterization, quantification and treatment, because of limited economic and technological resources. The same authors further postulate that the most appropriate treatment process of waste water depends on the physical and chemical characteristics of the water. In Zimbabwe, most gold processes make use of chemical techniques, for example addition of ferrous sulphate, to reduce the concentration of free cyanide. The other pollutants i.e. the heavy metals are not being controlled and reported. The nature of pollutants depends on the geochemistry of the mined deposit as well as the mineral extraction route followed (Love et al. 2006). At the studied mine, effluents are treated using ferrous sulphate to reduce cyanide levels from a range of 280 – 320mg/l to levels lower than 0.06mg/l before disposal. The Environmental Management Agency (EMA) in Zimbabwe has set the legal environmentally friendly cyanide concentration level at 0.07 mg/l. However, it is noted that severe environmental impacts result from the other components of the effluent. It was observed that the state of the water in the down-stream side of the tailings dam, Fig 1, is not good. Communities near the mining operations will have their livestock affected by the contaminated water bodies.

1.1 Physico-chemical parameters of the environment

A number of physico-chemical parameters of the environment have been studied and these include; electrical conductivity (EC), total dissolved solids (TDS), pH, dissolved oxygen (DO), chemical oxygen demand (COD) and turbidity. Orlob et al., (1983) suggests that in measuring environmental quality, key

Fig 1. Downstream water 60 m from the dam

variables might comprise the recorded day-to-day variations of total biochemical oxygen demand (BOD), total suspended solids (TSS), and ammonia and nitrogen concentrations in a treated sewage discharge to a river. Patil et al. (2012) cited Iron, Copper, Manganese, Lead, Zinc and Nickel as potentially harmful. Plants can accumulate heavy metals in their tissues in concentrations above the permitted levels which is considered to represent a threat to the life of humans, and animals feeding on these crops and may lead to contamination of the food chain, as observed that soil and plants contained many toxic metals, that received irrigation water mixed with industrial effluent (Amin *et al.*, 2010). Patil et al. (2012) further deduced that electrical conductivity shows significant correlation with ten parameters such as temperature, pH value, alkalinity, total hardness, calcium, total solids, total dissolved solids, chemical oxygen demand, chloride and iron concentration of water. Kumar & Sinha (2010) postulate that the underground drinking water quality of their study area can be checked effectively by controlling conductivity of water and this may also be applied to water quality management of other study areas. Patil et al. (2012) proceeded to say that both BOD and COD are key indicators of the environmental health of a surface water supply. Environmental Management Agency in Zimbabwe's effluent and solid waste disposal limit have been stated for magnesium, calcium, potassium, alkalinity, total hardness, and turbidity.

A research was undertaken by Magombedze (2006), at selected Zimbabwean mines which focused on the characterization of leachates from tailings dams. The researcher found out that the worst case of acid mine drainage ensues at the Iron Duke Pyrites underground mine which must cope with 180m^3/day of acid mine water with pH < 2.5, about 14000mg/l in sulphate, 9500mg/l iron and other dissolved metals. It can be noted that several mines are affected by AMD. Dissolution of metals is evident which accelerates their turbidity and mobilisation because of the AMD. A similar study was conducted across Zimbabwe by Meck et al. (2006) which assessed the potential of different mine tailings dumps to cause environmental pollution. The findings indicated elevated elements concentrations on the down-stream samples compared to the up-stream ones. Furthermore, the researchers deduced that the low pH levels in leachate were associated with elevated metal and metalloid concentrations in the leachate and in adjacent streams.

1.2 Electrical conductivity

The electrical conductivity of a solution is a measure of the ability of the liquid to carry charged particles in it when a potential difference is applied. Solutions can have charged particles in the form of dissolved metal and non-metal ions. Indirectly, conductivity measure the presence of ions, such as nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron (Kemker, 2014). Therefore, the value of electrical conductivity gives an indication of the contamination of the environment. Higher values will indicate the presents of pollutants. Literature sources have reported this parameter to have a positive correlation with temperature as well. Patil et al. (2012) stated the measurement of conductivity using the EC meter which measures the resistance offered by the water between two platinized electrodes. The same authors gave the recommended EPA guidelines range of EC to be <2500 μS/cm at a temperature of 298 Kelvins.

1.3 Total dissolved solids

Gyawu-asante (2012) defined total dissolved solids (TDS) as the term used to indicate the inorganic salts and small amounts of organic matter present in solution in water. The same author pointed out common components of TDS to be calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen carbonate, chloride, sulphate, and nitrate anions. According to EMA (2007), the TDS normal range is <500 mg/L. Kwarteng (2012) pointed out that TDS indicates the suitability of a water source for domestic use since high TDS values imparts saltiness to water and thus making it less palatable.

