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ANALYTICAL CHEMISTRY | RESEARCH ARTICLE

Assessment of microbiological, physicochemical, water-soluble anions and elemental contents of water and sediments of Bon Accord Dam, South Africa

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Abstract: Due to the scarcity of water resources, South Africa is mainly dependent on water stored in man-made reservoirs for urban, industrial and irrigation purposes. Hence, the quality of the water in these dams is important. The microbiological, physicochemical and elemental quality of water and sediment of Bon Accord Dam, South Africa were studied. The total coliform and *Escherichia coli* were measured, the physicochemical parameters were determined *in situ* and elemental analyses were carried out. The water from some sampling sites had pH>8.4, which could affect crop quality and yield. The electrical conductivity and total dissolved solid values implied that the water was of medium salinity where sensitive crops could be affected. The measured physicochemical parameters were within the national and/or international guidelines for irrigation water even if some of the parameters may have a negative impact on selected crops. The anion concentration in the water followed the order $\text{SO}_4^{2-} > \text{Cl}^- > \text{PO}_4^{3-} > \text{NO}_3^- > \text{Br}^- > \text{NO}_2^- > \text{F}^-$. The concentrations of the water-soluble anions (except PO_4^{3-} and at some sites NO_3^-) in samples were within their respective South African and/or WHO guidelines for irrigation water. However, the levels of PO_4^{3-} in this study were ≥ 0.130 mg/L makes the dam hypertrophic. The average concentration of potentially toxic elements in the sediments of the dam was found to be moderately to heavily polluted by Cr and Ni, non-polluted to moderately polluted by Cu and non-polluted by Pb and Zn. The bacterial levels in the dam were low and can hence not be considered a problem.

ABOUT THE AUTHOR

The research group currently working to see the quality of the Dams found in South Africa focusing on Bon Accord Dam and Loskop Dams, South Africa. As a research group, we are working on the determination of microbiological and physicochemical properties of the water, sediment and biota. Besides we are working on the determination of the levels of inorganic and organic pollutants in the aforementioned samples in the aquatic environment. We are also working on the remediation mechanisms towards increasing the threats of the aquatic environment with respect to the inorganic and organic pollutants.

PUBLIC INTEREST STATEMENT

Water resources are scarce in the world in general and in South Africa in particular. So the country is using man-made reservoirs (dams) for urban, industrial and irrigation purposes. Hence, the quality of the water in these dams is important. One of the dams is the Bon Accord Dam, the smallest impoundments in the Crocodile River catchment and found about 15 km north of central Pretoria, just north of the N4 highway. The Dam was completed in 1925 to supply irrigation water to areas for vegetable farming and hence its quality is of importance. Therefore, this study tries to assess the microbiological, physicochemical and elemental quality of the Dam.

Subjects: Agriculture & Environmental Sciences; Environment & Health; Environment & the City; Analytical Chemistry; Environmental Chemistry

Keywords: Bon Accord Dam; inductively coupled plasma-mass spectrometry; ion chromatography; sediment; South Africa; water

1. Introduction

The reuse of treated wastewater in irrigation provides important nutrients for crops, reduces the use and abstraction of freshwater and the discharge of effluents into freshwater ecosystems (Becerra-Castro et al., 2015). However, the reuse of wastewater has health and environmental risks since it is mainly composed of particulate and dissolved organic matter, inorganic substances, microorganisms, and also toxic, recalcitrant and/or bioaccumulative chemicals (Becerra-Castro et al., 2015; Chavez, Rodas, Prado, Thompson, & Jiménez, 2012; Farahat & Linderholm, 2015; Raja et al., 2015; Villanueva, Luna, Gil, & Allende, 2015). Irrigating with wastewater alters the physicochemical and microbiological properties of the soil and contributes to the accumulation of chemical and biological contaminants (Becerra-Castro et al., 2015; Chavez et al., 2012; Farahat & Linderholm, 2015; Raja et al., 2015). Given such complexity, the physicochemical and microbiological characterization of irrigation water is indispensable to assess its quality and its effect on the biota.

Sediments contain elements that are present in the earth's crust and may contain toxic metals generated by both geological and man-made sources (Ravisankar et al., 2015). They reflect the environmental changes that have occurred in sedimentary basins and provide useful information about the accumulation of contaminants, reflecting natural and anthropogenic impacts (El-Sayed, Moussa, & El-Sabagh, 2015; Pejman, Bidhendi, Ardestani, Saeedi, & Baghvand, 2015). Besides those of natural origin, contaminants are discharged into aquatic systems during transport and are distributed between the sediment and aqueous phase (Bestami et al. 2015a; Bastami et al., 2015b). Sediments have a high storage capacity for pollutants. In any part of the hydrological cycle, less than 1% of these are actually dissolved in the water, the remaining being stored in the sediments (Salomons, 1998; Suresh, Ramasamy, Sundarajan, & Paramasivam, 2015). This occurs as a result of long-term inputs of pollutants into the sediment, which then bind to sediment particles and organic matter (de Klerk, de Klerk, Chamier, & Wepener, 2012; Newman & Watling, 2007). Therefore, sediments are the most important pollutant sink while only a small portion of ions remain dissolved in the water column (Bastami et al., 2015a, 2015b; Nazeer, Hashmi, & Malik, 2014, Suresh et al., 2015; Tuna, Yilmaz, Demirak, & Ozdemir, 2007; Xu et al., 2015).

South Africa is classified as an arid country with a mean annual precipitation of 497 mm, less than the world average of 860 mm (Smakhtin et al., 2001). South Africa is known for having scarce and extremely limited water resources and depends mainly on surface water for most of its urban, industrial and irrigation requirements (Department of Water Affairs and Forestry, South Africa [DWAF], 2004; van Ginkel, 2011; van Ginkel, Hohls, & Vermaak, 2001). The country relies on water stored in man-made reservoirs for the sustained supply of potable and irrigation water (DWAF, 2004; Cessford et al., 2005; Hart, 2011). The main water quality problems in South Africa are salinity, water-borne diseases, low oxygen levels, eutrophication, suspended solids, hydrocarbons, acidification, persistent organic compounds, trace elements and radioactive material (Cessford et al., 2005; CSIR, 2010; Du Plessis, Harmse, & Ahmed, 2015). These stressors can impact on the aquatic environment (CSIR, 2010; van Ginkel, 2011; van Ginkel, Hohls, & Vermaak, 2000).

