

A COMPARATIVE STUDY OF THE PHOSPHATE LEVELS IN SOME SURFACE AND GROUND WATER BODIES OF SWAZILAND

A.O. Fadiran^{*}, S.C. Dlamini and A. Mavuso

Chemistry Department, University of Swaziland, P/Bag 4, Kwaluseni Swaziland

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ABSTRACT. The levels of total phosphate in selected surface water and groundwater bodies from Manzini and Lubombo regions of Swaziland were determined using UV spectroscopic method. Samples were collected from three rivers (upstream and downstream of each), three industrial effluents, one reservoir, one pond, one tap water and fifteen boreholes. Mean phosphate levels in the tap water and reservoir varied between 0.08-0.09 mg/L while for the river samples, the range was 0.11-0.37 and for the industrial discharge, it was 0.11-1.60 mg/L PO₄-P. For the ground water systems it ranged between 0.10-0.49 mg/L PO₄-P. The mean phosphate levels in all the analyzed surface and groundwater samples were below the recommended maximum contaminant level (MCL) by SWSC (Swaziland Water Service Corporation) – i.e. 1.0 mg/L for drinking water; 2.0 mg/L for rivers and industrial effluents, and the South African criterion of 1.0 mg/L PO₄-P, for sewage effluents being discharged into receiving waters. However, pooled mean values for all the sites were higher than the USEPA criterion of 0.03 mg/L maximum for uncontaminated lakes. Dominant factors considered to have influenced the levels of phosphates in both the surface and groundwater samples analyzed include industrial activities (where present), agricultural activities (including livestock), population density, location (urban, suburban or rural), soil/rock type in the vicinity of the sampling point, climate and rainfall pattern of the area or region concerned.

KEY WORDS: Surface water, Groundwater, Limiting nutrient, Eutrophication, Algal bloom, Anthropogenic phosphate sources

INTRODUCTION

Phosphorus is one of the essential nutrients necessary for the nutrition and growth of living organisms. Like nitrogen, it is a limiting nutrient for algal growth, because it occurs in the least amount relative to the needs of plants [1-3]. In natural and wastewaters, phosphorus occurs almost solely as dissolved phosphate and it is the most significant form of phosphorus in natural water. Orthophosphate is the most thermodynamically stable form of phosphate, and is the form commonly identified in laboratory analysis and also used by plants. Furthermore, polyphosphates in water are unstable and eventually convert to orthophosphate [1-6]. In contrast to nitrates, phosphates are not very mobile in soils and they are only moderately soluble. However, transportation through runoff and erosion can drastically enhance their levels in surface waters. Other factors that contribute to their low concentrations in water bodies include the usually large uptake by plants and adsorption by metal oxides [5].

Surface waters and groundwater become contaminated from both natural and anthropogenic sources of phosphates. Natural sources of phosphorus in both surface and groundwater include atmospheric deposition, natural decomposition of rocks and minerals, weathering of soluble inorganic materials, decaying biomass, runoff, and sedimentation. Anthropogenic sources include; fertilizers, wastewater and septic system effluent, animal wastes, detergents, industrial discharge, phosphate mining, drinking water treatment, forest fires, synthetic material development surface [2, 3, 5-7]. Naturally occurring levels of phosphates in surface and ground water bodies are not harmful to human health, animals or the environment. Conversely, extremely high levels of phosphates can cause digestive problems [3]. Furthermore, excessive amounts of phosphates in water bodies can lead to eutrophication, a condition of accelerated, algal production to extreme quantities until they die off. The bacteria responsible for their

^{*}Corresponding author. E-mail: fadiran@uniswacc.uniswa.sz

decomposition use up and hence deplete the dissolved oxygen concentration in the water bodies to such levels that can result in fish kills. Additionally excessive algae on the water surface can accumulate into a scum which can result in clogged pipelines, restricted recreation and foul odours, when they eventually decay [2, 3, 5, 6, 8]. Also algal blooms have been linked to health problems such as skin irritation and death (of both human and animals) depending on the type and duration of exposure [9]. Phosphate-phosphorus > 100 µg/L may interfere with coagulation process in water treatment plants [8].