1.4 pH

pH is the parameter which measures the hydrogen ion (H^+) concentration of a solution. The pH level of a system reflects how acidic or alkaline it is. pH is scale runs from 0 to 14, a pH level of 7 being neutral (Gyawu-asante, 2012). According to Kwarteng (2012), the pH plays an important function in assisting in the determination of the extent of an effluent or plume in a water body. The corrosive nature of water can also be deduced from the pH level (Jain 2011). According to Jain (2011), the lower the pH value the higher is the corrosive nature of water. Gupta et al. (2009) postulates that there is a positive correlation between pH, electrical conductivity and total alkalinity. Patil et al. (2012) observed that the reduced rate of photosynthetic activity, the up-take of carbon dioxide and bicarbonates which increase pH, the low oxygen concentrations coincided with high temperature during the summer month (Patil, Sawant and Deshmukh, 2012). The same authors indicated the normal pH range to be 6.5 to 9.5 according to both the EPA guidelines and the World Health Organisation.

1.5 Dissolved oxygen

Oyiboka (2014) defined dissolved oxygen (DO) as the measure of the amount of oxygen dissolved in water. According to U.S EPA (2012), if more oxygen is consumed than is produced in a water body, the DO levels decrease resulting in some sensitive animals moving away, weakening, or dying. Water pollution results in the decrease of DO of a water body Oyiboka (2014). Krishna et al. (2015) discussed the correlation of this parameter with water bodies which gives direct and indirect information e.g. bacterial activity, photosynthesis, availability of nutrients, stratification, etc. The authors pointed out that in summer, DO decrease due to increase in temperature and also the increased microbial activity. Acheampong et al. (2011) indicated a range of 0.9 to 7.1 mg/L for tailings dam waste water. EMA (2007) guidelines reported the normal DO range to be greater than 60 mg/L.

1.6 Chemical oxygen demand

Chemical oxygen demand (COD) is another important chemical property of water. According to Krishna et al. (2015), COD is another indication of waste material contamination in water specified in mg/L. To add to the above the same researchers defined COD as the amount of DO required to cause chemical oxidation of the organic material in water. COD has been reported to be similar and used together with BOD parameter (Tiwari, 2015). Higher values of COD (> 60mg/L) mean a higher pollution level in the analysed stream. Normal COD level in the water bodies is <60mg/L (EMA, 2007). Patil et al. (2012) reported the normal COD level to be <10mg/L according to World Health Organization standards.

1.7 Biochemical oxygen demand

Jain (2011) stated that high BOD indicates poor water quality since BOD is explained as a measure of organic pollution to both waste and surface waters. In agreement to the above, Krishna et al. (2015) defined BOD as a measure of organic material contamination in water, specified in mg/L. Furthermore, the same authors described BOD as the amount of DO required for the biochemical decomposition of organic compounds and the oxidation of certain inorganic materials. BOD test is usually carried out over a period of five days in a dark closed container. According to EMA (2007), the acceptable BOD levels must be below 30mg/L. However, Patil et al. (2012) gave the World Health Organization and Indian standard acceptable BOD levels to be <6mg/L and < 30mg/L respectively.

1.8 Turbidity

Turbidity can be defined as a measure of murkiness of water (Jain, 2011). High value of turbidity corresponds to polluted water since that indicates the presence of many suspended particles in the water. According to Oyiboka (2014), the ability of light to pass through water is directly proportional to the volume of suspended particles within the water body. Turbidity can be measured using an electronic turbidity meter or a turbidity tube. It is common to report turbidity using Nephelometric Turbidity Units (NTU). The normal range for turbidity is <5NTU (EMA, 2007).

1.9 Total suspended solids

Total suspended solids (TSS) refers to total solids per unit volume in water (mg/L). Booth et al. (1999) indicated TSS as both a significant part of physical and aesthetic degradation and a good indicator of other contaminants, particularly nutrients and metals that are carried on the surfaces of sediment in suspension. A research conducted by Huey & Meyer (2010) in the upper Pecos river basin, deduced that turbidity and TSS values were significantly correlated at all monitoring stations, suggesting that turbidity is a reliable indicator of total suspended solids. EMA (2007) reported TSS acceptable values to be in the range of < 25mg/ L.

1.10 Environmental Quality Standards

Environmental Management Agency (EMA) is the local body responsible for regulating the disposal of waste (solid waste and effluent). In Zimbabwe, the Environmental Management Act Chapter 20:27 No. 12 of 2002 is the legislation which administers the management of effluent and solid waste (Ndlovu, 2016). Furthermore, the same author indicated the roles of the act as; formulation of procedures for prevention of pollution and environmental degradation and the enforcement of closely monitoring measures to oversee waste management that comprises generation, collection, processing, transportation and disposal of the waste.

