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Spatiotemporal characterization of water chemistry and pollution sources of the Umhlatuzana, Umbilo and Amanzimnyama River catchments of Durban, KwaZulu-Natal, South Africa

Kavandren Moodley · Srinivasan Pillay · Keshia Pather

Abstract The physical, chemical and microbiological properties of three freshwater systems contributing inflows to the Bayhead Canal of the Durban Harbour: the Umhlatuzana and Umbilo Rivers, and the Amanzimnyama Canal of KwaZulu-Natal, South Africa are presented. Parameters targeted for analysis collectively included pH, total dissolved solids, dissolved oxygen, biological oxygen demand, chemical oxygen demand, conductivity, ammonium ions, phosphorous, sodium ions, sulphur, copper, calcium, magnesium, chromium, aluminium, nickel, lead, vanadium, mercury, potassium ions, *Escherichia coli* and total coliforms. These parameters were analyzed seasonally during the wet and dry seasons in relation to land use change for spatial characterization. Comparisons with relevant South African Water Quality Guidelines for freshwater systems showed that pollution associated with catchment activities was the main factor governing water quality, with nutrient concentrations that frequently exceeded prescribed standards and often rendered the system hypertrophic. In addition, the sanitary state of the rivers across all land use types was shown to be contaminated and polluted. This study also attempted to determine spatiotemporal (dis)similarity in the water quality of sample sites through Principal Components Analysis (PCA) with varimax rotation. Results show that although these systems were separated on the basis of water quality (both spatially and temporally), there were generally no apparent trends in water quality based on specific land use patterns which linked sites across different catchments. In the wet season, a few exceptions were noted for residential sites across the Umbilo and Umhlatuzana catchments and industrial sites across the Amanzimnyama catchment which showed spatial similarity. Finally, the study examined the impacts of the three freshwater systems on the water quality of the Bayhead Canal of the Durban Harbour, and identified the Amanzimnyama Canal as the most influential on heavy metal and microbiological contamination near the confluence.

Keywords PCA · Water quality · Land use · Spatiotemporal characterization · Interpolation · Pollution

Introduction

The concerns of water resource sustainability in the face of climate change and increasing demands have resulted in several process based studies in many countries which attempt to examine the influence of catchment activities on water quantity and quality (Zhou et al. 2004). This is due to the fact that addressing water quantity and quality issues requires knowledge on the ways in which water resources are affected by these changes (Guo et al. 2008; Jahnig and Qinghua 2010).

On a catchment scale, river chemistry is controlled by both natural and anthropogenic factors through diffuse or point pollutants (Ahearn et al. 2005). Gower (1980) identifies a complex system of dynamic interactions, in which river water quality is a product of several interactions between soil, rock and biotic components facilitated by catchment characteristics including geographical location, geology, geomorphology, biogeochemical processes, and the extent of human activity.

However, in recent years, several studies show that human-induced changes, in particular land use management, are

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strongly associated with declining water quality and river chemistry (Bullard 1966; Dauer et al. 2000; Farnsworth and Milliman 2003; Rhodes et al. 2001; Roselli et al. 2009; Wilkinson and McElroy 2007; Weijters et al. 2009). These have further been shown to have profound effects on the integrity of aquatic ecosystems, including the functioning, abundance and biodiversity of aquatic organisms (Allan et al. 1997; Chapin et al. 1997; Harding and Winterbourn 1995; Harding et al. 1998; Osmundson et al. 2002; Quinn et al. 1997; Richards et al. 1997; Wood and Armitage 1997). In general, human activities have strongly influenced water quality by upsetting the natural status quo (Boyd 2000).

The impact of human activities on the natural environment emphasizes the need for careful management of available water sources within the catchment ecosystem. Consequently, a comprehensive study of fluvial water quality is essential. This study attempted to account for seasonal pollutant loading in relation to natural causes and anthropogenic land use and activities of three major catchments contributing to freshwater inflows in the Bayhead Canal of the Durban Harbour—the Umhlatuzana, Umbilo and Amanzimnyama river catchments. In addition, the direct influence of these river systems on the quality of water in the Bayhead Canal of Durban Harbour into which they flow was explored through examination of water quality variables upstream and downstream of the associated confluences. While such characterization serves as a useful indicator for natural and anthropogenic influences on water quality, it may also contribute to water quality management for the broader catchment region on the basis of future land use planning.

Study area

The Umhlatuzana and Umbilo Rivers, and Amanzimnyama Canal are located in the eThekwini municipal area of KwaZulu-Natal, South Africa, at the core of its urban and industrial zone and comprise the three major freshwater systems contributing to inflows of the Bayhead Canal, Durban Harbour through associated canals at the confluence (Fig. 1). The catchments of these systems are cumulatively described as having land use associated with extensive residential, industrial and commercial development, with dispersed and isolated parcels of recreational parks and nature reserves (DEAT 2001). The catchments are also characterized by the presence of four registered wastewater treatment works (WWTW) discharging effluents into the river systems of the Umbilo and Umhlatuzana catchments (MER/ERM 2011). The broader catchment area is characterized by a typical warm sub-tropical climate and experiences an average annual rainfall of 1,054 mm mainly between the summer months of December and February (MER/ERM 2011).

Materials and methods

The locations of the sampling sites were chosen along the Umhlatuzana, Umbilo and Amanzimnyama river catchments in a manner to account for changes in land use practice, and are shown graphically in Fig. 1. As such, sampling sites were systematically sited at the interface of each land use type along the river systems to reflect the potential influence of land use management on water quality. Land use identification and sampling site identification was achieved from the use of topographic maps and aerial photographs, and was validated by ground truthing via site visits. Further sampling was conducted along the Bayhead Canal at regular intervals to assess the effects of the subsequent inflows emanating from each of the fluvial systems. Sample locations appearing in Fig. 1 are described in Table 1 below.

Four field surveys were conducted seasonally between December 2011 and September 2012, and were categorized into wet and dry season sampling. Following reconnaissance survey results which demonstrated near homogeneous mixing due to shallow depths (<1 m) and high turbulence, water samples were collected at approximately mid-depth at each site and were analyzed for several physico-chemical parameters including pH, total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), conductivity (Cond.), ammonium ions (NH_4), phosphorous (P), sodium ions (Na), sulphur (S), copper (Cu), calcium (Ca), magnesium (Mg), chromium (Cr), aluminium (Al), nickel (Ni), lead (Pb), vanadium (V), mercury (Hg), potassium ions (K) and microbiological parameters Escherichia coli (EC) and total coliforms (TC).

Analysis of metal ions (P, Cu, Ca, Mg, Cr, Al, Ni, Pb, V and Hg) was attained through Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES).

An ion-selective electrode system comprising a polyvinylchloride (PVC) membrane sensitive to ammonium ions was used to analyze the concentration of ammonia in the sample (Ngila 2008).

Analysis of sodium and potassium cation concentrations was quantitatively determined using a flame photometer. Concentrations of dissolved oxygen were determined using the Winkler method (Ngila 2008).

Determination of BOD concentrations were obtained by the aerobic decomposition of organic matter within a BOD incubator as outlined by Tomar (1999).

The COD of the sample was measured by the oxygen corresponding to the organic matter susceptible to oxidation by chromic acid following Tomar (1999).

Microbiological analysis was measured using membrane filtration and fermentation techniques as detailed by OECD and WHO (2003).

TDS was measured using an electronic TDS metre.