Factors that influence the levels of phosphates in water bodies include location, population density, degree of agricultural and industrial activities in its vicinity, rock type of the area, topography of the rainfall pattern, climate nature and frequency of sampling, biological activities in soil, atmospheric deposition and chemical weathering of bedrock, flow rate and proximity to ground water (for surface water) and top soil type and depth (for groundwater bodies. [2, 3, 7-10].

The World Health Organization (WHO), in 1980 concluded that there is no nutritional basis for the regulation of phosphorus levels in the US drinking water supplies [4]. However, to control eutrophication, USEPA makes the following recommendations [3, 5, 11]: (1) total PO₄-P ≤ 0.05 mg/L in a stream at a point where it discharges into a lake or reservoirs, (2) total PO₄-P ≤ 0.1 mg/L in streams that do not discharge directly into lakes or reservoirs, and (3) total PO₄-P ≤ 0.025 mg/L for reservoirs.

The Swaziland Water Services Corporation (SWSC) recommends a PO₄-P (total) of ≤1.0 mg/L for drinking water while the E.C. issues a guide level of 0.5 mg/L for drinking water. For the purpose of monitoring and water rating the following are the useful requisite levels of total PO₄-P [11], 0.01-0.03 mg/L: level in uncontaminated lakes; 0.025-0.1 mg/L: levels at which plant growth is stimulated; 0.1 mg/L: maximum acceptable for avoidance of rapid eutrophication; > 0.10: high level resulting in accelerated algal growth problems.

This paper aims at comparing experimental levels of total phosphate-phosphorus in selected surface water and groundwater bodies and employing available parameters (of sources and influential factors) to rationalize these levels. It also intends to identify those water bodies, especially the surface ones where the PO₄-P levels are rising to values that can likely soon result in an emergence of subtle, moderate or hyper-eutrophication, so that necessary control measures can be taken to avoid them.

EXPERIMENTAL

Instrumentation

The HACH-DR 2010 data logging, micro-processor controlled spectrophotometer (an advanced water quality laboratory series, from HACH company, USA) was employed for the analysis of total PO₄-P at the programmed reaction time and wavelength. Specially designed sample cells for the HACH DR 2010 spectrophotometer were used.

Reagents

Phos Ver 3 Phosphate reagent powder pillows (from HACH Chemical Company, USA), phosphate standard (HACH Chemical Company, USA), concentrated sulfuric acid (AR), and sodium hydroxide (AR) were used.

Sample collection, pretreatment and storage

Water samples were collected from nine surface water bodies (made up of three rivers, three industrial effluents, one pond, one reservoir, and one tap water) and fifteen ground water systems from the Manzini and Lubombo regions of Swaziland. Samples were collected in 500

mL brown borosilicate glass bottles cleaned with 1:1 HCl solution and rinsed with distilled-deionized water. Four samples were collected from each site. Samples were preserved by adding 2 mL of concentrated H_2SO_4 /L of sample with subsequent refrigeration at 4 °C after transportation to the laboratory (in cooler boxes containing ice-chips). Analyses were usually carried out within 48 hours after sampling [1, 12-14]. For both surface and ground water series sampling was carried out monthly over a period of five months. In both cases the sites were so carefully chosen to ensure good representation of urbanization, agricultural and industrial activities, rock type of the area and other factors that influence the $\text{PO}_4\text{-P}$ levels.

Principles (Phos Ver 3, ascorbic acid method)

Orthophosphate reacts with molybdate in an acidic medium to produce a phosphomolybdate complex. Ascorbic acid then reduces the complex and develops an intense molybdenum blue colour.