EMA uses polluter pays principle through licensing which is according to the following four categories on Table 1: (ema.co.zw accessed 21/04/2017)

Table 1. EMA pollution categories

COLOUR	COMMENT
Blue	In respect of a disposal which is considered to be environmentally safe.
Green	In respect of disposal that is considered to present a low environmental hazard.
Yellow	In respect of a disposal which is considered to present a medium environmental hazard.
Red	In respect of a disposal that is considered to present a high environmental hazard.

According to Nhapi & Gijzen (2002) the “polluter pays principle” in the EMA is meant to guarantee that the individual causing the most pollution shall bear the largest load in paying for cleaning of the environment. Organizations or individuals must come up with strategies which avoids or minimize pollution of the environment. However, some entities are reluctant to embrace new technologies in the dimension of pollution prevention or minimization.

2. MATERIALS AND METHODS

The study was carried out at a gold mine in the Bulawayo mining district. Four sampling campaigns of the water on the tailings dam and surrounding areas were made from the period February to April 2017. The water sampling points included; upstream water (40m from the tailings dam), tailings dam pond, process effluent discharge point into the dam**,** See-page water from underneath the tailings dam and downstream water (60m from the dam). Water samples were collected in well-labelled acid-washed and conditioned polypropylene 2.5 litre bottles. Grab sampling was used and samples were collected below the water surface to obtain representative samples.

The water samples characterization from the selected mine was done at NUST and ZSM laboratories. This was done within eight hours from the time of sampling. The following parameters were assessed in the laboratory; Electrical Conductivity, Total Dissolved Solids, pH, Dissolved Oxygen, COD and turbidity.

2.1 Determination of Electrical Conductivity

A PCS Tester 35 Multimeter, in an electrical conductivity mode was used. The electrode was thoroughly rinsed with the distilled water before taking the readings of the samples being examined. The samples to be analyzed were separately mixed thoroughly before taking measurements. The electrode was dipped into the test solution (about 5cm immersion). The measured value on the display was read after it stabilized.. and the values are recorded.

2.2 Determination of Total Dissolved Solids

The total dissolved solids function on the multimeter was selected. The electrode was thoroughly rinsed with the distilled water before taking the readings of the samples being examined. The samples to be analyzed were separately mixed thoroughly before taking measurements. The electrode was dipped into the test solution (about 5cm immersion).The measured value on the display was read after it had stabilized..and values are recorded..

2.3 Determination of pH

The instrument was calibrated using the buffer solutions in order of increasing pH.

The electrode thoroughly was rinsed with the distilled water before taking the readings of the samples being examined. The samples to be analyzed were mixed thoroughly before taking measurements. st solution (about 5cm immersion). The measured values were recorded..

2.4 Determination of Dissolved Oxygen

The dissolved oxygen function was selected on the multimeter. The electrode was thoroughly rinsed with distilled water before taking the readings of the samples being examined. The measured values were recorded.

2.5 Determination of Chemical Oxygen Demand

A water sample (2.5 ml) was taken in the tube and 2.5 ml of distilled water in another tube. Then 1.5 ml of potassium dichromate was added to both the tubes. Sulphuric acid (3.5 ml) was added to both tubes and the tubes tightly closed and incubated in a COD digester at 150 degrees for 2 hours. After cooling to room temperature the contents were transferred to conical flask. A burette was filled with freshly prepared ferrous ammonium sulphate. Two drops of Ferroin indicator are added. The contents are titrated against ferrous ammonium sulphate till the colour changed to reddish brown. COD was then calculated.

2.6 Determination of Turbidity

Turbidity measurements were done following the method of Myre and Shaw, 2006 and the turbidity value recoreded.

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3. RESULTS AND DISCUSSION

The results for the physiochemical parameters are analysed in the following section.

3.1 Electrical conductivity Electrical conductivity (EC) measures the proportion of dissolved ions in solution. In the present study, EC values ranged from 172.5 µS/cm to 6010 µ S/cm, as shown in Fig 3. It can be noted with concern that three sites recorded values in the red band of EMA limits, i.e. the process effluent (6010 µS/cm), see-page water (5810 µS/cm) and down-stream water (5030 µS/cm). Patil et al indicated the normal values of EC to be <2500 µS/cm according to the EPA guidelines. The high EC value in the process effluent stream is a result of dissolved metals and salts within the stream promoted by the chemicals used in the processing plant. Furthermore, see-page and down-stream values are a result of leaching activities within the tailings dam soil. The EC values depicts the extent of contamination of the environment by the electrolytes or ions. This will reduce the survival chance of aquatic organisms since most of these ions are toxic. Patil et al. (2012) highlighted that high values of EC increases the corrosive nature of water. However, relatively lower EC values were noted in the tailings dam water (1035 µS/cm) and the upstream water (172.5 µS/cm) which served as the control point. The lower EC values can be attributed to dilution of the soluble ions by rainfall. An effluent treatment plant can be set-up to reduce the levels of the dissolved ions and hence reduce the environmental impacts of the waste water.