Fig. 1 Study area with sample locations
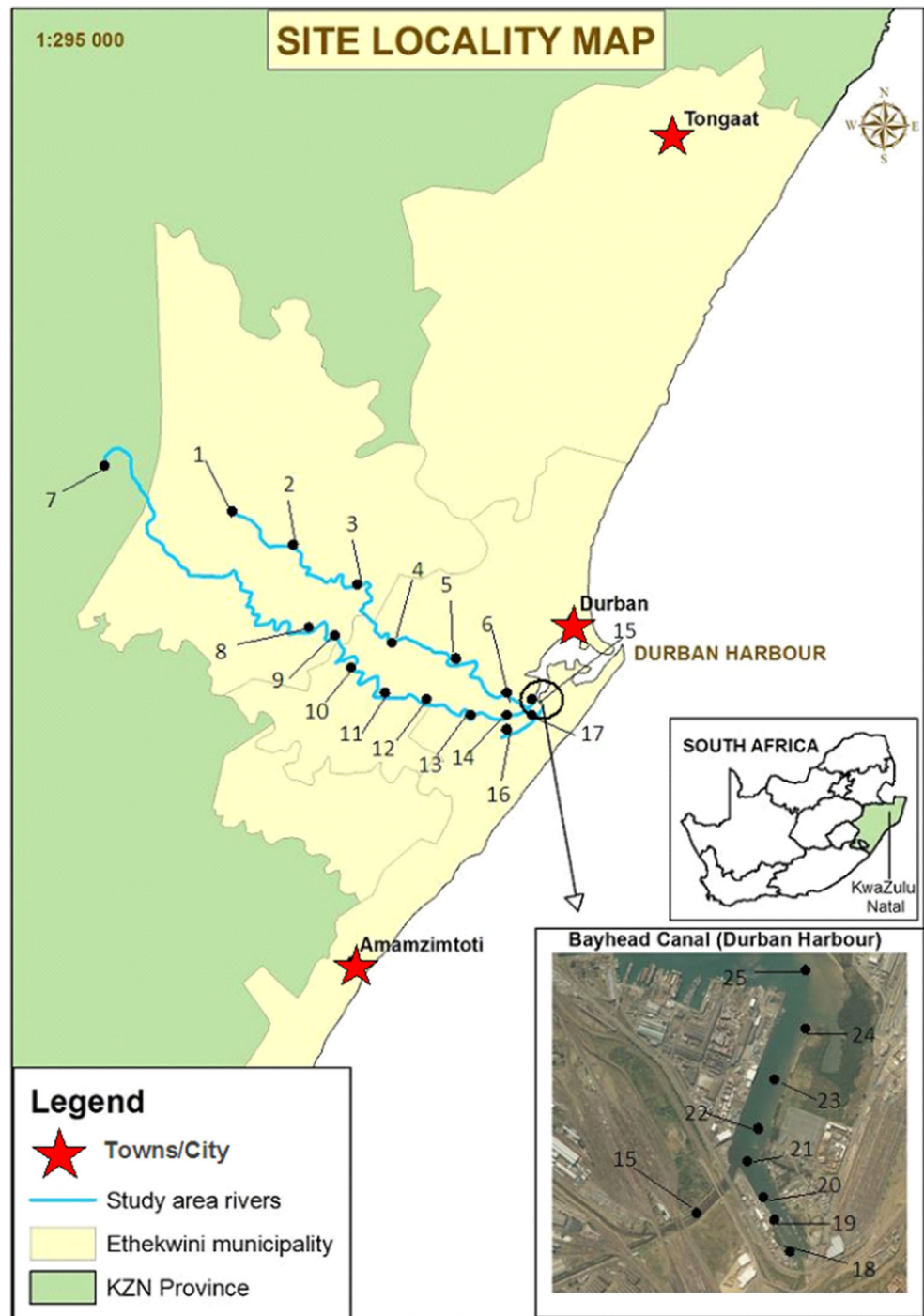
Water quality parameters were compared to the reference standards as outlined by the South African Department of Water Affairs and Forestry (DWAF 1996a, b).

Results and discussion

The variations of parameters defining water quality measured during the dry and wet seasons are illustrated in Table 2.

Statistical analysis

For parameters that were not detected (below detection limit), the values are normally set to half to ensure no missing data in the dataset (Nasir et al. 2011). Principal Component Analysis (PCA) with varimax rotation was used to detect spatiotemporal site variations across river catchments using measured parameters of both seasons (Fig. 3a–c). PCA was performed using the XLSTAT 2014® software.

Table 1 Description of sample locations and corresponding catchment land use types

Site	Site description in relation to land use zones	Coordinates		Distance from source (m)
		Latitude	Longitude	
Umbilo River				
1	Source (sparse residential area)	29°47′35.57″S	30°48′40.27″E	0
2	Interface of industrial and residential area (sited downstream of industrial area)	29°49′46.41″S	30°51′43.51″E	8,194
3	Interface of residential area and nature reserve (sited downstream of residential area)	29°49′54.82″S	30°53′33.02″E	12,873
4	Interface of nature reserve and residential area—also impacted on by WWTW (sited downstream of nature reserve)	29°51′50.78″S	30°55′09.29″E	22,128
5	Interface of residential and industrial area—also impacted on by WWTW (sited downstream of residential area)	29°53′48.95″S	30°58′31.88″E	31,008
6	Interface of industrial area and confluence with Umhlatuzana River (sited downstream of industrial area)	29°54′08.02″S	30°59′44.05″E	32,628
Umhlatuzana River				
7	Source (sparse residential area)	29°45′41.53″S	30°43′27.15″E	0
8	Interface of residential and industrial area—also impacted on by WWTW (sited downstream of residential area)	29°51′18.24″S	30°51′50.90″E	28,300
9	Interface of industrial area and nature reserve (sited downstream of industrial area)	29°51′48.53″S	30°52′27.53″E	31,134
10	Interface of nature reserve and residential area—also impacted on by WWTW (sited downstream of nature reserve)	29°52′28.68″S	30°52′51.28″E	33,468
11	Interface of residential and industrial area (sited downstream of residential area)	29°53′10.19″S	30°53′47.01″E	37,594
12	Interface of industrial area and nature reserve (sited downstream of industrial area)	29°53′44.66″S	30°55′13.67″E	42,440
13	Interface of nature reserve and industrial area (sited downstream of nature reserve)	29°54′26.94″S	30°57′29.74″E	43,960
14	Interface of industrial area and confluence with Umbilo River (sited downstream of industrial area)	29°54′18.17″S	30°59′40.88″E	51,220
Umbilo/Umhlatuzana Canal confluence				
15	Sited at confluence	29°54′10.13″S	31° 00′03.53″E	0
Amanzimnyama Canal				
16	Source (low density industrial area)	29°55′49.49″S	30°58′26.62″E	0
17	Interface of industrial area and confluence to Bayhead Canal (sited downstream of industrial area)	29°54′19.43″S	31°00′31.20″E	4,985
Bayhead Canal of Durban Harbour				
18	Receiving canal of catchment inflows (i.e., inflows from Umbilo, Umhlatuzana and Amanzimnyama catchments) (innermost site)	29°54′12.93″S	31°00′29.08″E	0
19	Receiving canal of catchment inflows	29°54′09.76″S	31°00′25.85″E	266
20	Receiving canal of catchment inflows	29°54′03.71″S	31°00′21.75″E	494
21	Receiving canal of catchment inflows	29°53′54.20″S	31°00′16.40″E	795
22	Receiving canal of catchment inflows	29°53′45.35″S	31°00′24.15″E	1,106
23	Receiving canal of catchment inflows	29°53′36.43″S	31°00′26.52″E	1,480
24	Receiving canal of catchment inflows	29°53′24.12″S	31°00′26.00″E	1,860
25	Receiving canal of catchment inflows (outermost site)	29°53′13.09″S	31°00′36.38″E	2,220

Water quality of the river catchments

The measured water quality parameters at sample sites along the river catchments are depicted in Table 2.

