

The characterisation of natural organic matter (NOM) in South African waters

T. I. Nkambule, R. W. M. Krause, J. Haarhoff and B. B. Mamba

ABSTRACT

The removal of natural organic matter (NOM) from water is becoming increasingly important in order to prevent the formation of carcinogenic disinfection by-products (DBPs). The inadequate removal of NOM has a bearing on the capacity of other treatment processes to remove organic micro-pollutants or inorganic species that may be present in water. In order to effectively study the nature of South African water sources in terms of their NOM composition, water samples were collected from drinking water treatment plants in the five geographic water regions of South Africa. A raw water sample, an intermediate sample taken before sand filtration and a final sample after sand filtration were collected three times from these water treatment plants at two-month intervals and over three different seasons. Fluorescence excitation-emission matrices (FEEM), biodegradable dissolved organic carbon (BDOC), ultraviolet (UV) characterisation (200–900 nm) and dissolved organic carbon (DOC) analyses were used to characterise the NOM in the water samples. The FEEM and UV results revealed that the samples were composed mainly of non-humic substances with low UV-254 absorbance, while some samples had high humic substances with high UV-254 values. The samples' DOC results were within the range of 3.25–21.44 mg/L carbon, which was indicative of the varying nature of the NOM composition in the regions where samples were collected. The BDOC fraction of the NOM, on the other hand, ranged from 20 to 65%, depending on the geographical location of the sampling site.

Key words | biodegradable dissolved organic carbon, disinfection by-products, fluorescence excitation-emission matrices, humic substances, natural organic matter

T. I. Nkambule
R. W. M. Krause
J. Haarhoff
B. B. Mamba (corresponding author)
Department of Applied Chemistry,
University of Johannesburg,
P.O. Box 17011,
Doornfontein, 2028,
South Africa
E-mail: bmamba@uj.ac.za

INTRODUCTION

Natural organic matter (NOM) is a mixture of organic compounds, having diverse chemical properties, that occurs in all natural water sources when animal and plant material breaks down (Kim & Yu 2005). NOM affects water quality in the following ways:

- It could be responsible for the colour, undesirable taste and odour of natural waters.
- It inhibits precipitative processes which form the backbone of drinking water treatment.
- It is a major membrane foulant and causes high disinfectant demand.
- It promotes bacterial re-growth in the distribution system and could be a source of nutrients for heterotrophic bacteria, which compromises water quality.

- It accelerates corrosion of the distribution network while increasing turbidity at the consumer end.
- It causes high disinfectant demand.
- In addition, it has recently become obvious that the interaction of NOM with disinfectants can form carcinogenic and mutagenic disinfection by-products (DBPs) (Kim *et al.* 2006).

All these problems, combined or individually, negatively affect human life and that of other aquatic organisms.

Since NOM emanates from many different sources, it can be predicted that the composition of NOM in different water sources may not be uniform and characterisation studies are therefore necessary. Many authors have suggested that the character of NOM varies per geographic location of the

water source. Indiana (2011) even suggests that the character of NOM is also dependent on the climatic conditions of that particular locality while Wong *et al.* (2007) suggested that the character of NOM per water source is dependent on the type of agricultural/industrial activities occurring in the surrounding catchment area. It is therefore crucial to understand the composition of the NOM in the source water, especially as applied to local NOM conditions. Once the character of the NOM in the water source has been understood, methods aimed at effectively removing the NOM from the water source can then be developed. The need to characterise the NOM before attempting to remove it is based on the fact that its aromaticity, functional group distribution, molecular weight and elemental composition have a great influence on how NOM can be effectively removed from water (Nkambule *et al.* 2009).

A review of NOM characterisation at water treatment plants in South Africa has revealed attempts to try and characterise the NOM occurring at individual plants, but that it has not been possible to conclusively determine the nature of NOM occurring in the country (Haarhoff *et al.* 2010). The primary objective of this study is thus to characterise the NOM occurring in South Africa through an extensive sampling of different water types, both as raw water and following certain treatment steps. Herein, we thus report NOM characterisation results of samples obtained from five different water treatment plants in South Africa, representing the five major source water types. Understanding the character of NOM within a short period of time would help inform water treatment engineers of necessary adjustments to be carried out within a water treatment plant, since the composition of NOM changes during the process or as a result of external factors like the weather or season.