The Bon Accord Dam is one of the smallest impoundments in the Crocodile River catchment with a mean and maximum depth of 3.6 m and 7.4 m, respectively (Hart & Harding, 2015). The dam is found about 15 km north of central Pretoria, just north of the N4 highway. It is an earth-fill type dam that is fed by the Apies River, which enters in the south-eastern corner as well as a small flow in the south-western corner. The dam was completed in 1925 to supply irrigation water to areas for vegetable farming (Department of Water Affairs and Forestry, South Africa [DWAF], 2008).

Small-scale farmers north of the dam use the water extensively for irrigation and hence its quality is of importance. The natural supply is supplemented by stormwater runoff from the canalized Apies River, as well as industrial and domestic effluent from the municipality. The Daspoort Waste Water Treatment Plant, initiated in 1906, is the major source of the Dam, particularly during the dry season (van Ginkel, 2007; van Ginkel et al., 2000). Despite its age, Wilsenach et al. (2014) found that the trickling filters used in the treatment plant still remove nitrogen from municipal wastewater most effectively.

There are very few studies in the literature regarding Bon Accord Dam and those can be found focused on eutrophication levels (Grobler & Silberbauer, 1985; van Ginkel, 2007; van Ginkel et al., 2000). Grobler and Silberbauer (1985) reported that more strict standards will be required for the Bon Accord Dam with respect to eutrophication. Supporting the previous findings, van Ginkel et al. (2000) reported that Bon Accord Dam was the fifth most eutrophic system in South Africa suggesting further reductions in phosphorus input in the reservoir. In another study, van Ginkel (2007) investigated the applicability of ecological informatics modeling techniques for predicting harmful algal blooms in hypertrophic reservoirs of South Africa, which was Bon Accord Dam. Despite the eutrophication level of the Dam, no studies could be found reporting the elemental, physicochemical and microbial levels of Bon Accord Dam. Therefore, this study focused on the determination of microbiological loads and water-soluble anions (F^- , Cl^- , NO_2^- , Br^- , NO_3^- , SO_4^{2-} and PO_4^{3-}) in water samples, and elemental concentration (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Ni, Pb, Se, Sr, V, U and Zn) of water and sediment samples from Bon Accord Dam, South Africa.

2. Materials and methods

2.1. Reagents

All reagents were analytical grade and doubly de-ionized water (18.2 M Ω /cm, Millipore, France) was used. For digestion of sediment samples, 40% HF (suprapur®) and 65% HNO₃ (suprapur®) were obtained from Merck KGaA, Darmstadt, Germany, 32% HCl (AAR®) was obtained from SMM Instruments, South Africa; H₃BO₃ (AR) was from Bio-Zone Chemicals, South Africa. Argon gas (>99.999% purity) and methane gas (>99.95% purity) were purchased from African Oxygen Limited (Afrox, Pretoria, South Africa) while helium gas (BIP®Technology 99.9997% purity) was purchased from Air Products South Africa (Pty) Ltd, (Pretoria, South Africa). Multi-element ICP-MS calibration standard containing Ag, Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Ni, Pb, Se, Sr, V, U and Zn (10 μ g/mL each, atomic spectroscopy standard) were purchased from PerkinElmer, USA.

2.2. Instrumentation

The pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO) and temperature were measured *in situ* using an HQ40d portable multi-parameter meter (Hach Lange GmbH, Germany). The sediment samples were digested using the Microwave Accelerated Reaction System (MARS®, CEM Corporation, USA). An ion chromatographic instrument (Metrohm AG, Herisau, Switzerland) was used for the determination of water-soluble anion (F^- , Cl^- , NO_2^- , Br^- , NO_3^- , SO_4^{2-} and PO_4^{3-}). A NexION® 350D ICP-MS instrument (PerkinElmer Inc., Waltham, USA) equipped with an autosampler was used for the determination of Ag, Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Ni, Pb, Se, Sr, V, U and Zn in the water and sediment samples. The instrument features quadrupole-based Universal Cell Technology (UCT™), allowing the device to be run in three modes (standard, collision or reaction mode). For Li, Pb, Sr and U, the assays were run in standard (STD) mode; for Ag, Ba, Ca, Cd, Hg, K, Se and Zn run with dynamic reaction cell (DRC using methane gas) mode; and Al, As, Co, Cu, Cr, Fe, Mg, Mn, Ni and V were determined using kinetic energy discrimination (KED with helium) mode. A triple nickel cone interface and a quadrupole ion deflector permitted a tightly focused ion beam. The spectrometer was monitored with software Syngistix™ for ICP-MS. The sample introduction system consisted of a glass cyclonic spray chamber and a glass concentric nebulizer. The ICP-MS operating conditions are summarized in Table 1.

Table 1. The ICP-MS NexION® 350D operating conditions for the analysis of selected elements in water and sediment samples of Bon Accord Dam, South Africa.

Parameters	Settings/Optimized values
ICP RF power	1500 W
Nebulizer gas flow (Ar)	0.88 L/min
Auxiliary gas flow (Ar)	1.20 L/min
Plasma gas flow (Ar)	18.00 L/min
Deflector voltage (Ar)	-12.00 V
Analog stage voltage	-1675.00 V
Pulse stage voltage	950.00 V
STD mode cell entrance/exit voltage	-3.00
KED mode cell entrance voltage	-9.00
KED mode cell exit voltage	-33.00
KED cell gas A	4.00
KED RPq	0.25
Cell gas A (KED)	0.10
DRC mode cell entrance/exit voltage (DRC)	-6.00
Sweeps per reading	20
Reading per replicate	1
Number of replicates	3
Detector mode	Dual
Scanning mode	Peak hopping
Integration time	1000 ms
Dwell time per AMU	50 ms

2.3. Sample collection

The water and sediment samples were collected from five sampling sites at Bon Accord Dam three times during 2015 and 2016. At each site surface, sediment samples (0–5 cm) were collected according to the methods described in the United States Environmental Protection Agency (US EPA, 2001) using an Auger and emptied into polyethylene bags. The water samples were collected just below the surface in 2.5 L high-density polyethylene containers. The bottles were first rinsed three times with water from the specific site before the water sample was taken. The water samples for elemental analysis were preserved with concentrated HNO₃. All samples were placed in a cooler box, transported to the laboratory and refrigerated in the laboratory prior to analysis.