Analytical findings indicated that nutrient water quality determinants (for NH_4, P, Cu) generally fell outside the target freshwater quality range for aquatic ecosystems, rendering the systems as hypertrophic and toxic for human

and animal consumption (DWAF 1996a). Exceptions were noted for P at sites 1, 2, 4–8, 10, 15–17 in the dry season; and Cu at sites 7–14 in the wet season. Decreases in P concentrations during the dry season has been shown to be a direct consequence of low surface runoff emanating from surrounding land use types and the subsequent reduction of nutrient loading into the systems (Shah et al. 2007). The reduction of Cu concentrations at sites 7–14 (Umhlatuzana River) in the wet season was indicative of low geochemical input of the system and in-stream diluting effects as a consequence of higher rainfall in the wet season. In the absence of relevant South African freshwater aquatic ecosystem guidelines for Na concentrations show that the water was unsuitable for human consumption at sites 16 in the wet season, and 17 in both seasons according to DWAF (1996b). These sites were associated with industrial activity and subsequent effluent discharge into the Amanzimnyama Canal. In general, principal inputs of nutrients (NH_4, P, S, Na, K, Mg, Ca and Cu) were often associated with industrial and residential land use (sites 8, 9, 16, 17 for NH_4 in the wet season; site 9 for P in both seasons; sites 3, 5, 6, 14, 16 and 17 for S in both seasons; sites 16 and 17 for Ca and Mg in the wet season; sites 16 and 17 in the dry season for Na and K). The significance of riparian vegetation in controlling general nutrient chemistry of water bodies is well documented in watershed studies. The findings of this study were no different in that the role of nature reserves/riparian habitat (represented by sites 4, 10 and 13) as natural filters in the environment were clearly demonstrated by the reduced concentrations of selected nutrients (particularly NH_4, P and S) detected/measured at these sites across both seasons.

In terms of basic water quality determinants, pH at sites 6 in the dry season, 17 in the wet season, and 14 and 15 across both seasons fell outside the expected range for natural freshwater systems in South Africa (DWAF 1996a). These sites were associated with industrial activity/effluent releases. COD concentrations in surface waters usually occur at values of 20 mg/L or less in unpolluted waters, which implies some degree of pollution at sites 16 and 17 in the dry season (Chapman 1992). The contaminant records at these sites were again associated with industrial effluent discharge into the Amanzimnyama Canal from surrounding industry.

When present, heavy metals (Al, Hg, Pb and Cr) generally exceeded the freshwater target values for aquatic environments as outlined in DWAF (1996a). Similarly, when present, trace metals V and Ni were at concentrations which rendered the water unsuitable for consumption by humans and animals (DWAF 1996b). Hg in the system was detected at industrial sites 2 in the wet season, and sites 9 and 16 in the dry season. The consistent presence of Hg in sites 1–6 (Umbilo River) in the dry season was unknown—possibly relating to the introduction of Hg containing compounds at the source through illegal dumping activities (photographic evidence in Fig. 2). This is further corroborated by the gradual decrease in Hg concentration in the downstream direction from site 1 to site 6. A similar trend is observed for Pb, V and Cr at sites 1–6, however, the possibility of geochemical origin of V and Cr cannot be dismissed as these do not show a downstream decrease in concentration as in the case of Hg and Pb. V, Pb and Cr inputs were also associated with industrial effluent discharge at sites 16 and 17 of the Amanzimnyama Canal.

Microbiological data revealed the poor sanitary state of all three freshwater systems in both seasons (DWA 1996b). Anomalously high combined values of EC and TC were recorded at sites 16 and 17 in the dry season, and sites 11 and 12 in the wet season. High coliform counts are often a common characteristic of residential areas accounting for the high count at site 11. High values are associated with industrial sites 12, 16 and 17, which could be a direct consequence of industrial effluent discharge and some untreated sewage entering the system directly from these sites. The slightly elevated total coliform count at site 10 after the nature reserve in the wet season was reflective of high organic carbon content of runoff water from such areas.

Specific inter-elemental relationships and spatiotemporal variability of water quality at sample sites were explored through multivariate statistics (Principal Component Analysis—PCA with varimax rotation), and depicted in relevant varimax factor bi-plots (Fig. 3a–c).

Spatiotemporal water quality variations

Principal Component Analysis (PCA) with varimax rotation was conducted on physico-chemical data for the dry and wet seasons to determine which parameters contributed significantly to water quality variations in the river catchments. PCA is a powerful pattern recognition technique which attempts to explain the variance of large datasets of inter-correlated variables using a small set of Principal Components (PCs) (Sudevi and Lokesh 2012). The principal components enable the isolation of dominant underlying processes operating within the hydrological systems—including anthropogenic or mineral sources (Ammar and Abderrahmane 2010). Considering the large numbers of variables studied (22), the first two factor loadings were isolated and plotted on the D1–D2 axes planes for greater clarity (Fig. 3a–c) (Parinet et al. 2004). The first two factors cumulatively represented 52.14 % of the total variance for the wet season, 77.37 % of the total variance for the dry season and 45.36 % for combined seasons (Table 3).

Table 2 Variations in water quality parameters for the dry (D) and wet (W) seasons along the river catchments [highlights indicate exceedances of guideline values; NA guideline values not available, a guideline values according to DWAF (1996a), b guideline values according to DWAF (1996b); < parameters below the specified detection limits]

Seasonal parameters	Sites										Precision	DWA Guideline values
	1	2	3	4	5	6	7	8	9	10		
pH												
D	7.56E+00	7.29E+00	7.17E+00	7.70E+00	7.58E+00	8.31E+00	6.96E+00	7.42E+00	6.92E+00	7.25E+00	1.19E-01	6–8a
W	7.57E+00	7.67E+00	7.21E+00	7.33E+00	7.47E+00	7.89E+00	7.75E+00	7.58E+00	7.59E+00	7.54E+00	6.64E-02	
Cond.*												
D	1.58E+02	1.95E+02	8.15E+02	3.61E+02	5.96E+02	5.96E+02	2.54E+02	2.79E+02	4.46E+02	2.94E+02	9.05E+02	NA
W	1.55E+02	2.05E+02	6.17E+02	3.11E+02	5.33E+02	5.01E+02	2.10E+02	2.58E+02	4.87E+02	2.96E+02	1.16E+03	
TDS*												
D	6.80E+01	8.40E+01	3.50E+02	1.55E+02	2.56E+02	2.56E+02	1.09E+02	1.20E+02	1.91E+02	1.26E+02	5.84E+02	NA
W	6.65E+01	8.85E+01	2.65E+02	1.34E+02	2.29E+02	2.16E+02	9.03E+01	1.11E+02	2.09E+02	1.27E+02	1.06E+02	
DO*												
D	8.62E+00	8.69E+00	8.48E+00	8.47E+00	8.69E+00	8.62E+00	8.42E+00	8.64E+00	8.56E+00	8.68E+00	2.53E-02	NA
W	7.05E+00	7.07E+00	7.07E+00	7.09E+00	7.07E+00	7.10E+00	7.20E+00	7.25E+00	7.02E+00	7.58E+00	4.29E-02	
BOD*												
D	3.52E+00	3.53E+00	3.52E+00	3.56E+00	3.54E+00	3.48E+00	3.41E+00	3.39E+00	3.27E+00	3.38E+00	1.78E-02	NA
W	6.84E+00	5.82E+00	5.33E+00	5.14E+00	5.37E+00	5.08E+00	1.99E+00	1.60E+00	1.51E+00	1.51E+00	5.38E-01	
COD*												
D	6.74E+00	7.22E+00	7.42E+00	6.06E+00	8.04E+00	6.38E+00	8.90E+00	7.44E+00	9.10E+00	9.00E+00	1.47E+00	NA
W	3.47E+00	6.64E+00	7.08E+00	4.67E+00	3.13E+00	7.01E+00	1.34E+01	1.22E+01	1.47E+01	7.41E+00	8.60E-01	
Na*												
D	<1.40E-02	<1.40E-02	2.92E+00	<1.40E-02	<1.40E-02	<1.40E-02	<1.40E-02	<1.40E-02	<1.40E-02	<1.40E-02	5.65E+01	100b
W	<1.40E-02	<1.40E-02	6.05E-01	<1.40E-02	<1.40E-02	<1.40E-02	<1.40E-02	<1.40E-02	<1.40E-02	<1.40E-02	1.42E+02	
NH4*												
D	1.19E-02	1.47E-02	2.39E-02	1.87E-02	3.26E-02	2.04E-02	2.10E-02	1.70E-02	3.55E-02	2.27E-02	6.85E-02	0.007a
W	6.49E+00	5.82E+00	8.51E+00	5.40E+00	4.58E+00	8.94E+00	7.52E+00	1.48E+01	1.22E+01	5.92E+00	1.04E+00	
Cu*												
D	1.45E+00	1.45E+00	1.46E+00	1.45E+00	1.45E+00	1.44E+00	6.00E-02	6.00E-02	3.50E-02	3.50E-02	1.76E-01	0.0014a
W	1.09E+00	1.03E+00	1.05E+00	1.03E+00	1.04E+00	1.04E+00	<4.00E-03	<4.00E-03	<4.00E-03	<4.00E-03	1.34E-01	
Ca*												
D	6.92E+00	9.97E+00	2.98E+01	2.80E+01	3.13E+01	2.75E+01	1.12E+01	2.04E+01	2.25E+01	1.33E+01	1.28E+01	NA
W	2.44E+00	7.73E+00	2.81E+01	2.47E+01	3.20E+01	2.82E+01	1.46E+01	1.41E+01	1.85E+01	1.35E+01	1.32E+01	
K*												
D	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	3.30E-01	NA
W	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	<5.00E-03	7.11E+00	