Analysis

The stored sample was first warmed to room temperature and then neutralized with 5.0 M NaOH solution. The wavelength was set at 890 nm. A 10 mL cell riser was placed in the cell compartment. Two 10 mL sample cells were each filled with 10 mL of a sample. A Phos Ver 3 powder pillow was emptied into one of them swirled to mix and afterward, two minutes reaction time was allowed. At the expiration of the two minutes reaction time, the other sample cell acting as the blank was used to zero the instrument. Thereafter, the sample containing the Phos Ver 3 powder pillow was inserted into the cell compartment and the reading taken in mg/L $\text{PO}_4\text{-P}$. The mean of the four samples taken from each sampling point was estimated and used for that site. To validate the method, a phosphate standards (500 mg/L $\text{PO}_4\text{-P}$) from HACH Company, was diluted serially within the expected real sample range. They were then analyzed following the same procedure as actual samples. The % recovery was calculated and the student t-test evaluated at the 95% confidence level.

RESULTS AND DISCUSSION

From the method validation test, a mean recovery of 106% was obtained. Furthermore, the student t-test carried out showed that there was no significant difference between the true $\text{PO}_4\text{-P}$ (mg/L) concentration from the Hach reference standard solution and the mean value obtained by the employed spectrophotometric (ascorbic acid) method.

Tables 1 and 2 depict the mg/L $\text{PO}_4\text{-P}$ mean ranges and pooled means in the sampled surface water and ground-water bodies with the observed prevalent features/factors around the sites that are most likely to influence them, while Table 3 shows the risk level of categorization of the water bodies for the onset of Eutrophication with respect to their $\text{PO}_4\text{-P}$. In both the surface and ground-water samples industrial effluents and sites that are located in or around industrial areas recorded the highest $\text{PO}_4\text{-P}$ values. These sites include FMI 1 (1.6 mg/L) and PMI (0.54 mg/L) both of which are direct factory effluents, and SP (0.49 mg/L). SP is the ground-water with the highest pooled mean $\text{PO}_4\text{-P}$ due most likely to its proximity to a manufacturing industry. It is also noteworthy that FMI 1 with a pooled mean value of 1.6 mg/L $\text{PO}_4\text{-P}$, which is an effluent from a food manufacturing factory, is not only the highest recorded value but it is about three times higher than the next highest value in all the samples, both surface and ground-water. This implies that the by products from these factories contain a lot of nutrient (including $\text{PO}_4\text{-P}$), which are detected in their effluents and would subsequently find their ways into the environment.

Table 1. PO₄-P (mg/L) – pooled mean, ranged mean value and dominant feature/factor for each surface water sampling site.

Sampling point	PO ₄ -P range (mg/L)	PO ₄ -P mean (mg/L)	Dominant feature/factor			
			Type	Population density/location	Soil/rock type of area	Vicinity type and activity
UUC	0.08 – 0.14	0.11	River	Sub-urban, low	Lochiel granite	Agriculture and industrial
UDC	0.07 – 0.15	0.12	River	Sub-urban, high	Lochiel granite	Agricultural and industrial
LUC	0.10 – 0.13	0.11	River	Sub-urban, high	Gabro and dolerite	Urban, domestic
LDC	0.14 – 0.25	0.18	River	Sub-urban, medium	Ngwane gneiss	Urban, domestic
MUC	0.33 – 0.42	0.37	River	Urban, high	Sobie River basalt	Agricultural, domestic
MDC	0.24 – 0.36	0.28	River	Urban, high	Lebombo rhyolite	Agricultural, domestic
SWSC	0.06 – 0.10	0.09	Reservoir	Urban, high	Ngwane gneiss	Industrial, domestic
TPW	0.04 – 0.10	0.08	Tap water	Urban, low	Ngwane gneiss	Urban
FMI 1	0.32 – 0.63	0.54	Factory effluent	Sub-urban, medium	Ngwane gneiss	Industrial, agricultural
FMI 2	0.35 – 2.11	1.60	Factory effluent	Sub-urban, medium	Ngwane gneiss	Industrial
FMI 3	0.09 – 0.15	0.11	Effluent	High	Usuthu intrusive snite	Industrial
SMP	0.05 – 0.16	0.12	Pond	Sub-urban, high	Sand stone and Nkondolo group	Sub-urban, agricultural