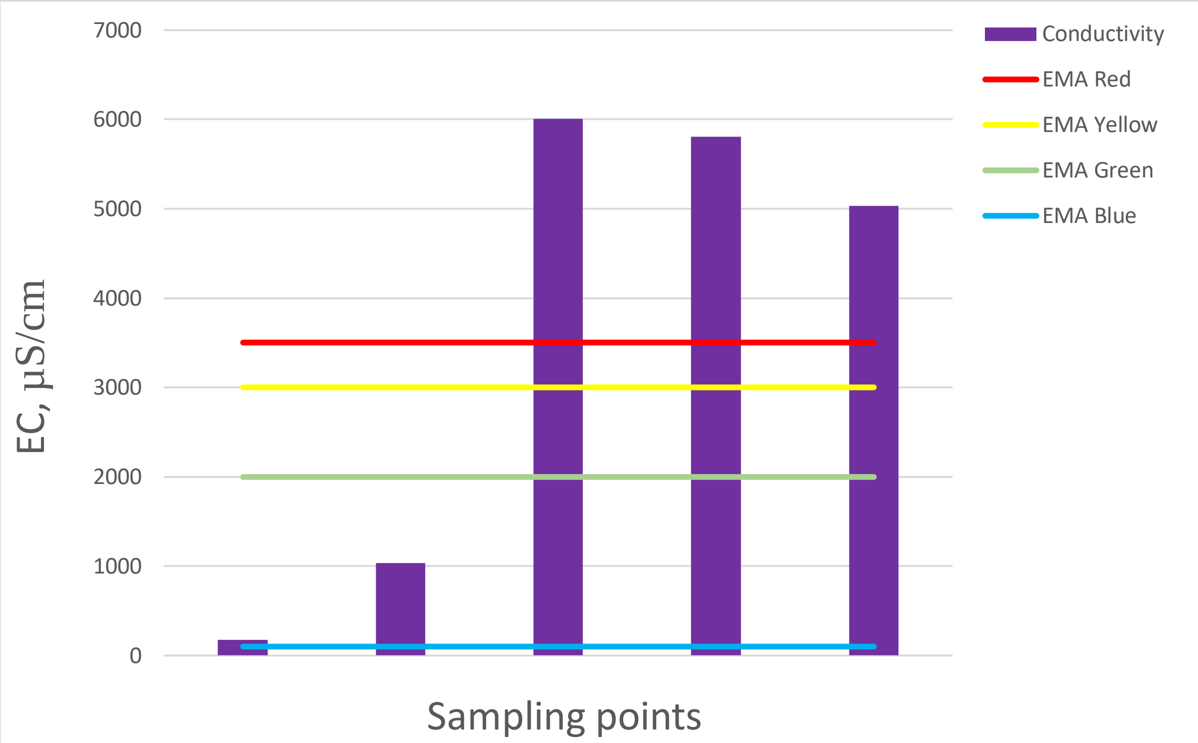

Fig 3: Electrical Conductivity of samples

3.2 Total dissolved solids

Total dissolved solids (TDS) in the study area ranged from 123 mg/L to 4250 mg/L. Fig 4 depicts that three sampling points i.e., process effluent (4250 mg/L), see-page water (4060 mg/L) and down-stream water (3440 mg/L) contain total dissolved solids in the red band of EMA standards (>3000mg/L). The higher values are attributed to the dissolution of minerals within the soils. Tailings dam water contained relatively low TDS (732 mg/L) in the green band of EMA standards (<1500 mg/L). The lower value in the dam water can be explained by significant dilution from high rainfall in the period January to March 2017. The upstream water recorded the lowest TDS (123 mg/L), which is logical since this area is on the upstream uncontaminated zone and hence the control point. Kwarteng (2012) pointed out that TDS values imparts saltiness to water and therefore making it less palatable. In addition to the above, dissolved solids can be toxic to living organisms if consumed with the water. The dissolved solids can be precipitated out of solution using chemicals before disposal of effluent to the tailings dam.