Table 2 continued

Seasonal parameters	1	2	3	4	5	6	7	8	9	10	Precision	DWA Guideline values
Mg**												
D	1.62E+00	3.92E+00	5.58E+00	8.16E+00	8.17E+00	8.29E+00	4.48E+00	5.19E+00	5.50E+00	5.56E+00	2.65E+01	NA
W	1.25E+00	3.43E+00	6.17E+00	5.88E+00	9.43E+00	8.83E+00	2.52E+00	4.21E+00	6.21E+00	5.19E+00	2.55E+01	
P**												
D	<2.50E-02	<2.50E-02	9.10E-01	<2.50E-02	<2.50E-02	<2.50E-02	<2.50E-02	<2.50E-02	2.11E+00	<2.50E-02	1.51E-01	0.025a
W	6.50E-02	5.50E-02	3.61E+00	1.70E-01	1.57E+00	1.67E+00	2.69E+00	2.36E+00	1.65E+01	3.98E+00	9.23E-01	
S**												
D	5.75E-01	5.25E-01	1.83E+01	3.21E+00	1.03E+01	8.01E+00	<1.00E+00	<1.00E+00	1.34E+00	<1.00E+00	1.71E+01	NA
W	3.29E+00	5.07E+00	1.56E+01	7.31E+00	1.46E+01	1.21E+01	4.14E+00	1.01E+00	6.18E+00	1.69E+00	1.85E+01	
Al**												
D	1.97E+00	1.92E+00	1.91E+00	1.88E+00	1.89E+00	1.90E+00	1.13E+00	1.10E+00	1.96E+00	1.18E+00	9.34E-02	0.01a
W	1.80E+00	1.72E+00	1.66E+00	1.64E+00	1.64E+00	1.65E+00	7.35E-01	7.60E-01	4.65E-01	4.65E-01	1.47E-01	
Hg**												
D	5.10E-01	4.65E-01	4.40E-01	4.30E-01	4.15E-01	4.10E-01	<1.00E-02	<1.00E-02	5.45E-01	<1.00E-02	7.23E-02	0.00004a
W	<1.00E-02	5.40E-01	<1.00E-02	<1.00E-02	<1.00E-02	<1.00E-02	<1.00E-02	<1.00E-02	<1.00E-02	<1.00E-02	3.15E-02	
V**												
D	7.85E-01	7.85E-01	7.85E-01	7.85E-01	7.90E-01	7.90E-01	<3.00E-03	<3.00E-03	<3.00E-03	<3.00E-03	9.78E-02	0.1b
W	<3.00E-03	<3.00E-03	<3.00E-03	<3.00E-03	<3.00E-03	<3.00E-03	<3.00E-03	<3.00E-03	<3.00E-03	<3.00E-03	5.99E-02	
Pb**												
D	9.80E-01	9.65E-01	9.65E-01	9.50E-01	9.60E-01	9.60E-01	<1.00E-02	<1.00E-02	<1.00E-02	<1.00E-02	1.20E-01	0.0012a
W	6.85E-01	9.15E-01	1.85E-01	9.00E-02	3.65E-01	2.35E-01	5.55E-01	1.20E-01	2.50E-01	1.35E-01	2.04E-01	
Ni**												
D	4.50E-01	4.50E-01	5.30E-01	4.45E-01	4.55E-01	4.65E-01	1.07E+00	1.37E+00	1.23E+00	1.12E+00	8.43E-02	0.2b
W	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	1.08E-19	
Cr**												
D	3.15E-01	1.85E-01	1.75E-01	1.75E-01	3.80E-01	1.75E-01	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	3.62E-02	0.012a
W	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	1.08E-19	
EC*												
D	3.00E+02	3.00E+01	1.23E+02	2.70E+02	2.00E+01	1.50E+01	9.80E+01	1.05E+02	1.30E+02	6.50E+01	3.37E+02	0 b
W	4.05E+02	7.50E+01	1.95E+02	1.00E+02	9.50E+01	1.90E+01	1.95E+02	4.45E+02	2.15E+02	1.65E+02	3.46E+01	
TC*												
D	1.33E+03	3.60E+02	5.66E+02	4.35E+02	1.65E+02	1.50E+01	1.61E+03	1.46E+03	1.04E+03	3.80E+02	5.53E+03	0–5 b
W	5.55E+02	4.30E+02	6.60E+02	1.59E+03	5.20E+02	6.90E+01	2.23E+03	2.61E+03	5.28E+03	5.51E+03	1.37E+03	

Table 2 continued

Seasonal parameters	Sites							Precision	DWA Guideline values
	11	12	13	14	15	16	17		
pH									
D	7.17E+00	7.24E+00	7.54E+00	8.41E+00	8.62E+00	7.34E+00	7.40E+00	1.19E−01	6–8a
W	7.58E+00	7.52E+00	7.61E+00	8.20E+00	8.06E+00	7.34E+00	8.08E+00	6.64E−02	
Cond.*									
D	4.18E+02	4.40E+02	4.37E+02	4.66E+02	4.43E+02	6.97E+02	1.58E+04	9.05E+02	NA
W	3.43E+02	3.70E+02	4.35E+02	4.64E+02	4.81E+02	1.35E+04	1.59E+04	1.16E+03	
TDS**									
D	1.80E+02	1.89E+02	1.88E+02	2.00E+02	1.92E+02	3.00E+02	1.01E+04	5.84E+02	NA
W	1.48E+02	1.59E+02	1.87E+02	2.00E+02	2.07E+02	1.75E+03	1.10E+03	1.06E+02	
DO**									
D	8.63E+00	8.50E+00	8.67E+00	8.66E+00	8.71E+00	8.42E+00	8.74E+00	2.53E−02	NA
W	7.13E+00	7.38E+00	7.57E+00	7.04E+00	7.09E+00	7.04E+00	7.19E+00	4.29E−02	
BOD**									
D	3.47E+00	3.47E+00	3.49E+00	3.50E+00	3.45E+00	3.50E+00	3.53E+00	1.78E−02	NA
W	1.50E+00	5.23E+00	5.23E+00	1.51E+00	4.69E+00	5.81E+00	8.61E+00	5.38E−01	
COD**									
D	5.30E+00	8.10E+00	5.98E+00	7.92E+00	5.44E+00	2.70E+01	2.31E+01	1.47E+00	NA
W	9.54E+00	8.93E+00	6.23E+00	2.90E+00	5.22E+00	4.18E+00	5.46E+00	8.60E−01	
Na**									
D	<1.40E−02	<1.40E−02	<1.40E−02	<1.40E−02	<1.40E−02	<1.40E−02	9.60E+02	5.65E+01	100b
W	<1.40E−02	<1.40E−02	<1.40E−02	<1.40E−02	<1.40E−02	1.61E+03	1.91E+03	1.42E+02	
NH$_4$**									
D	3.21E−02	4.33E−02	4.02E−02	3.82E−02	1.55E−02	4.18E−02	1.19E+00	6.85E−02	0.007a
W	3.66E+00	3.91E+00	3.23E+00	4.81E+00	4.16E+00	1.69E+01	1.41E+01	1.04E+00	
Cu**									
D	3.50E−02	4.50E−02	3.50E−02	3.50E−02	1.45E+00	1.49E+00	1.47E+00	1.76E−01	0.0014a
W	<4.00E−03	<4.00E−03	<4.00E−03	<4.00E−03	1.04E+00	1.20E+00	1.11E+00	1.34E−01	
Ca**									
D	2.33E+01	2.58E+01	2.55E+01	3.48E+01	3.47E+01	6.18E+01	2.36E+02	1.28E+01	NA
W	2.21E+01	1.93E+01	2.38E+01	3.13E+01	3.89E+01	1.83E+02	1.83E+02	1.32E+01	
K**									
D	<5.00E−03	<5.00E−03	<5.00E−03	<5.00E−03	<5.00E−03	<5.00E−03	5.62E+00	3.30E−01	NA
W	<5.00E−03	<5.00E−03	<5.00E−03	<5.00E−03	<5.00E−03	1.06E+01	1.21E+02	7.11E+00	
Mg**									
D	5.98E+00	3.34E+00	6.45E+00	9.07E+00	7.24E+00	1.38E+01	4.57E+02	2.65E+01	NA
W	5.62E+00	5.76E+00	7.34E+00	1.08E+01	1.01E+01	3.18E+02	3.28E+02	2.55E+01	