Interpretation of abbreviations: UUC- Usuthu river up control, PMI- Paper manufacturing industry, UDC- Usuthu river down control, FMI 1- Food manufacturing industry 1, LUC- Lusushwana river up control, FMI 2- Food manufacturing industry 2, LDC- Lusushwana river down control, SMP- Simunye pond, MUC- Mbuluzi river up control, TPW- Tap water, MDC- Mbuluzi river down control, SWSC- Swaziland Water Services Corporation.

Considering the rivers, which among the surface waters rank second highest in the mean levels of PO₄-P (mg/L), as expected, the down control sites have higher phosphate levels than the up controls, with the exception of Mbuluzi River. The observed higher levels for down control sites are due to the runoff from the intense agricultural practices and the many industries that discharge their effluents into the rivers (Usuthu and Lusushwana) before the downstream sites. The higher population density, the loamy soil and the rock type (Sobie River basalt), around the upstream site of the Mbuluzi river (MUC), coupled with the fact that the company by which it passes is now running a special water treatment plant, are the likely factors accountable for the observed high PO₄-P (mg/L) for this point.

From Tables 1, 2, and 4, all the sampled surface water and ground-water systems with the exception of FMI 1 (1.60 mg/L PO₄-P) satisfied the SWSC standard/MCL of 1.0 mg/L PO₄-P for drinking water as well as the South African Standard of 1 mg/L PO₄-P for sewage effluent being discharged into receiving waters [15, 16]. Moreover, the FMI 1 sampling site is a wastewater effluent from a food manufacturing factory. The relatively low values of <1.0 PO₄-P (mg/L) in these water bodies in general is due to the low solubility of phosphates in water as well as to its poor mobility in soil since soil has a strong affinity for the negatively charged phosphate ions. It tends to chemically attach to positively charged particles in soils. The soil thus acts as a storage medium for the PO₄³⁻ ions, thereby drastically slowing down its leaching into ground-water and washings to surface waters [2, 3, 6, 9]. Furthermore, rapid uptake of this

nutrient by plants and algae in water bodies, especially the exposed surface waters, also lends weight to the observed relatively low (<1.0 mg/L) levels of this nutrient in these water bodies.

Table 2. PO₄-P (mg/L): pooled mean, concentration range and dominant feature/factor for each groundwater sampling site.

Sampling site	PO ₄ -P range (mg/L)	PO ₄ -P mean (mg/L)	Dominant feature/factor			
			Location/population density	Rock type	Top soil type	Vicinity type and activity
ML	0.35 – 0.43	0.38	Sub-urban, low	Usuthu intrusive	Loam	Medium agric. grazing
MA	0.32 – 0.40	0.36	Sub-urban, low	Usuthu intrusive	Loam	Domestic, medium agric.
LU	0.33 – 0.42	0.39	Sub-urban, high	Usuthu intrusive	Loam	Domestic, medium agric.
TS	0.16 – 0.33	0.23	Sub-urban, mod.	Usuthu intrusive	Loam	Medium agric; domestic
KM	0.37 – 0.51	0.43	Rural, high	Sabie basalt	Silt	Medium agric.
SL	0.13 – 0.27	0.14	Rural, low	Sabie basalt	Silt	Grazing field
NK	0.06 – 0.14	0.10	Rural, low	Rhyolite acitic ignimbrates	Loam	Grazing field
TK	0.13 – 0.21	0.18	Rural, low	Sabie basalt	Loam	Agricultural
MF	0.16 – 0.29	0.24	Rural, low	Rhyolite acitic ignimbrates	Silt	Subsistence/medium agric.
KK	0.18 – 0.26	0.22	Rural, low	Lebombo rhyolites	Silt	Subsistence/medium agric.
LM	0.27 – 0.39	0.33	Rural, low	Lebombo rhyolites	Loam	Agric. domestic, laundry
TW	0.11 – 0.39	0.22	Rural, low	Sabie basalt	Loam	Grazing and laundry
TP	0.19 – 0.36	0.24	Rural, low	Sabie basalt	Silt	Grazing
HL	0.10 – 0.18	0.13	Rural, low	Rhyolite acitic ignimbrates	Loam	Grazing
SP	0.42 – 0.54	0.49	Industrial	Usuthu intrusive	Loam	Industrial