EXPERIMENTAL PROCEDURE

Sample collection

Samples were collected from five different water treatment plants three times, at 2 month intervals. The sampling times are referred to as Round 1, Round 2 and Round 3 for the first, second and third samplings respectively. Round 1 was done in spring, Round 2 in summer and Round 3 in

winter. The five different water treatment plants selected are: Olifantsvlei (O) Wastewater Treatment Plant north of Johannesburg (Johannesburg Water); the Plettenberg Bay (P) Water Treatment Plant in the Southern Cape; the Rietvlei (R) Water Treatment Plant of the Tshwane Metropolitan Municipality; the Stilfontein (M) Water Treatment Plant of Midvaal Water; and the Wiggins (W) Water Treatment Plant of Umgeni Water. Figure 1 shows the general water treatment train employed in South Africa for the production of drinking water. These processes vary per water treatment company and per type of raw water source used.

At each water treatment plant, two to four samples were collected depending on the particular water treatment train used. These were a raw water sample, an intermediate sample before sand filtration and a final sample after sand filtration where appropriate. The Olifantsvlei is a wastewater treatment plant and hence here only two samples were taken, i.e. before and after the maturation pond.

Bulk water characterisation

On site, the pH, turbidity, conductivity and temperature of all samples taken were determined using a Hanna 98129 multi-meter, in order to establish the NOM characteristics in the samples.

Organic carbon analysis

The dissolved organic carbon (DOC) analyses were carried out using a total organic carbon (TOC) analyser (Teledyne Tekmar, TOC fusion). Prior to analysis all samples were filtered through 0.45 µm filter paper. DOC is the organic constituent that can pass through 0.45 µm filter paper, while TOC is the measure of all organic molecules present in a water sample. Standards of 1, 5, 10, 20 and 30 mg/L carbon were prepared with potassium hydrogen phthalate (KHP) and de-ionised water, and were then run prior to analysis of samples to calibrate the instrument.

Ultraviolet-visible (UV-Vis) spectrophotometric analysis

A Shimadzu UV-2450 Spectrophotometer was used to analyse the samples in the UV range over the following four wavelengths: 214 nm (indicative of nitrites and nitrates;

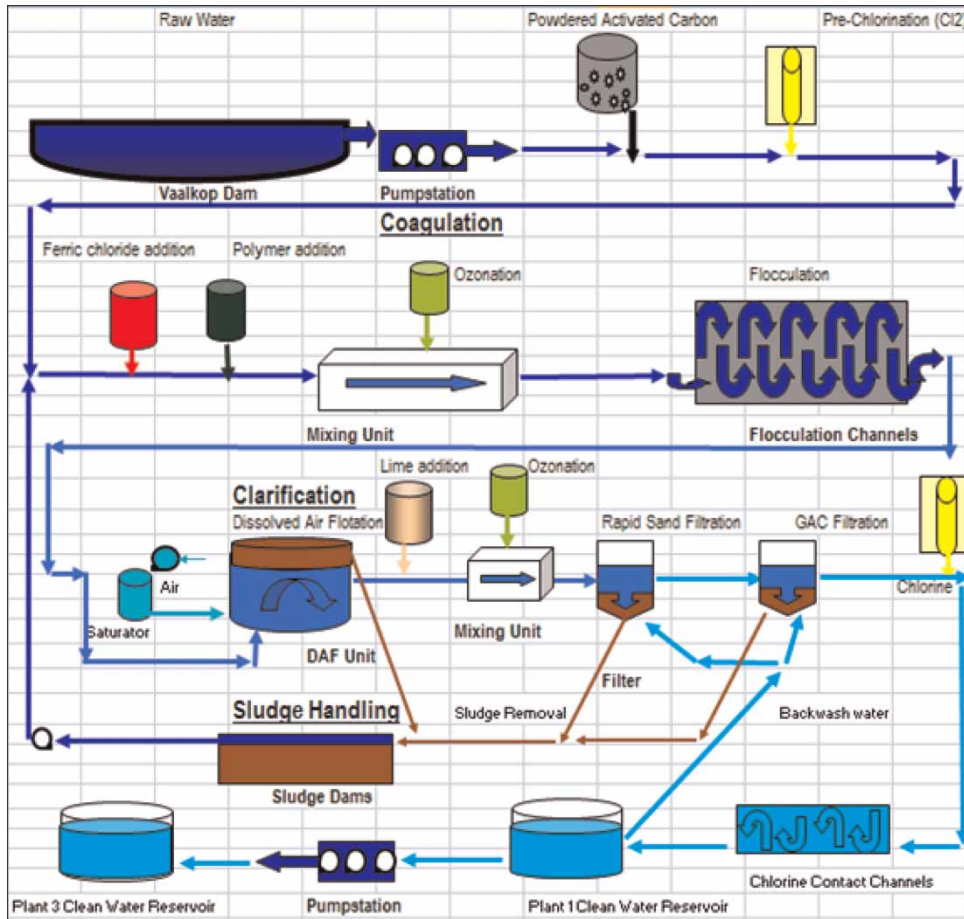


Figure 1 | The general layout of the South African water treatment process (an example of the Vaalkop water treatment plant).