Table 2 continued

Seasonal parameters	Sites							Precision	DWA Guideline values
	11	12	13	14	15	16	17		
P**									
D	1.27E+00	1.09E+00	7.55E-01	2.50E-02	<2.50E-02	<2.50E-02	<2.50E-02	1.51E-01	0.025a
W	3.33E+00	3.66E+00	3.24E+00	3.18E+00	2.25E-01	1.37E+00	1.15E-01	9.23E-01	
S**									
D	7.40E-01	1.27E+00	1.11E+00	3.52E+00	8.20E+00	2.21E+01	2.94E+02	1.71E+01	NA
W	2.62E+00	3.77E+00	2.42E+00	1.03E+01	1.92E+01	2.24E+02	2.49E+02	1.85E+01	
Al**									
D	1.33E+00	9.60E-01	1.27E+00	1.31E+00	1.89E+00	1.97E+00	1.94E+00	9.34E-02	0.01a
W	4.70E-01	5.10E-01	7.25E-01	4.80E-01	1.69E+00	1.91E+00	1.86E+00	1.47E-01	
Hg**									
D	<1.00E-02	<1.00E-02	<1.00E-02	<1.00E-02	4.05E-01	9.95E-01	6.55E-01	7.23E-02	0.00004a
W	<1.00E-02	<1.00E-02	<1.00E-02	<1.00E-02	<1.00E-02	<1.00E-02	<1.00E-02	3.15E-02	
V**									
D	<3.00E-03	<3.00E-03	<3.00E-03	<3.00E-03	7.90E-01	7.90E-01	7.70E-01	9.78E-02	0.1b
W	<3.00E-03	<3.00E-03	<3.00E-03	<3.00E-03	<3.00E-03	<3.00E-03	1.02E+00	5.99E-02	
Pb**									
D	<1.00E-02	<1.00E-02	<1.00E-02	<1.00E-02	9.60E-01	1.02E+00	9.70E-01	1.20E-01	0.0012a
W	1.50E-02	3.60E+00	2.85E-01	1.35E-01	1.05E-01	2.15E-01	1.65E-01	2.04E-01	
Ni**									
D	1.04E+00	1.05E+00	1.10E+00	9.25E-01	4.40E-01	4.60E-01	4.55E-01	8.43E-02	0.2b
W	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	1.08E-19	
Cr**									
D	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	1.75E-01	3.65E-01	3.85E-01	3.62E-02	0.012a
W	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	<6.00E-03	1.08E-19	
EC***									
D	1.25E+03	6.75E+02	3.10E+02	1.60E+01	4.00E+00	2.10E+03	5.60E+03	3.37E+02	0 b
W	2.90E+02	4.85E+02	1.90E+02	5.90E+01	5.80E+01	4.50E+01	2.03E+02	3.46E+01	
TC***									
D	6.15E+03	2.73E+03	3.65E+02	2.20E+01	2.70E+01	1.01E+04	9.51E+04	5.53E+03	0–5 b
W	2.40E+04	4.14E+03	3.58E+03	4.79E+02	4.93E+02	1.95E+02	9.37E+02	1.37E+03	

* Represented as µS/cm

** Represented as mg/L

*** Represented as colonies per 100 mL

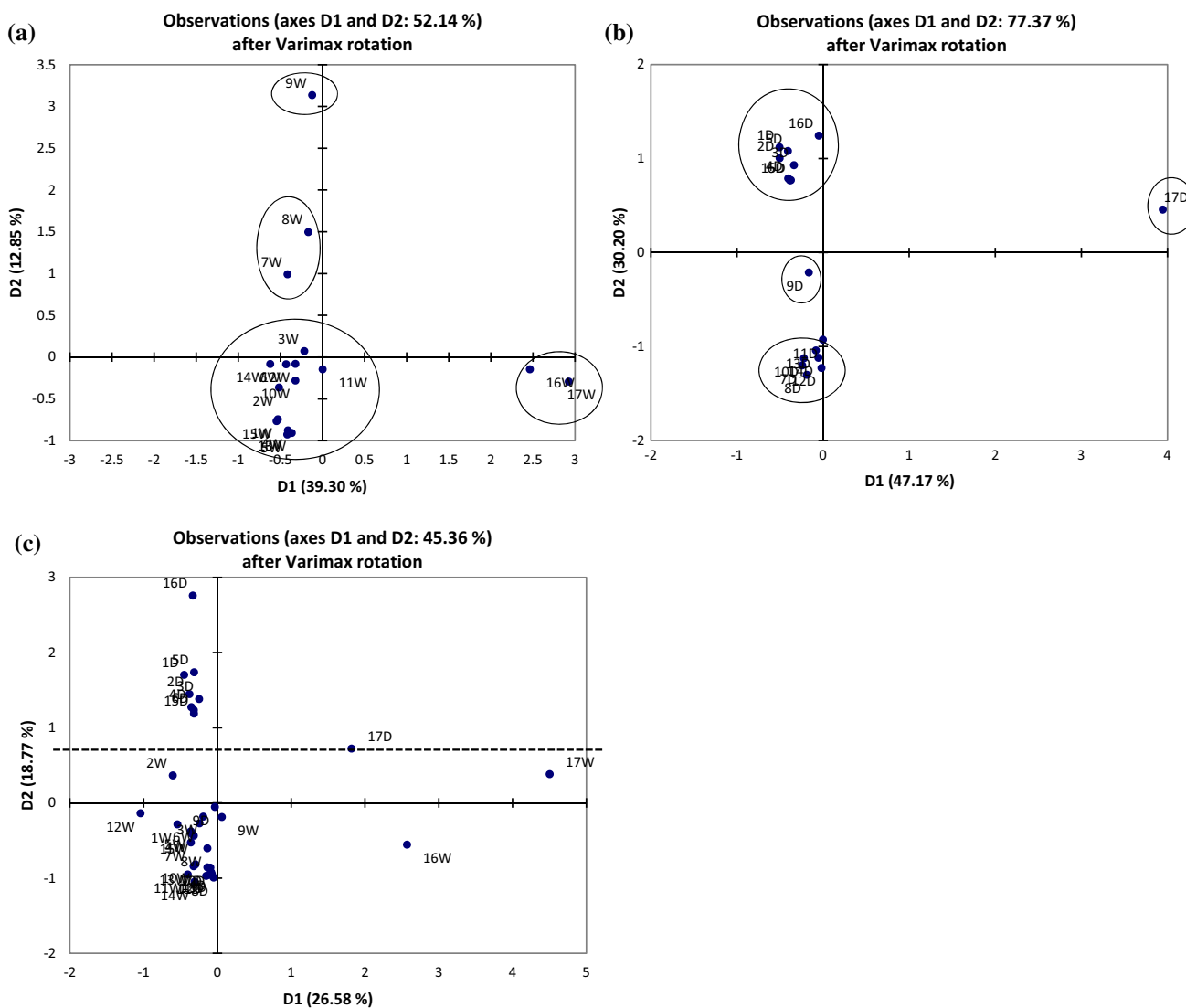**Fig. 2** Evidence of illegal dumping at site 1 (Umbilo River)