2.4. Microbiological analysis

The total coliform and *Escherichia coli* (*E. coli*) in the water samples were analyzed using Compact Dry EC plates (Nissui Pharmaceutical Co., Ltd., Japan). The plates were originally pre-sterilized and contained a cold water-soluble gelling agent and nutrients supplemented with selective substrates that develop red/pink color for coliform and white blue/blue color for *E. coli*. The center of the dry sheet of the plate was inoculated with 1 mL of the sample and the lid of the plate replaced. The medium was incubated for 24 h at 35 ± 2°C after which the coliforms and *E. coli* were counted.

2.5. Sample preparation for elemental analysis

Following Animal and Plant Health Agency (APHA, 2005) protocols, the water samples for elemental analysis was passed through 0.45 µm pore size membrane filters (Pall Corporation, Mexico). The filtrate was transferred to clean acid-washed polyethylene tubes and analyzed by ICP-MS (Table 1). The concentrations of the elements were determined by external mixed calibration standards. A portion of the water sample was passed through 0.45 µm pore size membrane filters with no additives for anions analysis using ion chromatography. Anion separation was carried out

in suppressor mode on a Metrosep A Supp 4 analytical column (250 mm × 4.0 mm) connected, in series, with a Metrosep A Supp 4/5 guard column (50 mm × 4.0 mm). A solution containing a mixture of 1.7 mmol/L NaHCO₃ and 1.8 mmol/L Na₂CO₃ and 5% acetone (flow rate - 1 mL/min) was used as eluent with an injection volume of 20 µL. The quantification of the anion concentrations was carried out using external mixed calibration standards.

The sediment samples were freeze-dried using a CRYODOS-80 laboratory freeze dryer (Telstar Industrial S.L., Terrassa, Spain), sieved to separate shells and stone, homogenized with an agate mortar and passed through a 2 mm sieve and then through a 600-micron sieve before storing for further analysis. The dried sediment samples were digested according to the Environmental Protection Authority digestion method (EPA Method 3052): about 0.25 g of freeze-dried sediment samples were weighed into a Teflon inset of a microwave digestion vessel and 9 mL 32% HCl, 3 mL 65% HNO₃ and 2 mL 40% HF were added in that order. They were digested using at 1600 W power, ramped to 175°C in 20 min, hold for 10 min and allowed to cool for 15 min. To the cool digest, 1 mL of saturated H₃BO₃ was added and the digestion was continued using the same program. The solution was made up to 50 mL with de-ionized water, and the elemental analyses were carried out using ICP-MS with external calibration. Analytical blanks were prepared and analyzed in the same way.

2.6. Quality control

Quality control and assurance protocols were followed with each batch of samples through the inclusion of blanks, certified reference material and standard calibration runs. All sediment and water samples were analyzed, and the %RSD for triplicate reading for each measurement was ≤10%. The calibration was carried out using matrix-matched calibration standards. Analytical accuracy for sediment samples was determined using a certified reference material for stream sediments (NCS DC73308, China National Analysis Center for Iron & Steel, China). Procedural blank and an intermediate standard were run, and the concentrations of elements were determined between each batch of 15 water or sediment samples to assess the method accuracy. Method precision was controlled by re-determining randomly selected replicate samples. Good agreement was obtained between the determined element concentrations, in the certified reference material, procedural blank and intermediate standards, with percentage recoveries of ≥90%. The %RSD of the randomly selected replicate samples was acceptable (≤10%).

2.7. Statistical analysis

The statistical analyses were done using SPSS software (SPSS 16.0.0., TEAM EQX, SPSS Inc., Polar Engineering and Consulting, USA, 2007), OriginPro 8.5.0 SR1 (OriginLab Corporation, Northampton, USA) and Microsoft Excel. An analysis of variance (ANOVA) was performed to compare the means and statistical significance was considered for $p < 0.05$. A correlation matrix was also performed so as to investigate the association between the analyzed elements in the sediment samples.

3. Results and discussion

3.1. Microbiological quality of the water of Bon Accord Dam

The various water sources used for irrigation can be ranked due to hazards resulting from microbial contamination. If the irrigation water is considered as a high risk for pathogen contamination, the microorganism causing plant disease or human food-borne illness can easily enter the system (Villanueva et al., 2015). The population densities of heterotrophic and indicator bacteria are commonly used as indices for microbial water quality (Alonso et al., 2006; Becerra-Castro et al., 2015; Bezuidenhout, Mthembu, Puckree, & Lin, 2002; Vergine et al., 2015).

The microbiological quality of the Bon Accord Dam is summarized in Table 2. The World Health Organization (World Health Organization [WHO], 1989, 2006) guideline permits up to 1000 CFU/100 mL for water used during unrestricted irrigation of fresh fruit and vegetables. The Bon Accord Dam is less contaminated, however, on sites 1 and 4, the presence of *E. coli* was observed. The

Table 2. Microbiological loads of water of Bon Accord Dam, South Africa for the third round.

Sampling	<i>E. coli</i>	Total coliform
Site 1	10 ± 1.7	103 ± 2
Site 2	0	76 ± 4.5
Site 3	0	169 ± 20
Site 4	68 ± 2.3	17 ± 0
Site 5	0	96 ± 1.2

South African government does not have guidelines specifying a limit for counts of heterotrophic bacteria present in water to be used for irrigation. However, the DWAF guideline (1996) specifies a value for heterotrophic plate count for safe domestic use smaller than 100 CFU/mL (Gemmell & Schmidt, 2012), which indicates that sites 1 and 3 are above the guidelines for safe domestic use of the water. The primary sources of these bacteria in water could be animal and human wastes, seepage or discharge from septic tanks, sewage treatment facilities and natural soil/plant bacteria (Shittu, Olaitan, & Amusa, 2008). The variation in microbiological quality of the sites could be attributed to the different flow rates of the water into the dam. As the flow rates of the water increases, the chances for microorganisms to remain in the water decreases (Brookes et al., 2004; Jung et al., 2014).

