Characterization and Pre-treatment of Water from the Vaal River

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***Abstract*—** Extensive urbanization, economic development, and industrialization coupled with water wastage are placing increased pressure on the quality of water from the Vaal River system. This research study was carried out to assess the water quality of the Vaal River in terms of physico-chemical parameters and heavy metals concentration. Three (3) locations were identified within the Upper Vaal Water Management Area (WMA) where water samples were collected in the months of July and September 2014. A total of eight water quality parameters namely pH, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Total Hardness ($CaCO_3$), Chemical Oxygen Demand (COD), Nitrate (NO_3^-), Phosphate (PO_4^{3-}), Sulphate (SO_4^{2-}) and Heavy Metals concentration were measured in the laboratory using standard analytical procedures. Values of measured parameters were then compared with the South African water quality guidelines for domestic use and aquatic ecosystems. The findings showed that all the physico-chemical parameters and heavy metals concentration measured were within the tolerable limits except nitrate which exceeded the recommended limit of 6 mg/l, with values ranging from 30-31 mg/l in July and 19-21 mg/l in September. The analytical data also indicated that after pre-treatment of the water sample by filtration and adsorption, the TSS level, TDS concentration, and nitrate content were significantly lowered. Nitrate was reduced to below the acceptable limit after treatment. It was therefore concluded that the river water in the Upper Vaal Water Management Area was not suitable for domestic purposes without any form of treatment and frequent monitoring of physico-chemical parameters is imperative in order to have a full representation of the variations in the water quality.

***Keywords*—**Water quality, Vaal river, Water monitoring. Water pollution control

I. Introduction

VAAL River is South Africa's most important river. The Vaal River System supplies water to 60% of economy and 45% of the population – the mines and industry on the Mpumalanga Highveld, the bulk of Eskom's coal fired power stations, Gauteng, the North West and Free State goldfields, Kimberley, small towns as well as large irrigation schemes. All users in the area contribute to the effluent and water quality issues [1].

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Vaal River has been described as South Africa's hardest working river and the backbone of South Africa's economy, however, the water quality of the Vaal River has been increasingly affected by mining, industrial, agricultural processes, and more recently by urbanization. Rapid and unplanned urbanization has surpassed the capacity of the existing waste water treatment infrastructure leading to problems with pollution of storm water and fecal pollution from urban runoff [2]. As the water demand rises, the volume of effluents returned to the river also increases. Effluents will therefore increasingly affect water quality [3].

The biggest problem that is facing the Vaal River System is the water quality in the Upper Vaal Water Management Area (WMA), Middle Vaal WMA and Lower Vaal WMA, these problems comes from different pollution sources such as untreated sewage from non-functioning municipal waste water treatment works, industrial effluents, acid mine drainage and other activities that are happening within the Vaal River System [4] & [5].

The aim of this study was to evaluate the surface water quality of the Vaal River in terms of physico-chemical parameters and heavy metals concentration and to treat the water using multimedia filtration and adsorption.

II. Experimental

A. Study area

The study area was the Integrated Vaal River System, which covers three water management areas (WMAs) namely the Upper Vaal WMA, Middle Vaal WMA and Lower Vaal WMA. The land use in the Upper Vaal WMA is characterized by large urban centers and industrial areas in the northern and western parts of the WMA. There is also extensive coal and gold mining activities located in the Upper Vaal WMA. These activities are generating substantial return flow volumes in the form of treated effluent from the urban areas and mine dewatering that are discharged into the river system. These discharges have significant impacts on the water quality in the main stem of the Vaal River, throughout all three WMAs. This research study made use of the water quality data obtained from three sampling point situated within the Upper Vaal WMA (Figure1).