Fig. 3 a Bi-plot for varimax factors in the wet season. **b** Bi-plot for varimax factors in the dry season. **c** Bi-plot for varimax factors in the combined seasons

Variables	Dry season		Wet season		Combined seasons	
	D1	D2	D1	D2	D1	D2
pH	−0.098	0.217	0.051	−0.022	0.069	0.078
Cond.	0.987	0.129	0.988	−0.082	0.927	0.080
TDS	0.987	0.124	0.923	−0.068	0.458	0.127
DO	0.309	−0.015	−0.085	−0.150	−0.101	0.374
BOD	0.150	0.522	0.447	−0.560	0.443	0.088
COD	0.619	0.260	−0.142	0.843	0.055	0.363
Na	0.986	0.115	0.988	−0.082	0.969	0.036
NH$_4$	0.991	0.102	0.708	0.512	0.486	−0.271
Cu	0.121	0.960	0.330	−0.479	0.186	0.805
Ca	0.973	0.179	0.967	−0.117	0.863	0.135
K	0.987	0.114	0.787	−0.076	0.837	0.064
Mg	0.987	0.121	0.985	−0.086	0.866	0.083
P	−0.073	−0.306	−0.124	0.810	−0.073	−0.237
S	0.982	0.169	0.981	−0.098	0.893	0.108
Al	0.112	0.936	0.361	−0.468	0.255	0.664
Hg	0.233	0.863	−0.129	−0.091	−0.060	0.866
V	0.105	0.962	0.732	−0.073	0.306	0.870
Pb	0.117	0.964	−0.136	−0.037	−0.217	0.502
Ni	−0.123	−0.918	0.000	0.000	−0.080	−0.068
Cr	0.336	0.863	0.000	0.000	0.007	0.862
EC	0.941	0.140	−0.088	0.267	0.258	0.216
TC	0.990	0.119	−0.056	0.117	0.275	0.095
% Variance	47.17	30.20	39.30	12.85	26.58	18.77

Table 3 Loadings of factors 1 and 2 with varimax rotation from PCA

In the dry season, D1 accounted for 47.17 % of the total variance and was positively and largely contributed by Ca, Cond., Mg, S, TC, TDS, Na, NH$_4$, K and EC; and negatively by Ni. This factor distinguished the importance of mineral-related parameters (Ca, Cond., Mg, TDS and K) and anthropogenic sewage-related parameters (S, TC, NH$_4$ and EC) over geochemical weathering inputs (Ni). D2 in the dry season accounted for 30.20 % of the total variance and was positively and largely contributed by V, Pb, Hg, Cu, Cr and Al; and negatively Ni. This factor in all likelihood measured the preponderance of anthropogenic industrial inputs of heavy metals (V, Pb, Hg, Cu, Cr and Al) over geochemical weathering inputs (Ni).

During the wet season, D1 accounted for 39.30 % of the total variance and was mainly contributed positively by Ca, Cond., K, Mg, Na, S and TDS; and negatively by COD, P, Hg and Pb. This factor appeared to distinguish the importance of mineral-related parameters (Ca, Cond., K, Mg, Na, S and TDS) over anthropogenic (possibly sewage)-related parameters (COD, P, Hg and Pb). D2 in the wet season accounted for 12.85 % of the total variance and was contributed positively mainly by COD, P and NH$_4$; and negatively mainly by Al, BOD and Cu. This factor showed

the importance of anthropogenic sewage-related parameters (COD, P and NH$_4$) over organic-related parameters (BOD) and industry-related heavy metal inputs (Al and Cu).

For combined wet and dry seasons, D1 accounted for 26.58 % of the total variance and was positively and largely contributed by Ca, Cond., K, Mg, Na and S; and negatively by Pb. This factor appeared to distinguish the long term importance of mineral-related (Ca, Cond., K, Mg, Na and S) parameters over industry-related heavy metal inputs (Pb) for the systems. D2 for combined seasons represented 18.77 % of the total variance and was positively and largely contributed by Cu, Cr, Hg, Ni and V; and negatively by NH$_4$ and P. This factor illustrated the prevalence of industrial heavy metal inputs (Cu, Cr, Hg, Ni and V) over nutrients (NH$_4$ and P).

The relationships between sites and water quality variables are displayed in the bi-plots of varimax factors along the D1–D2 axes planes (Fig. 3a–c), with distance between sampling sites approximating the (dis)similarity of water chemistry between sites as a function of Euclidean distance (Walsh and Wepener 2009). This allowed for detailed spatiotemporal evaluation of catchment sites on the basis of significant water quality variations at each of the sites.

As depicted in Fig. 3a, the varimax factor bi-plot for the wet season described 52.14 % of variation in the data, with 39.30 % represented by the first factor and 12.85 % by the second factor. Sites along the Umbilo and Umhlatuzana Rivers were separated along the D2 axis, with separation mostly influenced by Al and Cu (greater loading for Umbilo River and site 15 after the confluence with the Umhlatuzana River), and organic-related BOD, COD, P and NH_4 (greater loading for Umhlatuzana River). This suggested that both river systems were separated on the basis of varying anthropogenic influence through sewage discharge—corresponding to D2 in the prior PCA analysis with varimax rotation. Sample sites 7 and 8 in the Umhlatuzana River (associated with residential land use) were clustered and hence similar to each other in terms of water quality. Sites 1–6 (Umbilo River), 10–14 (Umhlatuzana River) and site 15 (after the confluence with the Umhlatuzana River) were clustered and hence similar to each other in terms of water quality, with site 15 more closely linked with the Umbilo River sites suggesting a greater influence of the Umbilo River on the water quality of site 15 after the confluence. Evidently, the wet season varimax factor bi-plot showed spatial dissimilarity in terms of the catchment river systems, with industrial sites 9 (Umhlatuzana River), and sites 16 and 17 (Amanzimnyama Canal) showing a distinct separation from the remaining catchment sites along the D1 axis, and is mostly influenced by greater loading of TDS, S, Ca, Mg, Cond., Na, K, COD, Hg, P and Pb. This separation corresponded to varying mineral and anthropogenic-related parameters of D1 as explained in the previous PCA analysis with varimax rotation. With the exception of sites 7 and 8 associated with residential land use, and sites 16 and 17 associated with industrial land use, no apparent trends in water quality based on specific land use patterns were indicated in the varimax factor bi-plot for the remaining catchment sites.