3.2. Physicochemical characteristics of Bon Accord Dam

The physicochemical water quality parameters, namely temperature, pH, salinity, electric conductivity (EC), total dissolved solid (TDS) and dissolved oxygen (DO) are the most commonly used water quality parameters (Hellar-Kihampa, de Wael, Lugwisha, & van Grieken, 2013). The physicochemical values of the water samples of Bon Accord Dam are reported in Table 3. The obtained values were also compared with national (target water quality range/value, Department of Water Affairs and Forestry, South Africa [DWAF], 1996) and international standards (WHO, 2006). The measured physicochemical parameters, except DO, had an RSD <10%. The pH of the water of Bon Accord Dam was found to be between 8.18 and 8.62, 6.89 and 7.41 and 7.64 and 8.76 for first, second and third round, respectively, with an average value of 8.39, 7.14 and 8.16, in that order (Table 3). According to DWAF guidelines (1996), irrigation water can be grouped into three classes: pH < 6.5, pH between 6.5 and 8.4 and pH > 8.4. Accordingly, some of the sites in the first and third round have pH > 8.4 which could affect the crop yield and quantity, while the other sites and the average reading of the Dam were in the target water quality range for irrigation water (Ayers & Westcot, 1985; DWAF, 1996).

The water temperature recorded during the sampling periods ranged from 13.0°C to 15.7°C, 20.1°C to 23.6°C and 15.8°C to 17.5°C for first, second and third round, respectively, with an average of 14.6°C, 21.8°C and 15.8°C, in that order. There is no guideline value for temperature; however, it is a factor of great importance for aquatic ecosystem, as it affects the organisms, the physical and chemical characteristics of water. Temperature exerts a strong influence on many physical and chemical characteristics of water, including the solubility of oxygen and other gases, chemical reaction rates, toxicity and microbial activity (Dallas & Day, 2004). Higher temperatures reduce the solubility of dissolved oxygen in water, decreasing its concentration and thus its availability to aquatic organisms (Dallas, 2008).

According to Bauder, Waskom, Sutherland, and Davis (2014), irrigation water with EC of ≤750 μS/cm is rated as excellent and can be used for irrigation purpose without restriction. The EC of the water from the sites of Bon Accord Dam varied between 499 and 580 μS/cm, 420 and 433 μS/cm and 354 and 396 μS/cm for first, second and third round, respectively, with an average reading of 534 μS/cm, 425 μS/cm and 374 μS/cm in that order, and could be classified as excellent and may be used for irrigation. These values were also within the guidelines of the WHO (2006) for EC in

Table 3. The physicochemical values of the water samples of Bon Accord Dam, South Africa in comparison with national (target water quality range/value, DWAF, 1996) and international standards (WHO, 2006).

Sampling	pH			EC, $\mu\text{S/cm}$			TDS, mg/L		
	Round			Round			Round		
	First	Second	Third	First	Second	Third	First	Second	Third
Site 1	8.18	ND*	8.45	545	ND	375	285	ND	193
Site 2	8.62	7.12	7.64	580	420	378	275	213	195
Site 3	8.20	7.12	8.76	501	422	354	256	213	182
Site 4	8.56	6.89	7.86	499	433	367	253	220	189
Site 5	8.38	7.41	8.09	547	426	396	300	215	204
Mean	8.39	7.14	8.16	534	425	374	274	215	193
%RSD	2	3	6	6	1	4	7	2	4
WHO	6.5–8			<700			450		
DWAF	6.5–8.4			-			40		
	DO, mg/L								
Site 1	139	ND	122	15.6	ND	17.5			
Site 2	127	82.2	51.5	15.7	23.6	17.0			
Site 3	78.2	62.5	104	13.9	21.7	16.3			
Site 4	100	**	61.9	14.6	20.1	17.1			
Site 5	40.4	69.1	91.5	13.0	21.7	15.8			
Mean	96.9	71.3	86.3	14.6	21.8	16.7			
%RSD	41	14	34	8	7	4			

ND*—Not determined due to bad weather conditions to access the sampling site; -**—no dissolved oxygen reading due to the site being covered by weeds.

irrigation water ($\leq 700 \mu\text{S}/\text{cm}$). However, according to Water Research Commission (WRC, 2010), an EC of the water between 500 and 750 $\mu\text{S}/\text{cm}$ can be considered as medium salinity where sensitive crops will be influenced (the edges of the leaves appear scorched or the loss of the leaves occurred). In addition, according to DWAF (1996), if the EC > 540 the waters can still be used for irrigation of selected crops provided sound management is practiced and smaller yields are acceptable. Therefore, the water from the dam could have a negative effect on some crops.

The TDS of water of Bon Accord Dam, which gives an indication of the salinity of the water, ranged from 253 to 330 mg/L, 213 to 220 mg/L and 182 to 204 mg/L for first, second and third round, respectively, with an average reading of 274 mg/L, 215 mg/L and 193 mg/L, in that order. The WHO (2006) recommends that the TDS should be less than 450 mg/L indicating that the water from the dam is well below the threshold. According to DWAF (1996), the water in contact with Paleozoic and Mesozoic sedimentary rock formations is generally in the range of 195–1100 mg TDS/L, which could be the reason for the TDS values of the current study. The DO levels of the water of the dam ranged from 40.4 to 139 mg/L, 62.5 to 82.2 mg/L and 51.5 to 122.4 mg/L for the first, second and third round, respectively. The high DO observed in the water of the dam could be the result of macroalgal photosynthesis (Nezlin, Kamer, Hyde, & Stein, 2009). With respect to the sampling time, the highest values were observed during the first round (except temperature). When considering the average reading of all the rounds, the measured physicochemical parameters were within the national and/or international guidelines for irrigation water even if some of the parameters may have a negative impact on selected crops.

3.3. Water-soluble anions in the Bon Accord Dam

In the determination of water-soluble anions of Bon Accord Dam, the peaks were resolved and reproducible (RSD < 5%). The reproducibility of chromatographic peak areas expresses as %RSD varied from 0.572 to 4.23 (Table 4). Applying the selected parameters, the method is well-suited for the routine determination of these anions in water samples. The calibration plots of the peak area against anion concentrations were linear in the range 1–32 mg/L with good correlation coefficients ($R \geq 0.9996$). The limits of detection (LOD) ranged from 0.003 (NO_2^-) to 0.010 (SO_4^{2-}) mg/L.

The concentration of the major anions in the water samples of Bon Accord Dam are reported in Table 5. The measured water-soluble anion concentrations were also compared with national (target water quality range/value, DWAF, 1996) and international standards (WHO, 2006). For irrigation water, WHO has no limit for NO_2^- and Br^- (Ayres and Westcost 1985; WHO, 2006), while the South African government has only guidelines for irrigation water quality for F^- , Cl^- and NO_3^- (DWAF, 1996). The F^- concentrations of the water of the Dam were less than the maximum permissible values of both national (DWAF, 1996) and international guidelines (WHO, 2006). The Cl^- concentrations of the water of the Dam were less than the maximum of 100 mg/L

Table 4. The order of elution, retention time, LOD and correlation coefficient for the determination of water-soluble anions of Bon Accord Dam.