Interpretation of abbreviations: ML- Malkerns, MA- Mahlanya, TP- Tsambokhulu primary, LU- Ludzeludze, TS- Tsekwane butchery, HL- Hhalane, KM- Ka-Mswati, SL- Sihlongwaneni, SP- Swazi paper mills, NK- Nkalashane, TK- Tsambokhulu, LM- Lomahasha, MF- Mafucula, KK- Kuhlamukeni, TW- Timbutini well.

Table 3. Risk level categorization of water bodies with respect to their PO₄-P (mg/L) levels for onset of eutrophication.

PO ₄ -P range (mg/L)	Nature/class of risk	% Surface water (within the range)	% Ground water (within the range)
0.01 - 0.03	Uncontaminated water bodies	0	0
0.025 - 0.1	Stimulation (or onset) of plant growth or algal bloom	16.7	6.7
> 0.10	Full blown eutrophication or hyper-eutrophication	83.3	93.3

Tables 3 and 4 give the pictures of the eutrophic level contamination or their degree of PO₄-P contamination relative to the maximum expected level prior to eutrophication. All the

sites both surface and ground-water bodies fail to meet the USEPA criterion of 0.01-0.03 mg/L PO₄-P for uncontaminated water bodies [17]. In this respect the analyzed industrial effluents are about 4 to 53 times higher, while the other surface water bodies' vis-a-vis rivers, reservoir, pond and drinking water contain between 3-12 times as much as the maximum value of 0.03 mg/L expected for uncontaminated water bodies.

Table 4. PO₄-P values in surface and groundwater relative to that of an uncontaminated lake and onset of eutrophication.

Surface waters mg/L PO ₄ -P				Ground water mg/L PO ₄ -P			
Sampling point	x _p (mg/L)	(x _p /x _{ou}) [*]	(x _p /x _{oe}) ^{**}	Sampling point	x _p (mg/L)	(x _p /x _{ou})	(x _p /x _{oe}) ^{**}
UUC	0.11	3.7	1.1	ML	0.38	12.7	3.8
UDC	0.12	4.0	1.2	MA	0.36	12.0	3.6
LUC	0.11	3.7	1.1	LU	0.39	13.0	3.9
LDC	0.18	6.0	1.8	TS	0.39	7.7	2.3
MUC	0.37	12.3	3.7	KM	0.43	14.3	4.3
MDC	0.28	9.3	2.8	SL	0.14	4.7	1.4
SWSC	0.09	3.0	0.9	NK	0.10	3.3	1.0
TPW	0.08	2.7	0.8	TK	0.18	6.0	1.8
PMI	0.54	18.0	5.4	MF	0.24	8.0	2.4
FMI 1	1.60	53.3	16.0	KK	0.22	7.3	2.2
FMI 2	0.11	3.7	1.1	LM	0.33	11.0	3.3
SMP	0.12	4.0	1.2	TW	0.22	7.3	2.2
-	-	-	-	TP	0.24	8.0	2.4
-	-	-	-	HL	0.13	4.3	1.3
-	-	-	-	SP	0.49	16.3	4.9

*x_p = pooled mean for the sampling point, x_{ou} = mg/L PO₄-P maximum for uncontaminated lake = 0.03