The varimax factor bi-plot for the dry season (Fig. 3b) described 77.37 % of variation in the data, with 47.17 % represented by the first factor and 30.20 % by the second factor. With the exception of site 9, all sample sites in the Umhlatuzana River were clustered and hence similar to each other in terms of water quality. Sites 1–6 (Umbilo River) and site 15 (after the confluence with the Umhlatuzana River) were clustered and hence similar to each other in terms of water quality. This also suggested a greater influence of the Umbilo River on the water quality of site 15 after the confluence. In contrast to the wet season, site 16 of the Amanzimnyama Canal displayed similar water quality to the sites of the Umbilo River catchment. Sites along the Umbilo and Umhlatuzana Rivers, and Amanzimnyama Canal (site 16 only) were separated along the D2 axis, with separation mostly influenced by Hg, Cr, Al, Pb, V and Cu (greater inputs for Umbilo River, site 15 after the confluence with Umhlatuzana River, and site 16 of the Amanzimnyama Canal), and Ni (greater loading for Umhlatuzana River). This suggested that the sites of the river systems were separated on the basis of varying anthropogenic influence—corresponding to D2 in the prior PCA analysis with varimax rotation. Site 17 of the Amanzimnyama Canal is separated to a large degree from the remaining sites along the D1 axis, with separation largely attributed to S, EC, Cond., NH_4, TDS, TC, Na, Ca, Mg and K (greater loading at site 17 relative to remaining sites). This suggested separation on the basis of varying mineral and anthropogenic influence—corresponding to D1 in the prior PCA analysis with varimax rotation. As in the case of the wet season, no apparent trends in water quality based on specific land use patterns were indicated in the varimax factor bi-plot for the remaining catchment sites.

Figure 3c depicted strong seasonal variations (seasonal separation indicated by dashed line parallel to the D2 axis) in water quality between selected sites in the Umhlatuzana and Umbilo Rivers along the D2 axis which primarily related to organic (P, NH_4) and heavy metal parameters (Cu, Cr, Hg, V, Ni)—as explained in previous PCA analysis with varimax rotation. The most distinct variations noted in terms of temporal water quality are those for sites 16 and 17 along the D2 axis which showed a large degree of seasonal spatial dissimilarity on the basis of Euclidean distances between corresponding wet and dry season sites. This was mainly attributed to variations in seasonal loadings of NH_4, Cond., TDS, COD, Na, Ca, Mg, S, EC and TC at site 16; and variations of seasonal loading in TDS, COD, Na, NH_4, EC and TC for site 17.

Influence of catchment water quality on the Bayhead Canal

Results of additional sampling in the Bayhead Canal of the Durban Harbour after the catchment confluences are depicted in Table 4 below. Chemical concentrations in the Bayhead Canal were used to generate interpolated images for visual interpretation (Fig. 4). Interpolations were created using ArcGIS 9®.

Chemical analyses of water quality variables in the Bayhead Canal of the Durban Habour showed that the Amanzimnyama Canal is most influential on the Bayhead Canal chemistry at the confluence with the loading of DO (wet season), BOD (both seasons), COD (both seasons), Cu (both seasons), Al (both seasons), *E. coli* (both seasons), total coliforms (both seasons), V (wet season), Pb (dry season), Hg (dry season) and Cr (dry season) at the confluence. The Umhlatuzana/Umbilo Canal appeared to contribute to loadings of pH (dry season), DO (wet season), BOD (both seasons), COD (wet season), P (both seasons), and total coliforms (wet season) at the confluence of the Bayhead Canal. Overall, it appeared that the

Table 4 Concentrations of the Bayhead Canal for dry (*D*) and wet (*W*) seasons

Seasonal parameters	Sites							
	18	19	20	21	22	23	24	25
pH								
D	7.39E+00	7.79E+00	7.99E+00	8.17E+00	7.90E+00	7.80E+00	7.77E+00	7.80E+00
W	7.47E+00	7.37E+00	7.44E+00	7.83E+00	7.69E+00	7.72E+00	7.68E+00	7.75E+00
Cond.*								
D	1.50E+04	3.22E+04	3.00E+04	3.00E+04	4.89E+04	4.84E+04	5.14E+04	5.07E+04
W	2.05E+04	3.99E+04	3.98E+04	2.80E+04	4.86E+04	4.87E+04	4.70E+04	4.91E+04
TDS**								
D	9.12E+03	1.14E+04	9.25E+03	9.15E+03	2.17E+04	2.28E+04	2.24E+04	2.21E+04
W	8.73E+03	1.14E+04	1.50E+04	1.05E+04	2.08E+04	2.43E+04	1.82E+04	2.48E+04
DO**								
D	8.62E+00	8.62E+00	8.73E+00	8.59E+00	8.58E+00	8.75E+00	8.60E+00	8.54E+00
W	6.99E+00	7.10E+00	7.10E+00	7.07E+00	6.97E+00	7.03E+00	6.92E+00	6.95E+00
BOD**								
D	3.30E+00	3.32E+00	3.33E+00	3.25E+00	3.27E+00	3.04E+00	3.02E+00	2.59E+00
W	4.54E+00	4.51E+00	3.80E+00	6.69E+00	3.44E+00	5.30E+00	5.59E+00	2.06E+00
COD**								
D	7.86E+00	4.14E+00	3.96E+00	6.14E+00	6.30E+00	6.22E+00	7.40E+00	7.10E+00
W	5.05E+00	7.70E+00	4.66E+00	7.94E+00	6.84E+00	4.66E+00	3.68E+00	4.34E+00
Na**								
D	8.64E+02	2.51E+03	2.46E+03	2.52E+03	3.26E+03	3.55E+03	3.84E+03	4.61E+03
W	2.50E+03	3.60E+03	3.61E+03	2.51E+03	4.25E+03	4.26E+03	4.14E+03	4.21E+03
NH$_4$**								
D	1.61E−01	8.03E−01	1.09E+00	1.35E+00	6.10E−01	1.01E+00	7.64E−01	1.07E+00
W	2.46E+01	4.11E+01	4.32E+01	1.16E+01	3.33E+01	2.09E+01	2.99E+01	2.85E+01
Cu**								
D	1.53E+00	6.00E−02	6.50E−02	6.00E−02	7.50E−02	5.50E−02	6.00E−02	6.00E−02
W	1.02E+00	<4.00E−03	<4.00E−03	<4.00E−03	<4.00E−03	<4.00E−03	<4.00E−03	<4.00E−03
Ca**								
D	2.27E+02	3.61E+02	3.29E+02	3.20E+02	5.49E+02	5.40E+02	5.42E+02	5.34E+02
W	2.68E+02	4.43E+02	4.55E+02	3.38E+02	5.15E+02	5.31E+02	5.07E+02	5.29E+02
K**								
D	<5.00E−03	9.24E+02	9.22E+02	9.08E+02	9.26E+02	9.15E+02	8.95E+02	8.94E+02
W	1.30E+02	2.68E+02	2.72E+02	1.55E+02	3.37E+02	3.44E+02	3.09E+02	3.33E+02
Mg**								
D	4.28E+02	6.52E+02	5.88E+02	5.62E+02	9.37E+02	1.04E+03	1.07E+03	9.11E+02
W	4.64E+02	9.24E+02	8.87E+02	6.46E+02	9.51E+02	9.70E+02	9.30E+02	1.19E+03
P**								
D	<2.50E−02	4.85E−01	5.80E−01	3.80E−01	3.00E−01	1.35E−01	3.15E−01	1.35E−01
W	4.30E−01	4.52E+00	4.54E+00	4.29E+00	3.36E+00	3.33E+00	3.08E+00	3.39E+00
S**								
D	2.74E+02	5.65E+02	4.88E+02	4.98E+02	8.55E+02	8.39E+02	8.61E+02	8.40E+02
W	3.26E+02	7.48E+02	7.80E+02	5.97E+02	9.06E+02	7.94E+02	7.91E+02	8.27E+02
Al**								
D	2.64E+00	1.17E+00	1.21E+00	1.13E+00	1.23E+00	1.14E+00	1.17E+00	1.13E+00
W	1.66E+00	5.25E−01	5.25E−01	5.15E−01	5.20E−01	5.20E−01	1.15E−01	9.45E−01
Hg**								
D	1.29E+00	5.25E−01	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02