No.	Analyte	Retention time, min	LOD, mg/L	RSD, %	Correlation coefficient (R)
1	Fluoride, F^-	3.63	0.005	0.572	0.999993
2	Chloride, Cl^-	4.99	0.019	2.29	0.999890
3	Nitrite, NO_2^-	5.73	0.003	0.83	0.999986
4	Bromide, Br^-	6.92	0.003	0.99	0.999980
5	Nitrate, NO_3^-	7.67	0.009	1.85	0.999926
6	Phosphate, PO_4^{3-}	10.0	0.005	4.23	0.999696
7	Sulfate, SO_4^{2-}	15.2	0.010	1.91	0.999919

Table 5. Water-soluble anion levels (mean, mg/L) of Bon Accord Dam, in comparison with national (DWAF, 1996) and international standards (WHO, 2006).

Sampling	F ⁻ mg/L			Cl ⁻ mg/L			NO ₂ ⁻ mg/L		
	Round			Round			Round		
	First	Second	Third	First	Second	Third	First	Second	Third
Site 1	0.098	ND	0.321	64.9	ND	39.0	0.077	ND	0.310
Site 2	0.109	0.279	0.352	66.3	43.4	39.2	0.095	<0.003	0.648
Site 3	0.032	0.270	0.350	65.8	42.6	38.2	<0.003	<0.003	1.32
Site 4	0.031	0.265	0.358	65.4	43.3	39.1	<0.003	<0.003	
Site 5	0.345	0.452	0.656	66.0	30.7	21.4	<0.003	<0.003	0.361
Mean	0.123	0.316	0.407	65.7	40.0	35.4	0.086	-	0.660
WHO	1			0-1062			-		
DWAF	2			100			-		
	Br ⁻ mg/L			NO ₃ ⁻ mg/L			PO ₄ ³⁻ mg/L		
Site 1	3.20	ND	0.372	20.6	ND	12.0	21.3	ND	0.149
Site 2	1.61	<0.003	0.267	9.54	2.90	0.944	24.4	11.4	<0.005
Site 3	1.38	<0.003	0.284	9.71	2.23	0.928	24.3	11.3	<0.005
Site 4	1.44	<0.003	0.455	9.15	0.788	0.960	25.5	13.4	<0.005
Site 5	2.88	<0.003	0.464	4.70	3.04	2.21	17.3	10.6	<0.005
Mean	2.10	-	0.368	10.7	2.24	3.41	22.6	11.7	0.030
WHO	-			0-44.3			0-2		
DWAF	-			5.00			-		
	SO ₄ ²⁻ mg/L								
Site 1	70.7	ND	42.1						
Site 2	85.6	41.2	41.4						

(Continued)

Table 5. (Continued)

Sampling	F ⁻ mg/L			Cl ⁻ mg/L			NO ₂ ⁻ mg/L		
	Round			Round			Round		
	First	Second	Third	First	Second	Third	First	Second	Third
Site 3	86.2	41.7	41.8						
Site 4	85.6	50.4	35.8						
Site 5	58.0	39.6	21.5						
Mean	77.2	43.2	36.5						
WHO	0-960								
DWAF	-								

according to South African guidelines for irrigation water, while being close to the value given by DWAF (DWAF, 1996) and within the range established by WHO (2006).

The NO_2^- concentrations varied between 0.086 mg/L (first round) and 0.660 mg/L (third round) while the Br^- concentrations was between 2.10 mg/L (first round) and 0.368 mg/L (third round). For both water-soluble anions, the concentration obtained for the second round were below the LOD. The NO_3^- concentrations of the water were within the WHO (2006) guidelines, but some of the sites for the first and third round sample collection were above the South African guidelines (DWAF, 1996). This could be due to organic waste contamination (Addo et al., 2012), the infiltration of sewage effluents, industrial wastes and agricultural production (Chen, Wu, Hu, & Li, 2010). The NO_3^- ion is an essential plant macronutrient; however, in excess it becomes a major concern in irrigation water, because of its stimulatory effect on plant growth and its potential to leach and contaminate groundwater resources (DWAF, 1996).

The PO_4^{3-} concentrations of the water found at most of the sites and, for the first and second round sample collection, were above the concentration limit set by WHO (2006). The levels of PO_4^{3-} in this study were ≥ 0.130 mg/L (except for the third round), making the water in the Dam hypertrophic (DWAF, 2002). Similar observations were reported by Grobler and Silberbauer (1985), van Ginkel et al. (2000) and van Ginkel (2011). Research has clearly identified phosphorus and its compounds, such as PO_4^{3-} , as a potential risk for many forms of irrigation (Turner, Will, Dawes, Gardner, & Lyons, 2013). The sources of the PO_4^{3-} in the dam are usually from point sources, primarily the wastewater-treatment plant and the use of phosphorus detergents. A further reduction in PO_4^{3-} is necessary to decrease the level of eutrophication of Bon Accord Dam. Changes to the treatment of water at Daspoort Waste Water Treatment Plant so as to reduce the PO_4^{3-} and restricting the use of phosphorus detergents could reduce the amount of PO_4^{3-} and therefore the level of eutrophication. During sample collection, the researchers also observed that the weeds were physically removed from the water, which resulted in the reduced concentrations of PO_4^{3-} found in the third round of sample collection.

The SO_4^{2-} concentrations of the water of the Dam were below the WHO (2006) guidelines. In general, the order of the concentrations of the water-soluble anions was $\text{SO}_4^{2-} > \text{Cl}^- > \text{PO}_4^{3-} > \text{NO}_3^- > \text{Br}^- > \text{NO}_2^- > \text{F}^-$. The concentrations of the anions (except PO_4^{3-} and some sites for NO_3^-) in the water samples were below the respective South African guidelines and/or WHO range in irrigation water.