Narayana & Sunil 2009); 254 nm (indicative of humic substances and aromatics); 272 nm (reported in the literature to be the best predictor of Trihalomethane (THM) formation; Liu *et al.* 2006); and 300 nm (used by Rand Water and other treatment plants as a measure of DOC). A full wavelength spectrum (200–900 nm) of each sample was also obtained to further study the NOM characteristics in the samples.

Specific ultraviolet absorbance analysis

The specific ultraviolet absorbance (SUVA) gives an indication of the amount of humic substances vs. non-humic substances in the NOM (Weishaar *et al.* 2003). SUVA can also be used to indicate the treatability of the water. The SUVA calculation requires both DOC and UV measurement. The UV_{254} and DOC values were used to calculate

the SUVA using Equation (1):

$$SUVA \left(\frac{L}{mgM} \right) = \frac{UV_{254} (Cm^{-1})}{DOC \left(\frac{mg}{L} \right)} \times 100 \quad (1)$$

Fluorescence excitation-emission matrices (FEEM) characterisation

The FEEM method is used as a technique for classifying and distinguishing between humic substances of various origins and natures (Chen *et al.* 2003). FEEM attempts to give the structural information of NOM based on the UV absorption of the molecular group. A Perkin Elmer LS 45 Fluorescence spectrometer was used in combination with the UV-Vis spectrophotometer to try and study the character of the NOM. 'FEEM regions' were chosen as per grouping by Chen *et al.*

(2003). These regions were chosen only as estimates and values slightly higher or lower than them can be chosen. These regions were:

FEEM region	Excitation (nm)	Emission (nm)
I	≤250	<350
II	≤250	340–380
III	≤250	380–540
IV	260–300	280–380
V	250–300	380–540

Biodegradable dissolved organic carbon (BDOC) analysis

BDOC in drinking water is an indicator of bacterial re-growth potential in the distribution network. The method of analysis chosen is based on measuring the reduction of DOC over 6 days by bacteria fixed on biologically active sand (BAS). The BDOC measurements were only carried out on the raw water samples. An inoculum of BAS, obtained from the Rietvlei water treatment plant, was washed until there was no further release of DOC. This was achieved by washing the BAS ten times or more with 500 mL rinsing solution (10 mL sodium thiosulphate solution, 0.1 M; 490 mL deionised). The DOC and UV content of the last washing were then measured, to study the background DOC and UV due to the sand. The inoculum was then rinsed with 100 mL of the raw water sample to be analysed, after which the solution was left to stand for 20 minutes to allow an acclimation of biomass to the water before gently pouring it out.

A fixed weight of sample (300 mL) and inoculated sand (100 g) was then placed together in clean Erlenmeyer flasks, aerated and kept at room temperature for 6 days. Each flask was covered with aluminium foil paper, to prevent any atmospheric interference in the condition of the bacteria and samples in the flask. The heterotrophic bacteria in the sand digest the carbon in the sample to get energy, while at the same time biologically degrading the sample. Daily measurements of the DOC concentration were made until no further changes in DOC were observed. BDOC is calculated as the difference between the initial DOC and the minimum DOC value reached. Sodium acetate was used as a control. Three different solutions (5, 8 and 10 mg/L) of sodium acetate were prepared as controls and run at the same time as the

samples (under similar conditions as those of the samples) as controls in order to monitor the activity of the bacteria in known concentrations of substrate. Sodium acetate was chosen because it is organic and has been widely used in many bacterial decay studies (Takundwa & Mvula 2007).

RESULTS AND DISCUSSION

Bulk water characterisation of samples

The five water treatment plants were selected based on the various source water supply regions in South Africa. Table 1 and Table 2 show the bulk characterisation of the water samples collected during the three sampling times.

According to Tan (2003), the type of soil and vegetation in the surrounding catchment area and seasonal variations influence the NOM in water bodies. It has been found that there is a strong relationship between the intensity of precipitation and the NOM concentration, since run-off leads to higher NOM discharge from the upper part of the soil profile or percolation through the soil column. This was