**x_{oe} = mg/L PO₄-P for onset of eutrophication = 0.10.

The ground water samples also contain multiples of the PO₄-P (mg/L) value expected for an uncontaminated water body with x_p/x_{ou} values ranging between 3 and 16, and most of the sites possess higher x_p/x_{ou} values than those of surface waters with the exception of the values for industrial waste waters. For the range (0.025-0.1) mg/L PO₄-P which represents the level at which plant growth (and algal bloom) is stimulated, up to the maximum acceptable for prevention of onset of eutrophication (0.1 mg/L), only two of the twelve sites or 16.7% of the surface water sites, one out of the fifteen sites or 6.7% of the ground water sites fall under this category (Table 3). Also from Table 4, the ground water sites generally have higher multiples of the eutrophication-concentration threshold values (x_p/x_{oe}), than those of the surface water with the exception of factory effluents. Furthermore, 93.3% (fourteen out of the fifteen sampled sites) of the groundwater bodies and 83.3% (10 out of 12 sites) of the analyzed surface water bodies contain pooled average concentrations of phosphorus exceeding the 0.10 mg/L indicative of full-blown or hypereutrophic level. These observations confirm the expectation that on the average, the groundwater bodies contain higher concentrations of mg/L PO₄-P, than the surface waters located in the same geographic areas [2, 3].

Table 5 and Figure 1 depict the details of the sites with the highest and lowest phosphorus levels among the surface waters and the ground water systems. The surface water sample with the highest phosphorus level (FMI 1) is an industrial effluent, while the ground water site with the highest PO₄-P level, SP is one located close to the paper manufacturing industry. The high phosphate concentration here must have been from the bye-product phosphates in the leaking sewage and effluent pipes of the paper mill and which inadvertently enter the ground water through leaching (though slowly). On the other hand and as expected the drinking water has the lowest PO₄-P (mg/L) level while NK (Nkalashane), the ground water site with the lowest

phosphate level is a rural location with very low population density, scanty agricultural activities and hence low fertilizer application (if any) – all of which account for the observed low phosphate level.

Figure 2 depicts the risk level categorization of water bodies with respect to their PO₄-P (mg/L) levels for onset of eutrophication.

Table 5. Comparison of highest (maximum) and lowest (minimum) PO₄-P value of the surface and ground waters on geographic basis.

Feature	PO ₄ -P highest value (mg/L)		PO ₄ -P lowest value (mg/L)	
	Surface water	Ground water	Surface water	Ground water
Value	1.60	0.49	0.08	0.10
Sampling point	FMI 1	SP	TPW	NK
Specific type	Industrial effluent	Ground water	Drinking water	Ground water
Region	Manzini	Manzini	Manzini	Lubombo
Dominant Feature/factor/activity	Industrial	Industrial	Domestic residential	Fields

Table 6 and Figure 3 depict the pooled mean levels of PO₄-P (mg/L) and overall ranges in specific categories of the analyzed water samples. The pooled mean phosphate levels for all these categories arranged in increasing order are as follows:

Drinking water < Reservoir < Pond < River < Groundwater < Factory Effluents.

It follows that apart from industrial effluents which constitute a special class on their own; the levels of phosphorus in ground water samples are on the pooled average greater than those of surface waters (rivers, pond, reservoir and tap water).

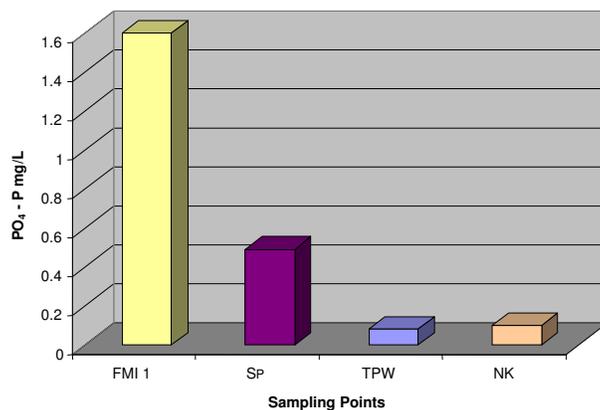


Figure 1. Comparison of highest and lowest PO₄-P mg/L of the surface and ground water.