3.4. Elemental concentration in the water samples from the Bon Accord Dam

The accumulation of elements in agricultural land is a serious threat to crop quality and productivity. One main source of elements pollution is untreated wastewater used for irrigation for prolonged periods (World Health Organization/Food and Agriculture Organization [WHO/FAO], 2007). Long-term wastewater application results in elemental accumulation in the soil to toxic levels, which in turn leads to the degradation of soil productivity and crop plant toxicity. The elemental concentrations in the water samples of Bon Accord Dam are presented in Table 6. In the samples, the amount of Ag, As, Cd, Co, Cr, Hg, Li, Pb, Se and U were below the limit of detection, while the general concentration trend for the rest of the elements was $\text{Mg} > \text{Ca} > \text{K} > \text{Fe} > \text{Al} > \text{Sr} > \text{Mn} > \text{Ba} > \text{Zn} > \text{V} > \text{Cu} > \text{Ni}$.

The maximum concentration values of Mg and Ca in the water samples of each site and round did not exceed the recommended values set by FAO guidelines, namely 60.8 mg/L and 401 mg/L, respectively (Ayers & Westcot, 1985). In Mg dominated water (ratio of $\text{Ca}/\text{Mg} < 1$, which is the case in this study), the potential effect or damage of Na may be slightly increased (Ayers & Westcot, 1985). Besides this, the soil being irrigated with high Mg water will be less productive due to Mg-induced deficiency (Ayers & Westcot, 1985). Even if K is considered as a nutrient, its concentration was generally above the guideline range for irrigation water of 0–2 mg/L (Ayers & Westcot, 1985). Although Fe is not toxic to plants irrigated with water with high concentrations of that element,

Table 6. Elemental concentration (Mean±SD, mg/L; N = 3) of water samples from Bon Accord Dam in comparison with national and international standards.

Sampling	Al			Ba			Ca		
	Round			Round			Round		
	First	Second	Third	First	Second	Third	First	Second	Third
Site 1	0.003 ± 0.000	< 0.006	0.283 ± 0.007	0.050 ± 0.002	< 0.0003	0.147 ± 0.006	13.5 ± 0.63	22.2 ± 0.43	21.2 ± 0.09
Site 2	< 0.006	0.007 ± 0.001	0.733 ± 0.067	0.067 ± 0.003	0.040 ± 0.000	0.153 ± 0.015	16.9 ± 0.57	16.2 ± 0.14	20.9 ± 0.12
Site 3	< 0.006	0.080 ± 0.000	0.553 ± 0.045	0.060 ± 0.003	0.043 ± 0.003	0.143 ± 0.012	16.6 ± 0.60	15.9 ± 1.3	17.7 ± 0.24
Site 4	< 0.006	< 0.006	1.73 ± 0.052	0.087 ± 0.003	0.050 ± 0.000	0.170 ± 0.013	15.9 ± 0.66	18.7 ± 0.84	20.5 ± 1.6
Site 5	< 0.006	0.170 ± 0.010	0.390 ± 0.013	0.067 ± 0.001	0.063 ± 0.006	0.180 ± 0.000	8.49 ± 0.20	18.1 ± 0.89	23.7 ± 0.32
Mean	0.001	0.051	0.737	0.066	0.039	0.159	14.3	18.2	20.8
WHO	5.0								
DWAF	5.0								
	Cu			Fe			K		
Site 1	< 0.001	0.060 ± 0.005	0.013 ± 0.001	< 0.0002	0.010 ± 0.000	0.300 ± 0.017	6.87 ± 0.56	0.783 ± 0.015	5.04 ± 0.04
Site 2	< 0.001	0.007 ± 0.001	0.010 ± 0.000	< 0.0002	< 0.0002	0.993 ± 0.064	6.34 ± 0.58	5.16 ± 0.05	6.44 ± 0.15
Site 3	< 0.001	0.007 ± 0.001	0.007 ± 0.001	< 0.0002	0.167 ± 0.006	0.513 ± 0.038	5.68 ± 0.24	4.69 ± 0.31	5.41 ± 0.08
Site 4	< 0.001	< 0.001	0.020 ± 0.000	< 0.0002	0.003 ± 0.000	5.223 ± 0.312	6.93 ± 0.62	5.72 ± 0.23	5.72 ± 0.19
Site 5	< 0.001	0.010 ± 0.000	< 0.001	< 0.0002	0.233 ± 0.004	0.277 ± 0.011	7.02 ± 0.70	5.65 ± 0.40	2.54 ± 0.05
Mean	-	0.017	0.010	-	0.083	1.46	6.57	4.40	5.03
WHO	0.20								
DWAF	0.20								
	Mg			Mn			Ni		
Site 1	53.4 ± 5.19	43.9 ± 0.76	40.6 ± 0.7	< 0.0001	< 0.0001	0.480 ± 0.030	0.003 ± 0.0001	< 0.0001	0.007 ± 0.0006
Site 2	48.9 ± 4.20	34.4 ± 0.20	44.5 ± 1.0	< 0.0001	< 0.0001	0.237 ± 0.012	0.007 ± 0.0005	< 0.0001	0.010 ± 0.000
Site 3	45.3 ± 1.71	34.1 ± 3.4	42.1 ± 0.7	< 0.0001	0.053 ± 0.004	0.467 ± 0.039	< 0.0001	0.010 ± 0.000	0.003 ± 0.000

(Continued)

Table 6. (Continued)

Sampling	Al			Ba			Ca		
	Round			Round			Round		
Site 4	36.1 ± 3.21	38.7 ± 2.6	41.6 ± 1.5	< 0.0001	< 0.0001	0.373 ± 0.021	0.010 ± 0.000	< 0.0001	0.040 ± 0.002
Site 5	76.6 ± 5.83	38.4 ± 2.3	55.0 ± 0.2	< 0.0001	0.140 ± 0.010	0.340 ± 0.027	0.003 ± 0.0003	0.010 ± 0.000	0.007 ± 0.0001
Mean	52.0	37.9	44.8	-	0.039	0.379	0.005	0.004	0.013
WHO	0-60.8			0.20			0.20		
DWAF	-			0.20			0.20		
	Sr			V			Zn		
Site 1	0.143 ± 0.010	0.033 ± 0.003	0.113 ± 0.006	0.010 ± 0.000	< 0.0001	0.010 ± 0.000	< 0.0001	0.310 ± 0.026	0.157 ± 0.015
Site 2	0.140 ± 0.010	0.100 ± 0.000	0.117 ± 0.006	0.013 ± 0.0004	0.010 ± 0.000	0.003 ± 0.0002	0.017 ± 0.001	0.013 ± 0.001	0.163 ± 0.015
Site 3	0.130 ± 0.010	0.097 ± 0.008	0.107 ± 0.006	0.010 ± 0.000	0.010 ± 0.000	0.010 ± 0.000	0.027 ± 0.002	0.033 ± 0.002	0.157 ± 0.002
Site 4	0.153 ± 0.015	0.107 ± 0.010	0.123 ± 0.006	0.010 ± 0.001	0.010 ± 0.000	0.040 ± 0.002	0.027 ± 0.003	< 0.0001	0.173 ± 0.003
Site 5	0.267 ± 0.021	0.160 ± 0.010	0.177 ± 0.006	0.023 ± 0.002	0.020 ± 0.000	0.020 ± 0.000	0.003 ± 0.0003	0.030 ± 0.002	0.127 ± 0.006
Mean	0.167	0.099	0.127	0.013	0.010	0.017	0.015	0.077	0.155
WHO	-			0.10			2.0		
DWAF	-			-			1.0		