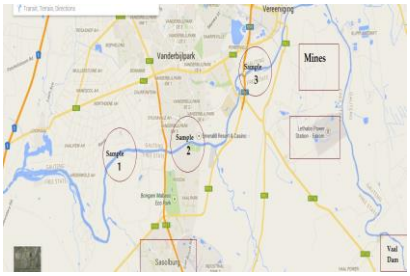

Fig.1 Map of the study area

B. Apparatus

The pH of the water samples was measured using a pH meter (Mettler Toledo) with a Mettler Toledo InLab Pro ISM pH electrode. Total Suspended Solids (TSS) was determined by the gravimetric method. TDS of the water samples was measured using a TDS meter (Mettler Toledo, Inlab74×series). Total hardness of the water sample collected was determined by EDTA titrimetric method. The chemical oxygen demand analysis was performed using a Hach COD reactor (model 45600) followed by calorimetric determination of Cr^{3+} at a wavelength of 620 nm using a Hatch spectrophotometer (model DR 2010). The concentrations of nitrate, phosphate, and sulphate were determined in various water samples by ion chromatography (Dionnex). The levels of heavy metals (Al, Co, Cu, Fe, Mn, and Ni) in the water samples collected were determined by Atomic Absorption Spectrometer (Thermo Scientific ICE 3000Series). The equipment used for pre-treatment of the water samples was an Automated Water Filtration Pilot Plant equipped with a multi-media filter and an activated carbon filter (Figure 2).

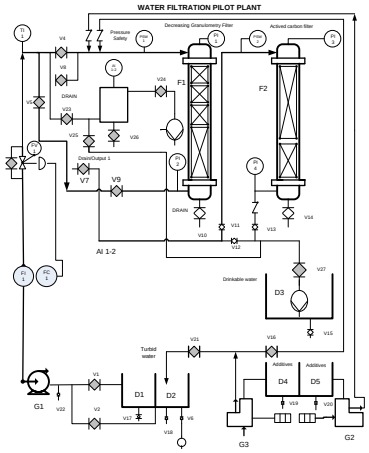

Fig.2 P&ID of the water filtration pilot plant

C. Experimental Procedure

Samples were collected in plastic bottles at the between July and September 2014. Parameters such as pH, total suspended solids (TSS), and total dissolved solids (TDS) were measured to assess the water quality of the Vaal River. The samples were also analysed for total hardness, chemical oxygen demand, nitrate, phosphate, sulphate and heavy metals using standard methods for analysis of water and wastewater as outlined in the Standard Methods Handbook for the Examination of Water and Wastewater [7]

III. Results and Discussion

A. Physical quality of the water samples

The physical parameters obtained from the water samples analysed are shown in Table I and Table II.

TABLE I
PHYSICAL QUALITY OF WATER IN JULY

Parameters	Target Water Quality Range	Sample 1	Sample 2	Sample 3
pH	6.5-9.0	6.79	6.81	6.82
TSS (mg/l)	<100	19	8	10
TDS(mg/l)	0-450	361	346	285

TABLE II
PHYSICAL QUALITY OF WATER IN SEPTEMBER

Parameters	Target Water Quality Range	Sample 1	Sample 2	Sample 3
pH	6.5-9.0	6.79	6.81	6.82
TSS (mg/l)	<100	19	8	10
TDS(mg/l)	0-450	361	346	285

The results reveal that the physical parameters estimated for pH, TSS, TDS fell within the tolerable and permissible levels recommended.

B. Chemical quality of the water samples

The chemical parameters of analyzed water samples are shown in Table III and IV respectively.

TABLE III
CHEMICAL CHARACTERISTICS OF WATER IN JULY

Parameters	Target Water Quality Range	Sample 1	Sample 2	Sample 3
$CaCO_3$ (mg/l)	75-200	100	120	80
COD (mg/l)	20	21	17	14
NO_3^- (mg/l)	0-6	30	31	30
PO_4^{3-} (mg/l)	-	-	-	-
SO_4^{2-} (mg/l)	100	100	99	102

TABLE IV
CHEMICAL CHARACTERISTICS OF WATER IN SEPTEMBER

Parameters	Target Water Quality Range	Sample 1	Sample 2	Sample 3
$CaCO_3$ (mg/l)	75-200	140	130	126
COD (mg/l)	20	16	13	10
NO_3^- (mg/l)	0-6	21	19	20
PO_4^{3-} (mg/l)	-	-	-	-
SO_4^{2-} (mg/l)	100	121	99	100

The IC analysis results for anions revealed that there were no phosphates in the water samples analyzed in the month of July or September. With the exception of nitrate and sulphates, most of the chemical parameters fell within the tolerable and permissible levels recommended. The Nitrate values ranged from 30 – 31 mg/l in July and 19 – 21 mg/l in September. This indicates that the nitrate concentrations in the surface water is normally low but can reach high levels as a result of agricultural runoff, refuse dump runoff or contamination with human or animal wastes [7]. The results show that sulphates levels ranged from 99 - 102 mg/l in the month of July and from 99 - 121 mg/l in the month of September.