Key: ■ Highest PO₄-P in surface water, ■ Highest PO₄-P in ground water, ■ Lowest PO₄-P in surface water, ■ Lowest PO₄-P in ground water.

Table 6. Overall range for mg/L PO₄-P levels in specific categories of surface water and groundwater bodies.

Water body	Overall range (mg/L PO ₄ -P)	w = x _n -x ₁	x _p ±s _p
Factory effluents	0.11 – 1.60	1.49	0.75
Rivers - up control	0.11 – 0.37	0.26	0.20
Rivers - down control	0.12 – 0.28	0.16	0.20
River - all together	0.11 – 0.37	0.26	0.20
Pond	0.12	-	0.12
Reservoir	0.09	-	0.09
Drinking water (tap)	0.08	-	0.08
Groundwater	0.10 – 0.49	0.39	0.27

w = range, x_n = highest pooled mean, x₁ = lowest pooled mean.

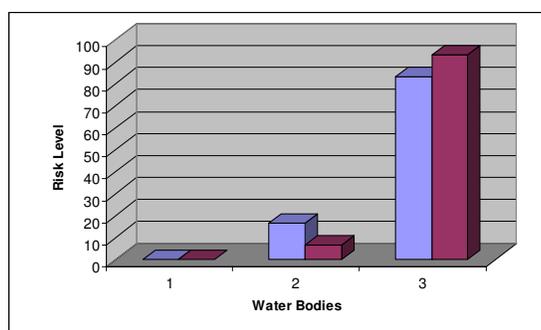


Figure 2. Risk level categorization of water bodies with respect to their PO₄ – P (mg/L) levels for onset of eutrophication. Key: ■ surface water, ■ ground water.

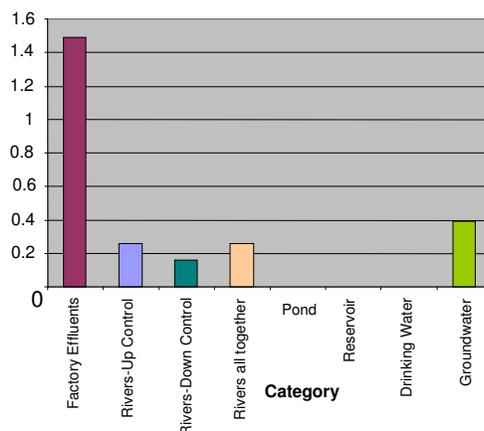


Figure 3. Overall range for PO₄-P (mg/L) levels in specific categories of surface water and ground water.

This is most likely due to the more weighty influence of the phosphate pollution sources on the ground water bodies relative to the surface waters. These phosphates are derived from natural contact with minerals, i.e. geologic weathering, fertilizer application, sewage and

industrial waste water, the weathering being a key factor in this respect [1-4]. Additionally active take-up of phosphorus as a nutrient by algae greatly depletes its levels in surface waters [1, 2, 4]. From Tables 1, 2 and 5, it can be concluded that apart from natural factors, which are diverse, the major anthropogenic factors that influenced the observed levels of $\text{PO}_4\text{-P}$ (mg/L) are industrial activities (through sewage and actual industrial effluents), urban sources and high population density (derived from urban runoff, domestic sewages, storm drainage and industrial waste), agricultural sources (from fertilizer application and animal wastes), and rural sources (from agriculture, animal and domestic wastes from rural dwellers. The last source is also characterized by low population density and very low application of fertilizers. Hence the $\text{PO}_4\text{-P}$ (mg/L) levels in sites located in the rural or sub-urban areas such as UUC, UDC, LUC among the surface waters and SL, NK, TK and HL among the groundwater sites have lowest levels relative to their counterparts from the same regions. On the other hand, sites located in industrial areas, or urban/high population density or intense agricultural practice areas such as FMI 1, MUC and MDC among the surface waters and SP, KM and LU among the ground water sites.