the Fe can contribute to soil acidification and loss of availability of some essential elements (such as P and Mo) (Ayers & Westcot, 1985).

The maximum concentration of Al set by WHO (Ayers & Westcot, 1985) and DWAF guidelines (1996) for irrigation water is 5 mg/L in both cases, while for Mn it is 0.20 and 0.02 mg/L, respectively. The Al and Mn concentrations in the water were below both these values. However, Al can cause non-productivity while Mn is toxic to a number of crops even at low concentration (Ayers & Westcot, 1985). There are no irrigation water guideline values for Ba and Sr set by WHO (Ayers & Westcot, 1985) or South Africa (DWAF, 1996). The V concentration in the water samples was slightly higher than the maximum value given by WHO guidelines (Ayers & Westcot, 1985) and South Africa (DWAF, 1996), which could result in adverse toxic effects to many of the plants irrigated with the water. Even if the concentration of Zn, Cu and Ni were below the maximum concentration set by WHO (Ayers & Westcot, 1985) and DWAF guidelines (1996) for irrigation water, these elements are toxic to a number of plants at varying concentration (Ayers & Westcot, 1985). Therefore, the use of water from the Bon Accord Dam for irrigation purposes needs to be applied with caution.

3.5. Elemental concentration in the sediment samples from the Bon Accord Dam

The elemental concentrations in the sediments of Bon Accord Dam are summarized in Table 7. In the sediment samples, the overall concentration trend of the elements was Fe > Al > Mn > Mg > Ca > K > Cr > Sr > V > Ni > Zn > Co > Cu > Pb > Ba > Li > U > As, while Ag, Cd, Hg and Se were below the limit of detection. The increase in the concentration of elements beyond their toxicity limits results in loss of water quality, making the water unfit for drinking, irrigation, aquaculture and recreational purposes (Nazeer et al., 2014). Numerical sediment quality guidelines (SQGs) have been used to identify the concern of elemental contaminants in the aquatic ecosystem (Harikumar, Nasir, & Rahman, 2009; MacDonald, Ingersoll, & Berger, 2000). Based on the SQG of US EPA, the sediments could be classified as non-polluted, moderately polluted and heavily polluted (Harikumar et al., 2009; Perin et al., 1997). The average concentration of potentially toxic elements in the sediments of Bon Accord Dam was found to be moderately to heavily polluted by Cr and Ni, non-polluted to moderately polluted by Cu and non-polluted by Pb and Zn.

The ecotoxicological sense of potentially toxic elements contamination in sediments was determined using SQGs, i.e., the “effects” data. According to SQGs, the toxic elements Ag, As, Cd and Hg in the sediment of Bon Accord Dam were less than the effect range low (ERL) value (Long, Macdonald, Smith, & Calder, 1995). Therefore, the incidences of biological effects are rare with respect to the selected elements. For Cu and Zn the sampling sites were found to have less than the ERL and were between ERL-ERM (effect range medium) ranges, which indicate possible contamination. For Cr and Ni, the concentrations found were less than ERL, between ERL-ERM and greater than ERM ranges (Long et al., 1995), which indicates possible contamination and also the study area could be toxic to aquatic organisms and therefore require strict policy measures so as at least to decrease the status of contamination. Furthermore, these metals could be released to the water column through sediment re-suspension, adsorption-desorption, reduction-oxidation reactions and the action of degrading organisms, which possibly could be the reason for the presence of some of the elements in the water samples (Barakat, El Baghdadi, Rais, & Nadem, 2012).

A correlation matrix is one of the statistical approaches useful for investigating associations between variables by presenting the overall coherence of the dataset, in this case between the concentration of elements in the sediment samples (Chen, Jiao, Huang, & Huang, 2007; Helena et al., 2000). A matrix was used to identify correlations between the 16 elements. Strong positive correlations ($p < 0.01$) with coefficients varying from 0.440 (Co-Cr) to 0.932 (Fe-V) (highlighted in bold and italics in Table 8) between each pair of elements where the highest (≥ 0.700) for the pairs Cr-Ni, As-K, Li-Pb, K-Mg, Ba-K, Al-Fe, Ba-Mg, Al-Li, Co-Mn, Co-V, Co-Ni, Ni-V, Fe-Ni, Co-Fe and Fe-V,

Table 7. (Continued)