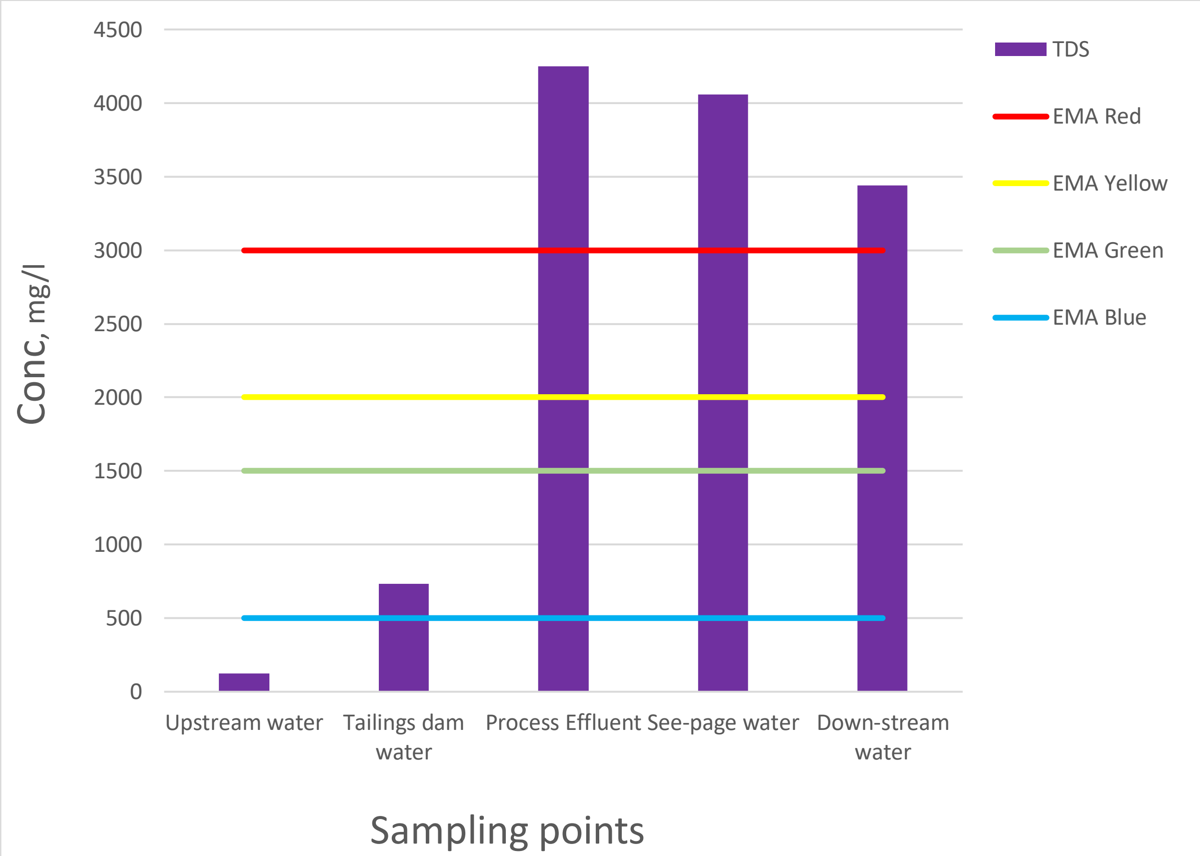

Fig 4. Total Dissolved Solids concentrations in samples

3.3 pH

The results of pH are shown in Fig 5. From the graphs, the pH values ranged from 6.23 to 13.69. Process effluent pH (13.69), is too high and falls in the red band of EMA standards (pH >12). High values of pH of gold process effluents can be attributed to the presence of strong base contaminants, i.e. caustic soda (NaOH) and lime ($Ca(OH)_2$). EMA standards stipulates the environmentally friendly pH range to be 6 to 9. According to Patil et al. (2012), a range of 6.5 to 9.5 using the EPA guidelines is deemed to be normal. Bitter taste and corrosion of water can be attributed to low and high pH values. Tailings dam water pH (9.77), is relatively high and in the green band of EMA standards. This can be said to be a result of slight dilution of the process effluents discharged into the tailings dam by rain water which is slightly acidic. Three sampling points recorded environmentally friendly pH values, i.e. up-stream water (7.06), see-page water (7.01) and the down-stream water (6.23). pH levels can be corrected by using acids and alkalis before water is discharged into the environment.