Table 1 | DOC and turbidity values for the three rounds of sampling

Sample	DOC (mg/L)			Turbidity (NTU)		
	Round 1	Round 2	Round 3	Round 1	Round 2	Round 3
R1	7.94	11.62	8.24	1.80	6.41	3.60
R2	6.79	11.02	6.35	2.51	0.69	4.18
R3	6.35	7.65	6.22	6.57	0.37	0.64
R4	5.89	–	5.93	0.56	–	0.34
O1	9.91	9.51	8.99	1.91	3.64	3.64
O2	8.78	9.80	9.29	2.00	1.89	2.08
M1	7.60	9.06	8.45	7.50	18.1	114
M2	7.29	8.05	8.05	1.53	6.25	1.48
M3	6.78	9.30	5.80	2.03	1.55	63.1
M4	6.40	7.03	5.86	0.51	0.90	114
M5	–	–	4.42	–	–	76.5
W1	4.64	3.20	3.19	3.15	1.57	1.63
W2	3.75	2.64	2.86	5.21	3.28	1.73
W3	3.30	2.51	1.16	0.70	0.48	0.53
P1	21.44	9.98	13.46	1.93	1.34	2.23
P2	3.85	5.01	11.37	0.84	1.02	1.20
P3	3.25	3.68	5.63	0.25	0.19	0.23

Table 2 | Conductivity, pH and temperature for the three rounds of sampling

Sample	Conductivity (mS/m)			pH			Temperature (°C)		
	Round 1	Round 2	Round 3	Round 1	Round 2	Round 3	Round 1	Round 2	Round 3
R1	0.42	0.43	0.39	8.07	9.47	7.79	12.4	21.3	21.2
R2	0.40	0.40	0.41	8.08	9.16	9.67	11.9	22.3	21.3
R3	0.40	0.41	0.42	8.05	9.18	9.47	11.7	21.7	21.4
R4	0.41	–	0.40	7.99	–	9.14	–	–	21.3
O1	0.46	0.42	0.51	7.49	8.75	9.64	11.7	22.9	26.0
O2	0.47	0.43	0.53	8.10	7.96	10.14	15.9	22.5	23.7
M1	0.49	0.62	0.20	9.50	8.63	8.22	13.4	23.7	25.7
M2	0.51	0.64	0.29	9.53	8.97	8.76	16.9	23.4	26.4
M3	0.53	0.63	0.26	9.51	8.75	9.66	16.2	23.9	25.0
M4	0.51	0.64	0.22	9.46	8.26	8.34	16.2	23.8	25.7
M5	–	–	0.26	–	–	9.48	16.2	–	27.0
W1	0.23	0.22	0.29	7.96	8.45	8.78	17.1	23.4	26.1
W2	0.22	0.22	0.29	7.90	8.24	8.76	17.1	23.1	26.4
W3	0.22	0.22	0.29	7.91	8.13	8.72	17.0	23.0	28.1
P1	0.12	0.07	0.10	6.73	7.65	6.23	13.7	21.3	26.0
P2	0.12	0.11	0.22	6.73	6.50	6.22	13.6	21.3	25.5
P3	0.12	0.11	0.22	6.39	6.66	6.22	13.6	20.5	25.2

evidenced by the high variability of the DOC and turbidity of the raw water samples during the three rounds of sampling which occurred in different seasons.

The **P** sample water is characteristic of the organically coloured surface water found on the south-west coast in South Africa; its brownish colour is usually due to humic and fulvic substances. This is evidenced by the high DOC values of the raw water (**P1**) samples (21.44, 9.98 and 11.37 mg/L for the first, second and third sampling, respectively). The turbidity of the raw water samples is also high (ranging from 1.34 to 1.93 NTU), indicative of a high content of colloids and clay particles in these samples.

The **W** sample is characterised by Montaigne water flowing eastwards from the Drakensberg and Amatola escarpments. This water is generally low in colour as evidenced by the low DOC values of the raw water from this treatment plant (DOC = 3.75, 3.20, and 3.19 mg/L for first, second and third sampling, respectively). The DOCs were higher after rainfall (Round 3), with a few exceptions, for all the samples. These findings correlate well with a study by Krasner (1999), who also demonstrated that seasonal variation would lead to increased DOC and UV values after

rainfall. They attributed these increases to the leaching of soil organic matter during river discharge.

The **O** samples are treated sewage effluent, which dominates the NOM character in many streams and rivers in South Africa. These are thus very high in DOC as evidenced by an average concentration of 9.00 mg/L DOC for all these samples. They also have the highest turbidity values, indicative of high concentrations of colloids and clay particles. During the sampling periods, turbidity ranged from 0.56 NTU to as high as 114 NTU, indicative of the varying nature of the NOM character within South African waters. The turbidity governs the coagulation process in raw waters. Pernitsky (2003) pointed out that coagulant dosages increase where raw water turbidity rises, but the relationship is not linear.