Furthermore, the 0.09 mg/L $\text{PO}_4\text{-P}$ in the reservoir sample is critically close to the 0.1 mg/L $\text{PO}_4\text{-P}$ maximum contaminant level for prevention of eutrophication. Additionally, when $\text{PO}_4\text{-P}$ (mg/L) in water is >0.10 , it can interfere with the coagulation process in water treatment plants [8]. This calls for a better water treatment procedure to further reduce the present $\text{PO}_4\text{-P}$ level in the reservoir. Also regular and frequent monitoring of the $\text{PO}_4\text{-P}$ levels in reservoirs, ponds or rivers such as Lusushwana river which is a major source of water being used by the Swaziland Water Corporation Services for public consumption (after treatment) should be carried out as part of the quality control programme for drinking water.

Failure of all the sampled points to meet the USEPA criterion for uncontaminated lake (0.01-0.03) mg/L $\text{PO}_4\text{-P}$ is indicative of anthropogenic impact on the degree of their pollution by phosphates. However, all the surface water sites except one (FMI 1 = 1.60 mg/L $\text{PO}_4\text{-P}$), and all the underground water sites meet the EC guide level of 0.50 mg/L $\text{PO}_4\text{-P}$ and the SWSC guide level of 1.0 mg/L $\text{PO}_4\text{-P}$ for drinking water as well as the South African criterion of 1.0 mg/L $\text{PO}_4\text{-P}$ for sewage effluents that will be discharged into receiving waters [15, 17]. A deeper look at the levels of phosphate in the reservoir (0.09) and in drinking water (0.08) mg/L $\text{PO}_4\text{-P}$ shows that the water treatment only slightly reduces the phosphate level in the raw, untreated water.

CONCLUSIONS

The observation that all the analyzed samples have $\text{PO}_4\text{-P}$ (mg/L) values in multiples of the value for uncontaminated water bodies is indicative of significant anthropogenic inputs from domestic sewage, agricultural and industrial practices in addition to natural sources of rock weathering and phosphate cycles in water. With about 83% of the analyzed surface water sites and 93% of the ground water samples having $\text{PO}_4\text{-P}$ levels that exceed the maximum acceptable level of 0.10 mg/L $\text{PO}_4\text{-P}$ for prevention of eutrophication, it follows that virtually all the water bodies in these two regions (with the exception of the reservoir and the drinking water) are already under hypereutrophic state. The 0.09 mg/L $\text{PO}_4\text{-P}$ level in the reservoir is nothing to be excited about as this can be considered to be critically approaching the 0.10 mg/L $\text{PO}_4\text{-P}$ threshold level that imposes negative interference on water treatment processes in plants. Hence to forestall an outbreak of an uncontrollable hypereutrophic state in Swaziland water bodies, steps have to be taken early enough to control the inputs of phosphorus from anthropogenic sources into these water bodies. Furthermore, it has become necessary to include phosphorus in basic water quality surveys or background monitoring programmes. Countries like the USA have banned the use of phosphate detergents with beneficial results [18]. If Swaziland government can take a similar step, it would go a long way to enhance the quality of our water bodies with respect to their $\text{PO}_4\text{-P}$ levels.

Finally, since industrial effluents have been found to contain the highest levels of PO₄-P (mg/L), treatment of wastewaters as well as effluent discharges from these factories into receiving waters and the environment at large in these regions of the country should be properly controlled and monitored. Our results confirm the usual assertion [1, 2, 4] that groundwater have the tenancy to have higher phosphate concentrations than surface waters.

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