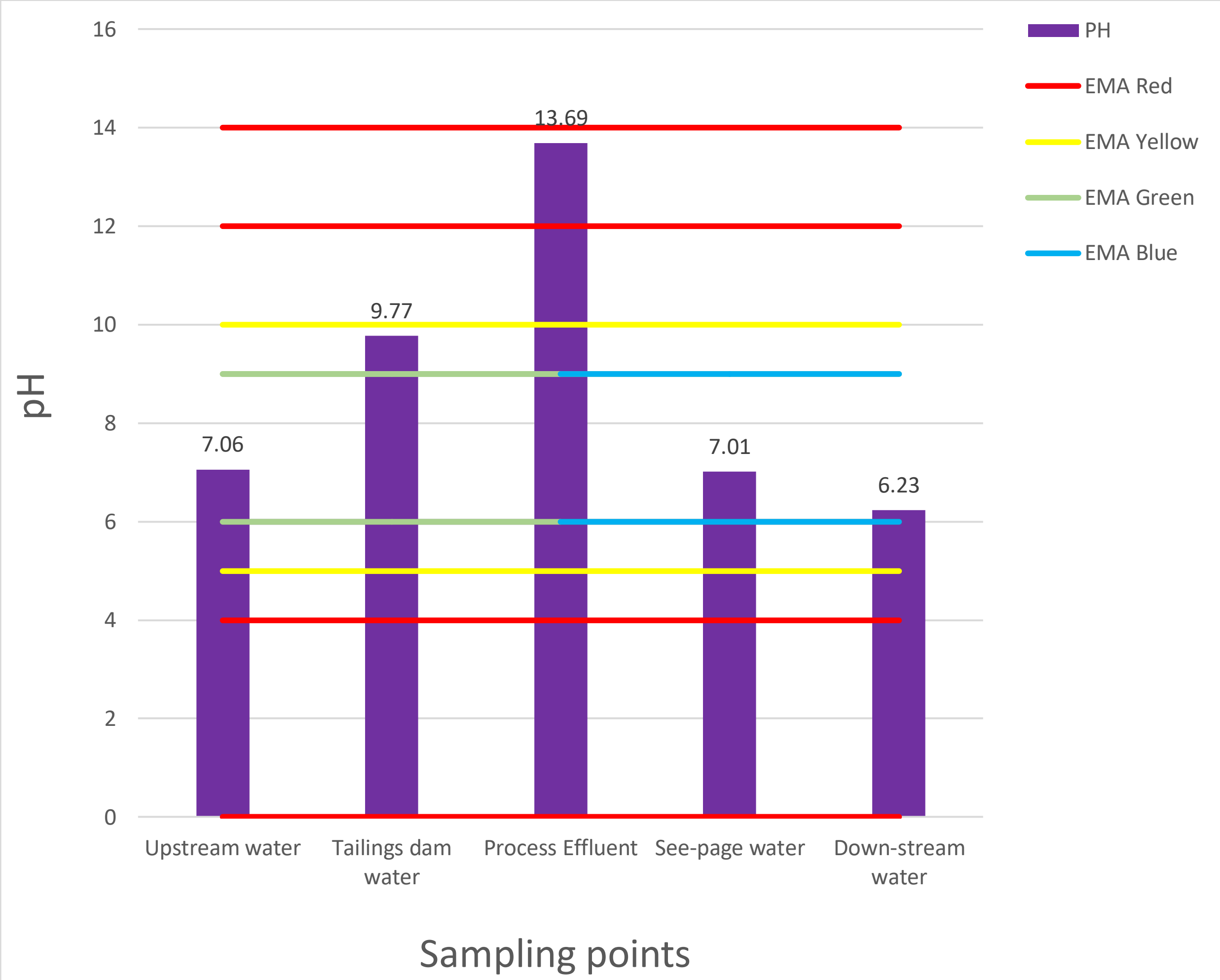

Fig 5. pH of samples

3.4 Dissolved oxygen

Results for dissolved oxygen (DO) are shown in *Fig 6* lying in the red band according to EMA regulations (<15 mg/L). DO values are supposed to be high in order to be environmentally friendly. Dissolved oxygen supports aquatic life and hence low values will eliminate living organisms from these water bodies. Literature sources report low dissolved oxygen to be a result of increased temperatures and possibly due to accelerated microbial activity (Patil, Sawant and Deshmukh, 2012). Moreover, other processes like photosynthesis which produce oxygen can be said to be absent or minimal when DO levels are low. DO levels can be improved if pollutants are removed from the waste water. Therefore, an effluent treatment plant can be developed to reduce contamination of the water before disposal into the environment.