The **M** and **R** samples are characteristic of oligotrophic waters, supplemented by the Lesotho Highlands Water Project (LHWP). These samples had relatively similar amounts of DOC and turbidity throughout the sampling period, as can be seen from Table 1 and Table 2. It is interesting to note that DOC removal efficiencies for all the water treatment plants are relatively high, as can be seen with an 85% DOC removal efficiency at Plattenberg Bay. It is also noteworthy

that all the water treatment plants distribute water to consumers that meets South African National Standards (SANS), and in some instances the water supply meets even the stringent World Health Organization (WHO) standards.

Coagulation and flocculation processes are not efficient in low temperatures because the viscosity of the water is high, shifting the coagulant stability and reducing the kinetics of the hydrolysis reactions and particulate flocculation. As can be seen in Table 2, the temperature range of the water in all sampling rounds and samples is not low (11.7–28.1 °C), thus enabling DOC removal by coagulation and flocculation.

Ultraviolet-visible (UV-Vis) spectrophotometric analysis

UV absorbance is usually measured at a wavelength of 254 nm (and reported in cm^{-1}), which is the wavelength used as an industrial standard for the maximum UV absorption of NOM samples. Absorption at this wavelength has been reported to represent the aromatic character of the organic species. An increase in UV absorbance at 254 nm indicates that NOM is increasing in aromaticity and unsaturated carbon bonds (Kiwa 2006). UV was also measured at 214, 272 and 300 nm for a more in-depth analysis of the NOM character in this study. As already discussed above, UV_{214} nm is indicative of nitrites and nitrates, UV_{272} nm has been reported in the literature to be the best predictor for THM formation (Liu *et al.* 2006), while UV_{300} nm is used in South Africa by Rand Water and other treatment plants as a measure of DOC. Table 3 shows the various UV values at different wavelengths for the three sampling periods.

All the samples generally exhibit high UV_{214} , which implies that the samples are high in nitrates and nitrites. The highest UV_{214} values were seen in the **O** samples. This was expected, as this is sewage effluent. The samples exhibit generally low UV_{254} values; this could imply that the samples mostly contain non-humic substances. SUVA generally gives a better indication of the aromaticity of the samples, as will be discussed below. There is a strong correlation between UV_{254} and DOC (see below). The highest UV_{254} absorbance was recorded for the **P** sample, which is from a highly coloured raw water source expected to be high in humic substance content. The lowest UV_{254} was recorded for the **W** samples, implying that these samples are characterised by non-humic substances. It is also interesting to note that there is a great

decrease in the UV absorbance of the samples after each treatment process, indicating the effectiveness of the water treatment techniques employed for NOM removal.

Specific ultraviolet absorbance analysis

SUVA is calculated by dividing the UV-absorbance of the sample at 254 nm (in cm^{-1}) by the DOC of the sample (in mg/L) and then multiplying by 100 mg m. It is a method used to determine the relative aromaticity of the humic fraction (Weishaar *et al.* 2003). Generally a SUVA value of above 4 is considered to represent high aromatic content, i.e. humic substances, while a SUVA value of below 2 represents low aromatic content, i.e. non-humic substances. Table 4 gives the various SUVA values for all the samples analysed during the different sampling periods.

Only the **P** samples exhibited $\text{SUVA} > 4 \text{ l/mg m}$, implying that these were the only samples that were predominantly composed of highly aromatic humic substances. The other samples (**R**, **M**, **O** and **W**) had $\text{SUVA} < 2 \text{ l/mg m}$, for the first and second round of sampling, implying that these samples contained non-humic substances. However, during the third round of sampling, these samples had SUVA values greater than 2 l/mg m but still less than 4 l/mg m , which meant that the samples had slightly aromatic NOM but were still not as highly aromatic as the **P** samples.

SUVA values can also be used to indicate treatability. Edzwald & Tobiason (1999) presented guidelines for interpretation of SUVA, proposing that water with a higher SUVA (> 4) has an expected TOC removal of above 50%. This assertion was found to hold true in this study as the **P** samples had high SUVA values and thus had a % DOC removal of up to 85%.

Fluorescence excitation-emission matrices (FEEM) characterisation

The FEEM method is used as a technique for classifying and distinguishing between humic substances of various origins and natures. It is often used as a 'discrimination technique', i.e. it gives a distinction between humic-like (fulvic acids, humic acids and humin) or other NOM components (Weishaar *et al.* 2003). The principle of fluorescence is the ability of a molecule to absorb light of a certain wavelength

Table 3 | UV values at different wavelengths for the three rounds of sampling (in m^{-1})