Total hardness results of the water samples collected in the months of July and September shows that the river water in the month of July was moderately soft to slightly hard and the water samples in the month of September was slightly hard across all three locations.

With the exception of one sample that was analysed in the month of July, all the other water samples exhibited lower level of COD and were well within the recommended limit. The minimum COD value was recorded in the month of September and the maximum value in July. The chemical oxygen demand (COD) value obtained in this study ranged from 14 - 21mg/l and 10 - 16mg/l in the month of July and September respectively.

C. Heavy metal concentration

The concentrations of heavy metals in the water samples from Vaal River were low at all sampling sites, and Co, Cu, Mn and Ni were not detectable in the month of July or September. The mean values of the different elements shown in Table V.

TABLE V
HEAVY METALS CONCENTRATION IN THE WATER SAMPLES

		July			September		
	Limit (mg/l)	S1	S2	S3	S1	S2	S3
Al	< 5	1.23	1.23	1.41	1.23	0.86	0.96
Co	-	ND	ND	ND	ND	ND	ND
Cu	0.2	ND	ND	ND	ND	ND	ND
Fe	0.5-1	0.13	0.11	0.23	ND	ND	ND
Mn	-	ND	ND	ND	ND	ND	ND
Ni	-	ND	ND	ND	ND	ND	ND

The results reveal that aluminium and iron were the only elements present in the water samples. Al concentrations were found to be within the permissible limits and ranged from 1.23–1.41 mg/l and 0.86–1.23 mg/l, respectively. The concentration of aluminium in natural waters can vary significantly depending on various physico-chemical and mineralogical factors. Dissolved aluminium concentrations in waters with near-neutral pH values usually range from 0.001 to 0.05 mg/l but rise to 0.5–1 mg/l in more acidic waters or water rich in organic matter.

The concentration of Fe on the other hand, ranged from 0.11-0.23mg/l in the month of July which was also found to be within the permissible limits. No traces of iron were detected in the water samples analysed in the month of September.

D. Physico-chemical parameters after pre-treatment of the water samples

Water samples collected in the month of September were combined and pre-treated by filtration and adsorption using an automated water filtration pilot plant. The treatment significantly lowered the TSS level, TDS concentration, and nitrate content but had little to no effect on water hardness and COD level. Results are presented in Table VI.

TABLE VI
PHYSICO-CHEMICAL PARAMETERS AFTER PRE-TREATMENT

Parameters	**Target Water Quality Range**	**Composite Sample Before Treatment**	**Composite Sample After Treatment**	**% Removals**
pH	6.5-9.0	8.32	7.48	-
TSS (mg/l)	<100	13	ND	100
TDS(mg/l)	0-450	402	64	84
$CaCO_3$ (mg/l)	75-200	132	132	0
COD (mg/l)	20	13	13	0
NO_3^- (mg/l)	0-6	20	5	75
SO_4^{2-} (mg/l)	100	107	98	8

IV. Conclusion

The results of this study indicated a temporal variation in the parameters measured over the three months study period. All the physico-chemical parameters and heavy metals concentration except for nitrates and sulphates fell within the permissible levels recommended by the South African water quality standard for domestic use and aquatic ecosystems. The analytical results also indicated that after pre-treatment of the water sample by filtration and adsorption, the TSS level, TDS concentration and nitrate content were significantly lowered. Nitrate was well within the guideline recommended limit after treatment. It was therefore concluded that the river water in the Upper Vaal Water Management Area was not suitable for domestic purposes without any form of treatment.

Acknowledgment

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