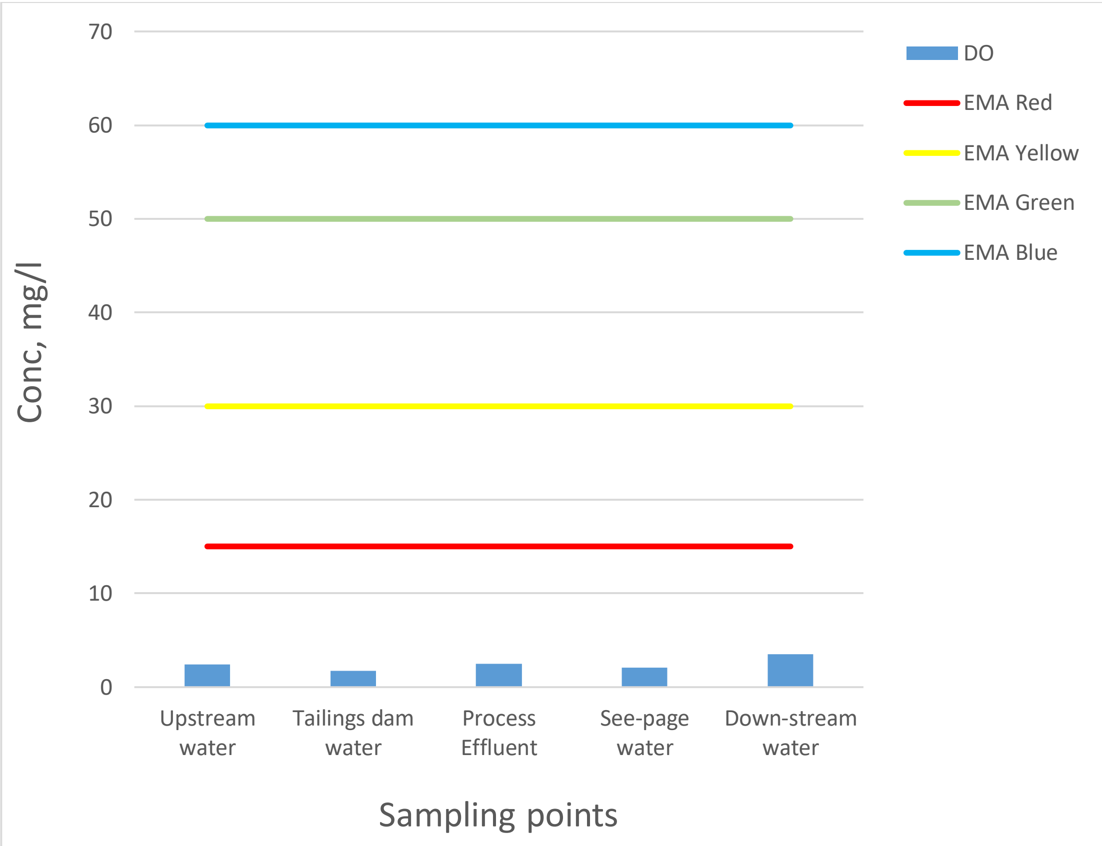

Fig 6. Dissolved Oxygen concentrations in samples

3.5 Chemical Oxygen Demand

The higher the COD the higher the contamination of the water or effluent stream. COD results for the study area are shown in Fig 7. The graphs indicate that the water within the process effluent stream has the highest COD (1176.47 mg/L), followed by the tailings dam water (258.82mg/L). Both values being in the red band of EMA standards (>200 mg/L). However, the other sampled points outside the tailings dam have very low COD level indicating none contamination to the environment. The up-stream water, which is the control point, had undetected COD. This is reasonable since the upstream water represents the uncontaminated zone outside the mine. According to EMA (2007), the normal COD levels is <60mg/L, however, Patil et al. (2012) reported a normal range of less than10 mg/L according to WHO standards. Effect of high COD level is that it decreases oxygen required to support aquatic life. Levels of COD and BOD can be reduced if operations make use of a biological treatment plant before effluent disposal. The treatment plant would reduce the organic material contamination in the water.