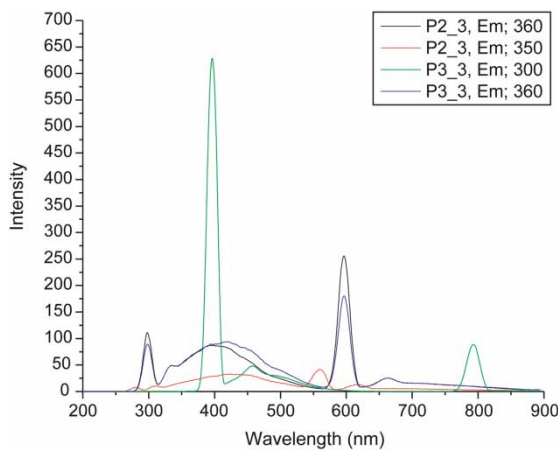
Sample	214 nm			254 nm			272 nm			300 nm		
	Round 1	Round 2	Round 3	Round 1	Round 2	Round 3	Round 1	Round 2	Round 3	Round 1	Round 2	Round 3
M1	72.9	38.9	75.5	14.1	17.4	29.9	11.7	14.0	24.7	7.6	8.3	18.1
M2	67.7	35.7	66.5	9.3	14.0	19.8	7.4	10.9	13.8	4.4	6.1	9.4
M3	63.5	32.6	55.9	15.7	12.0	15.3	14.0	8.8	12.4	11.7	4.7	8.7
M4	67.7	39.0	85.3	7.1	9.5	30.7	5.0	7.0	25.0	2.7	3.6	17.2
M5	–	–	60.2	–	–	17.7	–	–	14.3	–	–	10.0
R1	78.8	41.8	69.2	14.7	17.3	28.5	11.7	133	22.1	6.6	7.4	15.8
R2	78.6	36.6	52.3	9.6	12.2	15.4	7.2	9.2	12.5	3.6	4.7	8.8
R3	73.8	32.0	78.7	10.2	9.8	19.8	7.8	7.0	14.7	3.9	3.3	10.3
R4	81.0	–	63.4	8.3	–	14.6	6.1	–	11.9	2.9	–	8.3
O1	235.7	262.2	217.3	16.4	14.2	19.5	13.3	10.9	14.5	8.0	6.4	10.1
O2	198.6	141.3	205.2	14.2	13.6	19.0	11.3	10.3	15.5	6.9	5.4	10.9
P1	47.6	37.5	111.1	128.2	112.7	167.3	23.5	1.9	55.4	15.4	0.5	38.8
P2	24.5	15.6	23.3	16.1	61.7	18.5	4.3	0.4	4.4	1.4	1.3	1.6
P3	12.8	15.2	22.8	14.6	12.6	14.0	3.0	1.6	1.4	0.4	0.1	2.6
W1	41.8	44.3	38.0	1.4	1.8	4.0	6.0	0.8	0.4	1.1	0.5	2.0
W2	39.2	42.6	41.9	0.8	0.1	6.4	1.4	0.7	3.3	2.5	1.3	1.1
W3	37.9	42.8	27.2	0.01	0.2	12.0	1.9	0.6	9.0	2.9	1.3	4.5

and to emit light of another wavelength depending on specific molecular bonds (Hua *et al.* 2007). Usually, the absorption/emission wavelength pair is different for different groups of molecules, and hence aromatics can be differentiated from carbohydrates. FEEM attempts to give the structural information of NOM based on the UV absorption of the molecular group. Figures 2–5 show the results obtained for the **P** samples at different excitation-emission wavelengths (guided by the FEEM regions given in section 2.6). As can be seen from Figures 2–5, the **P** samples have a very broad peak occurring at 420–500 nm with a maximum intensity occurring at 600 intensity units. This peak is symbolic of hydrophobic acids, humic and humic acid-like material. At a different excitation, again the **P** sample has a broad peak occurring at 580–680 nm (Figure 5). This peak is symbolic of microbial by-products such as tryptophan-like and fulvic acid material. The intensity here is approximately 200 intensity units.

The results obtained for the other samples indicate that the samples had very low aromatic content, i.e. low humic substances, as evidenced by very narrow peaks or no peaks at all where peaks for humic substances were expected. The results are also in agreement with the SUVA values, which suggest that only the **P** samples contain a high hydrophobic NOM. The different spectrum displays the extent of the varying composition of NOM from place to place and season to season. The spectrum also displays the difference in the character of NOM as evidenced by the varying peak intensities. The results obtained after the second and third sampling indicate characteristic features of NOM (with different concentrations) similar to the ones from the first sampling. Even though FEEM analysis is not entirely conclusive, by comparing the data against standard literature fluorescence emission-excitation data, important inferences of NOM characteristics can be drawn.