Sampling	Al			As			Ba		
	Round			Round			Round		
	First	Second	Third	First	Second	Third	First	Second	Third
Site 4	5.62 ± 0.214	12.3 ± 0.197	52.8 ± 1.31	12,693 ± 169	28,269 ± 2795	48,330 ± 938	13.0 ± 0.238	55.4 ± 2.14	311 ± 11.6
Site 5	8.23 ± 0.114	21.4 ± 0.302	28.7 ± 2.27	6842 ± 640	14,188 ± 197	16,925 ± 193	12.9 ± 0.180	25.0 ± 0.597	122 ± 2.13
Mean	7.85	12.8	35.7	12,513	23,796	45,249	16.5	47.9	502
SQG	34–270			-			-		
Sampling	Li			Mg			Mn		
	Round			Round			Round		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Site 1	15.1 ± 0.923	ND	35.2 ± 1.08	510 ± 34.1	ND	1864 ± 67.4	374 ± 26.0	ND	1151 ± 12.0
Site 2	4.84 ± 0.116	10.8 ± 0.417	28.1 ± 2.08	342 ± 13.9	400 ± 11.3	1842 ± 89.9	525 ± 43.1	980 ± 11.7	4097 ± 98.9
Site 3	6.84 ± 0.643	9.50 ± 0.116	19.3 ± 1.13	159 ± 3.82	72.3 ± 2.37	471 ± 13.4	204 ± 12.1	184 ± 5.85	430 ± 8.53
Site 4	4.80 ± 0.120	10.7 ± 0.117	15.9 ± 0.190	416 ± 7.63	533 ± 8.11	580 ± 28.8	255 ± 2.60	939 ± 18.1	1396 ± 22.1
Site 5	2.16 ± 0.030	5.45 ± 0.113	6.12 ± 0.061	540 ± 6.09	895 ± 20.97	908 ± 18.4	322 ± 3.78	679 ± 10.5	948 ± 67.3
Mean	6.75	9.11	20.9	394	475	1133	336	695	1604
SQG*	-			-			-		
Sampling	Ni			Pb			Sr		
	Round			Round			Round		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Site 1	24.6 ± 0.247	ND	78.0 ± 3.69	35.7 ± 0.595	ND	49.0 ± 0.836	37.5 ± 0.382	ND	127 ± 1.50
Site 2	35.8 ± 1.51	52.7 ± 1.52	159 ± 2.66	4.72 ± 0.229	18.6 ± 1.28	39.2 ± 1.44	23.7 ± 1.49	40.7 ± 0.515	222 ± 2.79
Site 3	15.9 ± 0.604	64.4 ± 5.00	103 ± 1.04	1.88 ± 4.58	9.38 ± 0.201	15.9 ± 1.15	11.1 ± 0.172	17.8 ± 0.759	44.7 ± 2.32
Site 4	19.0 ± 1.47	53.3 ± 0.666	203 ± 4.89	29.9 ± 2.33	11.3 ± 0.345	21.7 ± 0.708	14.3 ± 0.263	60.5 ± 0.732	60.7 ± 1.40
Site 5	15.0 ± 0.967	31.5 ± 0.521	38.1 ± 0.399	0.095 ± 0.003	3.36 ± 0.196	11.3 ± 0.350	44.2 ± 0.669	141 ± 9.68	173 ± 9.72

(Continued)

Table 7. (Continued)

Sampling	Al			As			Ba		
	Round			Round			Round		
	First	Second	Third	First	Second	Third	First	Second	Third
Mean	22.0	50.5	116	14.5	10.6	27.4	26.2	65.0	126
SQG	20.9–51.6			46.7–218			-		
	V			U			Zn		
Site 1	40.8 ± 0.475	ND	129 ± 4.39	1.94 ± 0.046	ND	2.65 ± 0.116	11.6 ± 0.388	ND	323 ± 18.6
Site 2	35.8 ± 1.12	75.1 ± 1.80	163 ± 10.5	< 0.00003	1.98 ± 0.012	1.99 ± 0.007	3.31 ± 0.115	25.03 ± 0.317	129 ± 4.19
Site 3	23.21.86±	35.2 ± 0.986	75.1 ± 2.48	0.665 ± 0.012	0.663 ± 0.011	1.975 ± 0.003	0.665 ± 0.012	5.97 ± 0.199	35.6 ± 1.05
Site 4	31.5 ± 2.50	77.0 ± 0.840	148 ± 2.85	< 0.00003	1.98 ± 0.013	1.96 ± 0.020	2.63 ± 0.117	19.1 ± 0.414	83.0 ± 2.42
Site 5	18.9 ± 0.925	40.6 ± 0.453	49.3 ± 0.671	< 0.00003	1.97 ± 0.005	1.97 ± 0.019	1.96 ± 0.027	8.52 ± 0.111	14.5 ± 0.405
Mean	30.0	57.0	113	0.522	1.65	2.11	4.04	14.7	117
SQG	-			-			150–410		

*Sediment quality guidelines range values for effect range low (ERL)-effect range medium (ERM) according to Long et al. (1995).

Table 8. Correlations matrix of elements in sediment samples of Bon Accord Dam, South Africa.

	Li	Sr	Pb	U	K	Ba	Mg	Al	V	Cr	Mn	Fe	Ni	Cu	As	Co
Li	1															
Sr	-0.042	1														
Pb	0.721**	0.036	1													
U	0.596**	0.030	0.373*	1												
K	0.091	0.501**	0.348*	0.088	1											
Ba	0.146	0.409*	0.568**	0.009	0.729**	1										
Mg	0.265	0.485**	0.614**	0.079	0.726**	0.803**	1									
Al	0.808**	0.002	0.504**	0.494**	0.157	0.162	0.167	1								
V	0.513**	0.450**	0.370*	0.532**	0.418*	0.345*	0.350*	0.635**	1							
Cr	0.399*	0.018	0.283	0.403*	0.150	0.032	0.117	0.281	0.549**	1						
Mn	0.575**	0.264	0.402*	0.402*	-0.006	-0.004	0.204	0.491**	0.601**	0.277	1					
Fe	0.649**	0.289	0.445**	0.553**	0.258	0.248	0.291	0.794**	0.932**	0.477**	0.685**	1				
Ni	0.521**	0.246	0.299	0.491**	0.194	0.151	0.171	0.615**	0.868**	0.700**	0.641**	0.887**	1			
Cu	0.430*	0.579**	0.316	0.420*	0.308	0.127	0.283	0.301	0.593**	0.602**	0.543**	0.528**	0.631**	1		
As	-0.196	0.385*	0.011	-0.380*	0.715**	0.491**	0.575**	-0.123	0.053	-0.066	-0.18	-0.068	-0.085	0.06	1	
Co	0.516**	0.366*	0.329	0.469**	0.239	0.167	0.276	0.613**	0.864**	0.440**	0.843**	0.901**	0.865**	0.555**	-0.048	1

Bold italics: strong positive correlation coefficients.
 **: Correlation is significant at the 0.01 level (2-tailed).
 *: Correlation is significant at the 0.05 level (2-tailed).

increasing in that order. Helena et al. (2000) affirmed that elements with high correlation coefficients in the waterbody could have similar hydrochemical characteristics in the study area.

4. Conclusions

The elemental, physicochemical and microbiological qualities of the water and sediment of Bon Accord Dam were assessed in this study. The eutrophication problem in the dam still exists and therefore strict follow-up not to dump waste to the dam, and also prevention, remediation and minimizing its eutrophication problem are required since the water is used for irrigation purposes. Other parameters, including bacterial infestations, indicated a healthy dam.

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Competing Interest

The authors declare no competing interests.

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