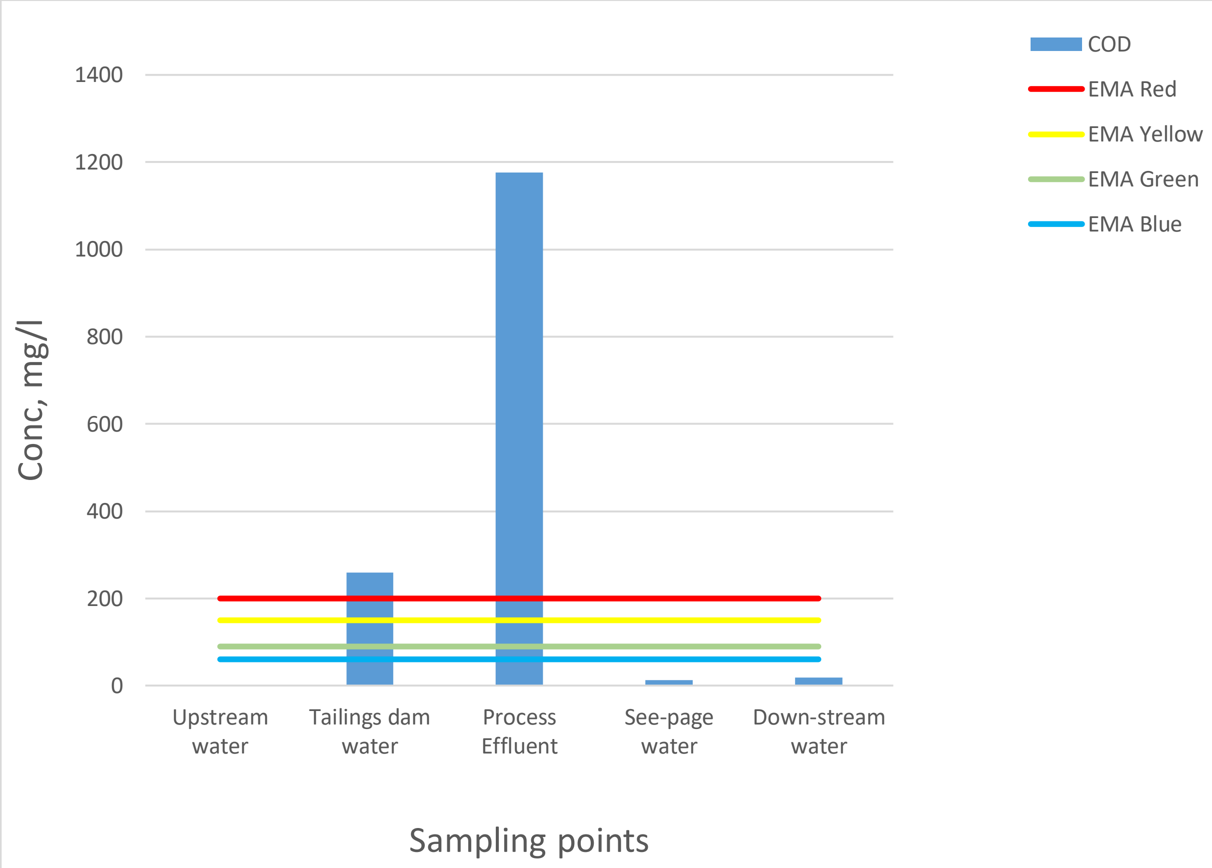

Fig 7. Chemical oxygen demand (COD) concentrations in samples

3.6 Turbidity

Turbidity is the degree of murkiness of water (Jain, 2011). EMA regulations specify turbidity values greater than 5 NTU to be environmentally unfriendly. Fig 8 is shows that all the sampled points had higher turbidity than the EMA stipulated limit of 5 NTU. Turbidity values varied from 10 NTU in the upstream water to 500 NTU in the process effluent water. This signifies a high level of suspended solids in the water streams. The process effluent turbidity (500 NTU) is highest as compared to the other sampled points of the study area. This is a result of the higher level of percentage of solids in the effluent. Higher levels of turbidity are commonly associated with disease causing bacteria (Patil et al, 2012). Solid-liquid separation must be encouraged in the tailings dam by using environmentally friendly coagulants and flocculates reagents. This will promote a better clarity on the waste water streams.

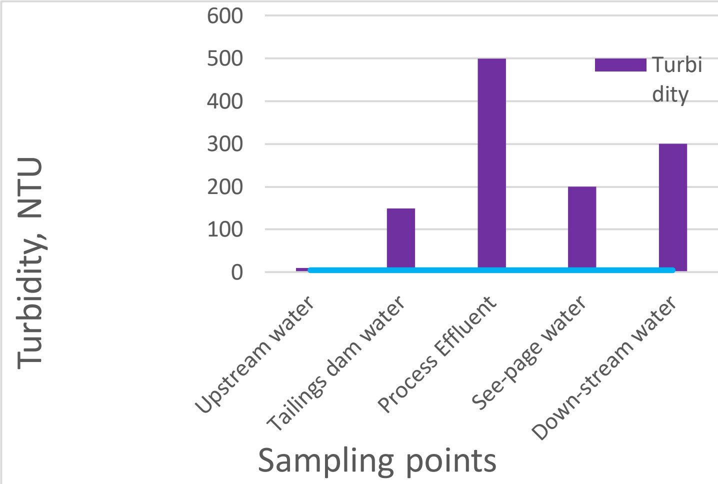

Fig 8. Turbidity in water samples

4.CONCLUSIONS

The results of the study revealed that the water within the effluent, see-page and down-stream sources is significantly contaminated. The three sites recorded EC values in the red band of EMA limits, i.e. the process effluent (6010µS/cm), see-page water (5810µS/cm) and down-stream water (5030 µS/cm). Higher values of EC imply that they are a lot of contaminants in the form of dissolved ions and hence the water not suitable for discharge into the environment. To add to the above, total dissolved solids (TDS) in process effluent (4250mg/L), see-page water (4060mg/L) and down-stream water (3440mg/L) are in the red band of EMA standards. Kwarteng (2012) pointed out that TDS indicates the suitability of a water source for domestic use since high TDS values imparts saltiness to water and thus making it less palatable. It was also noted that the pprocess effluent pH (13.69), is too high and falls in the red band of EMA standards (>12). The authors recommend mining operations to treat processing plant effluents before disposal to the tailings dam and hence reduce the environmental contamination. An effluent treatment plant can be developed which incorporates; biological treatment, neutralization, precipitation and solid-liquid separation processes. There is great need to increase the volume of water that is being recycled back to the processing plant from the tailings pond to reduce the water volumes entering the natural environment.

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