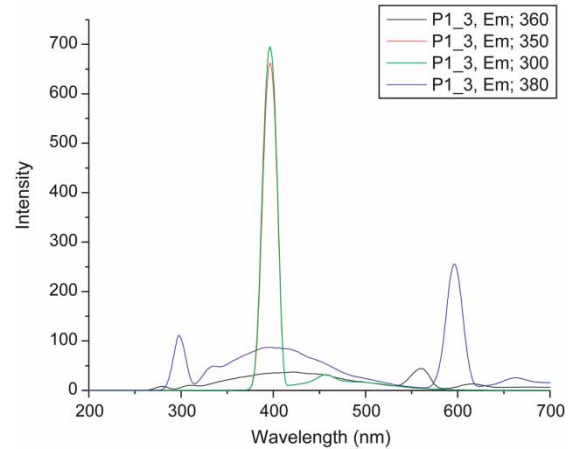
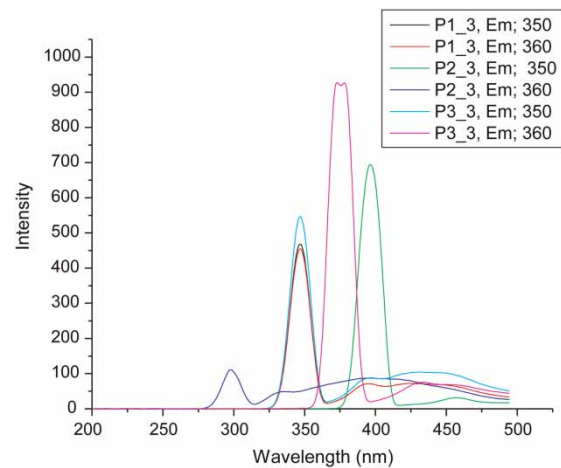
Table 4 | SUVA values for samples after first, second and third sampling

Sample	SUVA (L/mg m)		
	First sampling	Second sampling	Third sampling
R1	1.85	1.49	3.46
R2	1.41	1.11	2.43
R3	1.61	1.28	3.18
O1	1.65	1.49	2.17
O2	1.62	1.39	2.05
M1	1.86	1.92	3.54
M2	1.28	1.74	2.46
M3	2.32	1.29	2.64
M4	1.11	1.35	5.24
W1	0.30	0.56	1.25
W2	0.21	0.38	2.24
W3	0.01	0.08	10.34
P1	5.98	11.29	12.43
P2	4.18	2.36	5.42
P3	4.49	3.42	2.24

**Figure 2** | Excitation emission of the P samples before sand filtration.

Biodegradable dissolved organic carbon (BDOC) analysis

The BDOC gives a ratio of the BDOC content of any sample vs. the NBDOC content of that sample. Figures 6, 7 and 8 show the BDOC analysis of the samples obtained over the 6 day period. From a microbial perspective, the aim of drinking water treatment is to eliminate all pathogenic bacteria and to minimise the presence and potential regrowth of heterotrophic bacteria in the distribution system. Such regrowth can give rise to biofilm formation in pipelines

**Figure 3** | Excitation emission of the P raw water samples.**Figure 4** | Excitation emission of the P raw water samples and those before sand filtration.

which in the long run causes operational problems such as bio-fouling and bio-corrosion (Hammes & Egli 2005).

The percentage DOC removal of the samples ranged between 20 and 65% (Table 5). The highest percentage removal was noted for the P sample (65%) and the least for the W and M samples (20%). It has been reported by Volk et al. (2000) that water with high humic substances easily undergoes biological biodegradation as confirmed by the highest % BDOC removal of the P samples, which are highly coloured waters with a high concentration of humic substances. The lower % DOC removal was noted in the water that has low SUVA values (implying low humic substances content).

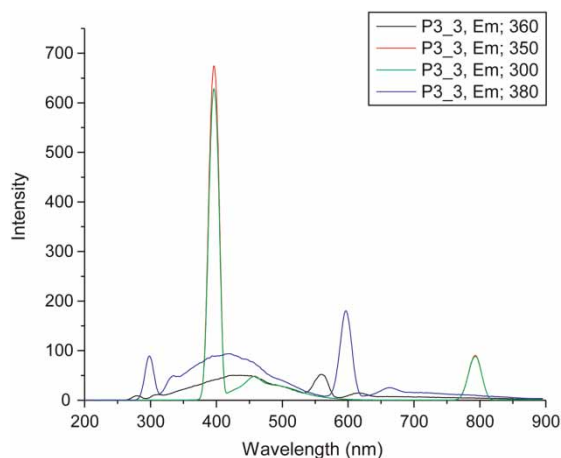


Figure 5 | Excitation emission of the P raw water samples after sand filtration.