Table 4 continued

Seasonal parameters	Sites							
	18	19	20	21	22	23	24	25
W	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02
V**								
D	7.80E−01	1.87E+00	1.81E+00	1.86E+00	2.08E+00	2.10E+00	2.12E+00	2.07E+00
W	9.90E−01	<3.00E−03	<3.00E−03	<3.00E−03	6.45E−01	8.20E−01	7.85E−01	8.80E−01
Pb**								
D	9.60E−01	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02
W	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02	<1.00E−02	4.00E−02
Ni**								
D	4.45E−01	2.38E+00	2.40E+00	2.39E+00	2.31E+00	2.36E+00	2.35E+00	2.42E+00
W	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03
Cr**								
D	3.85E−01	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03
W	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03	<6.00E−03
EC***								
D	1.80E+02	<1.00E+01	1.00E+01	5.00E+00	<1.00E+01	<1.00E+01	1.00E+01	<1.00E+01
W	3.13E+02	4.00E+01	3.00E+01	4.40E+01	1.30E+02	1.10E+02	1.00E+02	5.50E+01
TC***								
D	3.10E+02	<1.00E+01	2.50E+01	5.10E+01	7.00E+00	2.00E+00	6.53E+02	2.00E+02
W	4.17E+03	1.30E+03	3.48E+02	6.71E+02	6.00E+03	1.10E+03	2.50E+03	3.85E+03

* Represented as μS/cm

** Represented as mg/L

*** Represented as colonies per 100 mL

Amanzimnyama Canal is responsible for a greater degree of chemical loading in the Bayhead Canal as compared to the Umbilo/Umhlatuzana catchment inflows. The fact that marine waters of the port itself tend to control dissolved Na, K, Mg, TDS and Cond. values is not unusual, as this phenomenon is a characteristic of marine waters (DWAF 1995). On the other hand, elevated values of Ni, V and S which appears to be controlled by the marine waters of the port, is more likely associated with anthropogenic pollution originating from port activities itself. Whilst the marine guideline values for S and V are unavailable, Ni concentrations for the dry season exceeded the prescribed value of 0.025 mg/L, indicative of anthropogenic pollution most likely of port origin. Whilst the interpolated images provides an indication of the influence of the freshwater canal inflows on the Bayhead Canal, it is difficult to accurately quantify the effects of the freshwater inflows on chemical patterns in the Bayhead Canal, as the chemicals are highly variable with factors such as temperature, water turbulence and volume and biological productivity (DWAF 1996a). More detailed and scientific evaluation of chemical behaviour associated with the Bayhead Canal can be obtained through detailed, chemical specific hydrodynamic wave modelling.

Conclusion

A diverse variety of activities characterize the catchments of the Durban Harbour—primarily intense anthropogenic alteration and modification of the landscape through industry, WWTW and urbanization over the past few decades. The influence of human activities on these catchments accounts for substantial spatial and temporal water quality variability across catchments as illustrated in the varimax factor bi-plots and individual factor loadings. Anthropogenic catchment activities have also shown to affect water quality of the receiving Bayhead Canal of the Durban Harbour with respect to selected physico-chemical parameters—with the highly industrialized Amanzimnyama catchment being most influential. Although not all possible water quality variables were analyzed, this study has been very comprehensive in that it has assessed the impacts of a wide range of physical and chemical parameters, as well as microbiological aspects which have allowed for subsequent spatiotemporal characterization of the catchments. The study demonstrated that there is no doubt that intensification of anthropogenic activities and processes operating within the catchments have caused a general deterioration of
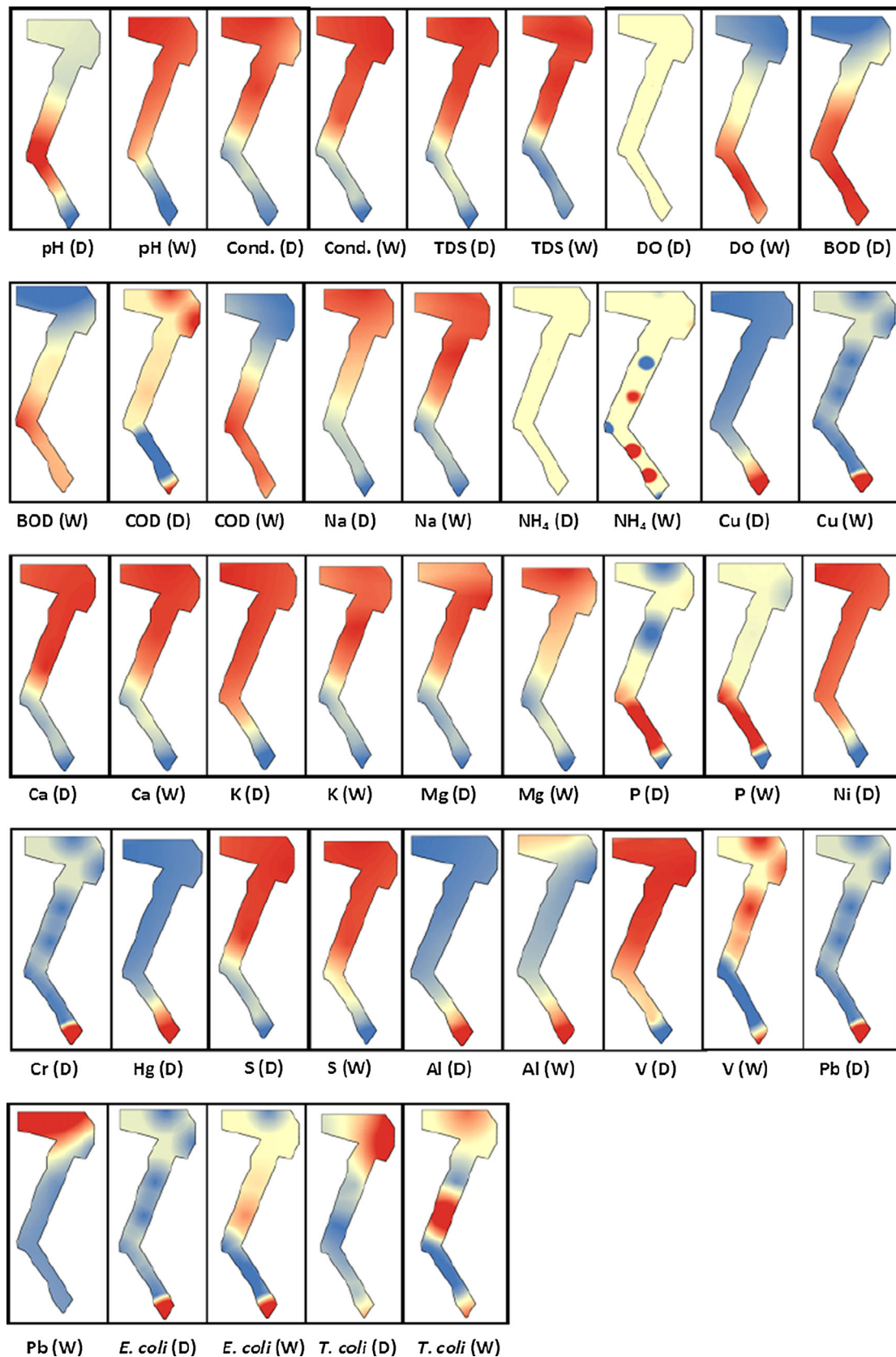
Fig. 4 Interpolated images of Bayhead Canal chemical data—*blue* indicates low values transitioning to *red* indicating high values. No Ni, Cr and Hg was detected in the wet season

nutrient, heavy metal and microbiological water quality across all land use types on the basis of water quality variables that were analyzed. Specific land use types are shown to affect the river's water quality in different ways. Combined ammonia and phosphorous concentrations emanating from the different land use types were typically high, with the levels of ammonia and phosphorous causing hypertrophic conditions thus rendering sections of the river as unsuitable aquatic habitats. Further analysis of water quality variables reveal disturbing amounts of pathogenic microbes associated with all land use types rendering the sanitary quality of the systems as unacceptable. While the nature reserves display a limited purifying capacity with regard to certain nutrients, the anthropogenic stresses placed on the catchment ecosystems as a whole renders the water source as severely polluted across all land use types.

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