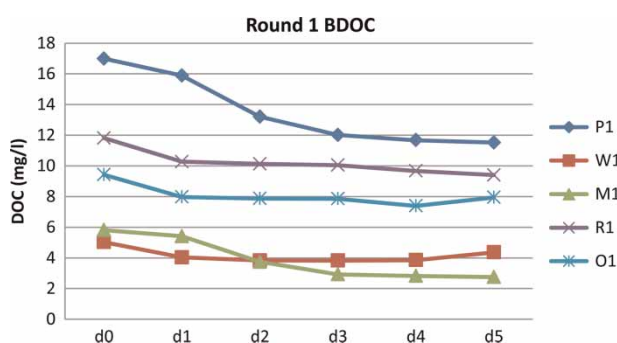


Figure 6 | BDOC and NBDOD results for the raw water samples after first sampling.

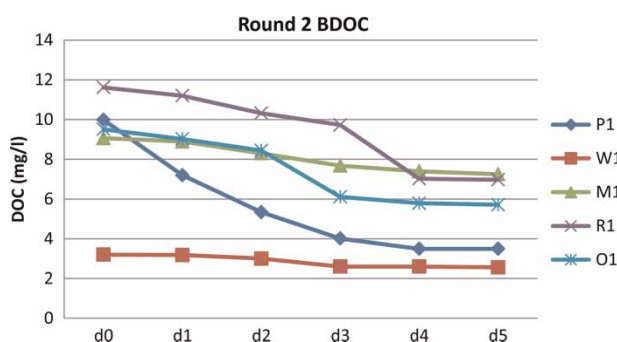


Figure 7 | BDOC and NBDOD results for the raw water samples after second sampling.

Eikebrokk (2004) suggested that the BDOC could be improved by about 10% through coagulation optimised for removal of DOC and particles. Generally, Eikebrokk argues that water containing high molecular weight hydrophobic fractions is more amenable to water treatment processes such as coagulation than waters with a low molecular

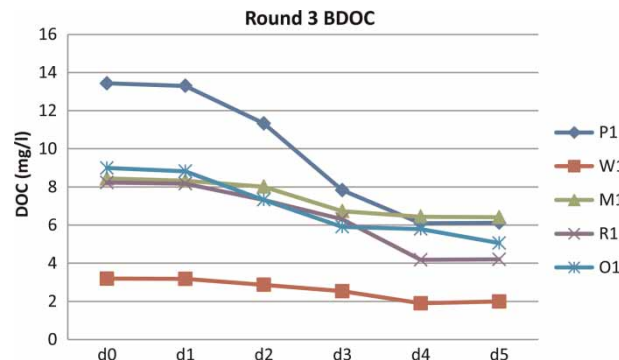


Figure 8 | BDOC and NBDOD results for the raw water samples after third sampling.

Table 5 | A summary of the BDOC and NBDOD of the raw water samples over the three rounds of sampling

Sample	BDOC (%)			NBDOD (%)		
	Round 1	Round 2	Round 3	Round 1	Round 2	Round 3
P1	32.2	65.0	54.4	67.8	35.0	45.6
W1	24.1	20.3	37.6	75.9	79.7	62.4
M1	52.7	20.0	24.1	47.3	80.0	75.9
R1	20.4	40.0	49.0	79.6	60.0	51.0
O1	21.5	40.0	43.7	78.5	60.0	56.3

weight fraction. This also explains the question of why water with high BDOC values (the P1 samples) had the highest DOC removal percentages compared to the low DOC removal percentages of the water with least BDOC (W1 and O1).

CONCLUSIONS

Characterisation results have given an indication of the character of NOM in all the water samples. UV-Vis and DOC results indicate that most of the samples were not aromatic in nature since they had relatively low UV absorbance at UV₂₅₄ (between 0.01 and 128.2 absorbance units). The various water treatment processes employed at the different treatment plants were able to effectively reduce NOM, as evidenced by a percentage DOC removal of up to 82% for the P samples. The turbidity of the samples was used as an indicator of the amount of clay particles and colloidal NOM. Some raw water samples (e.g. V) had a high turbidity value (114 NTU) indicative of a high amount of colloids in the raw waters. FEEM characterisation of the samples indicated that the P samples had

hydrophobic acids, humic and humic acid-like material but in varying proportions. The Wiggins (**W**) sample contained the least amounts of humic substances. For the BDOC analysis, the percentage DOC removal for the samples ranged from 20 to 65%. The highest percentage DOC removal in terms of BDOC was again noted in the **P** sample, further confirming that the NOM levels of highly coloured waters with high levels of aromatic substances are easy to treat. Knowing the NOM composition of the local water source is an important prerequisite for better understanding NOM and for designing water treatment plants for its optimal removal. The results presented in this paper clearly demonstrate the high variability of NOM in South African water treatment plants.

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