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Research Article

Characterization of Reverse Osmosis Concentrates from Drinking Water Reclamation Sources in Makurdi Metropolis-Nigeria

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Abstract

Reverse osmosis concentrate (ROC) is considered to be an obstacle in the production of high quality water from water reclamation and desalination plants using dense membrane systems. The ROC contaminants include many harmful micro-pollutants and nutrients in addition to the organics recalcitrant to biological treatment, the ROC can pose significant risks to environment and human health if discharged to receiving water environments without proper treatment. The increase in the number of drinking water companies that employ reverse osmosis technology in Makurdi metropolis has necessitated the current study. In this study, reverse ROC from two different sources (groundwater and surface water treatment companies) in Makurdi metropolis-Nigeria was monitored continuously for six months which covered both the rainy and dry season. Standard procedures for sampling and laboratory test were followed in analyzing the ROC samples.

The average seasonal values of the tested ROC parameters were compared with the USEPA Wastewater Discharge Limits as well as the FAO Irrigation Water Quality Standards. Results of the study revealed that the ROC were highly polluted and unfit for re-use in irrigation or discharge into surface water bodies and as such needs to be further treated onsite by the companies generating the waste.

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1. INTRODUCTION

Reverse osmosis (RO) membranes have increasingly been applied in portable water treatment, wastewater reclamation for agriculture, industry, and indirect potable water purposes [1]. However, an issue identified as one of the major drawbacks for the adoption of pressure-driven membrane processes is the need for additional treatment of the concentrate (brine) stream before final disposal or reuse [2].

According to Shahzad [3], reverse osmosis concentrate (ROC) is considered to be an obstacle in the production of high quality water from water reclamation and desalination plants using dense membrane systems.

RO treatment generates a high quality water stream and a reverse osmosis concentrate (ROC) stream which contains elevated levels of a wide variety of rejected inorganic constituents and natural organic matter (NOM); a major fraction of NOM are soluble humic substances (HS) which are the end product of the secondary wastewater effluents.

As ROC may also be associated with anthropogenic organics [4], its release into the environment needs to be managed carefully [5]. The ROC contaminants include many harmful micro-pollutants and nutrients in addition to the organics recalcitrant to biological treatment, the ROC can pose significant risks to environment and human health if discharged to receiving water environments without proper treatment. The organics present in the ROC are refractory to further biodegradation because these organics are originated from the secondary effluent that has been subjected to extensive secondary treatment [6].

While coastal water reclamation plants have the opportunity to discharge the RO concentrate directly into the ocean, inland facilities depend on controversial options such as surface water discharge, evaporation ponds, deep well injection and land applications. However, all these options are not sustainable or environmentally friendly [3] [5]. Therefore methods for proper disposal of RO concentrate especially for inland plants are urgently required According to Van der Bruggen *et al.*, [7], the first step toward the efficient management of ROC is the proper characterization of its various sources. ROC streams vary greatly in their compositions depending on the sources from which they are produced.

In Nigeria, there exists a wide range of water industries that utilize RO treatment for the production of portable water and or reclamation of wastewater for reuse. However, little attention is paid to the sustainable management of the secondary byproduct of the RO processes i.e. the ROC. Thus ROC streams from water corporations in Nigeria are generally disposed to land or surface water bodies without any form of treatment. This practice is globally unacceptable as its hold great potentials for environmental pollution.

In Benue State and Makurdi metropolis in particular, the trend is not different as there are numerous water industries springing up within the metropolis that utilize RO processes for the production of drinking water. Some of the industries obtain their raw water from groundwater sources while others get theirs from pre-treated surface water sources, which is a potential reason for the likely variability in the characteristics of the various ROC.

However, as far as the authors knowledge is concerned no study has reported the characteristics of ROC from municipal water reclamation processes in the study area. The present study therefore, aims at filling this gap by characterizing ROC from selected drinking water production companies in Makurdi metropolis. The study also covers the seasonal variability in the ROC by sampling both in the dry and wet seasons with a view to drawing valid conclusions aimed at sustainable management of ROC in the study area.

2. MATERIALS AND METHODS

2.1 Study Area

The study was carried out in Makurdi metropolis of Benue State. Makurdi is located on latitude $7^{0}43^{'}50^{''}$ N and longitude $8^{0}32^{'}10^{''}$ E, on the geographical map of Nigeria (Fig. 1). The town is located along the shore of River Benue and as such is famous for its vast agricultural activities where farmers mainly produce rice, maize, guinea corn, groundnuts and assorted vegetables and fruits.

The Makurdi climate is a tropical one with two seasons namely; the dry and wet seasons. The wet season is between April and October of each year, while the dry seasons begins in November and ends in March. The average annual temperature of Makurdi is about 32^{0}C and the relative humidity is between 65-69%. The average annual rainfall of the area is between 1000 – 2500mm. The vegetation is a guinea savanna comprising of grasses, trees and shrubs. The major occupations of residents of the town is civil service, trading and farming. As of 2006 (Census), Makurdi had an estimated population of 4,253,641 people.

2.2 Materials and Equipment

The materials and equipment used for the study included, half-litre plastic cans which were used for the collection of ROC samples from the selected locations over a period of six

(6) months. Samples were collected and analyzed in triplicates and the average values were recorded. Cell tapes were used to label each sample for easy identification. Some of the equipment used in the study were a digital pH meter for determination of pH, thermometer was used to temperature measurements, while a spectrophotometer was used for the determination of COD, calcium, magnesium, sodium, nitrate, chloride and phosphate concentrations in the ROC samples. Conductivity and TDS were determined using a TDS/conductivity meter. All reagents used were of analytical grade.

2.3 Sample collection and Analysis

Samples were collected in triplicate once every month for a period of 6 consecutive months to cover both the wet and dry seasons. Samples were collected from two sources: Aqua Fresh drinking water Company ROC (Plate 1) which uses groundwater (borehole) as its source of raw water. These samples are designated as sample A in this study. The second source of samples for this study were from V-Fresh drinking water Company, which uses pre-treated surface water from the Makurdi Water Works as its source of raw water. These samples are designated as sample B in the current study.

ROC characteristics such as pH and temperature were determined immediately after sample collection using a pH meter model H1 96107, manufactured by Hanna Instruments Italy and an environmental thermometer (ELE) model HPC7H15, respectively. They were then put in an ice-filled container and taken to the laboratory for further tests and analysis.

Samples were subjected to the following tests at the Benue State Environmental Sanitation Agency's Central Laboratory (UN- Assisted Project) in Makurdi; in accordance with the methods described by Iwar *et al.*, [8]. Chemical oxygen demand (COD), total dissolved solids (TDS), turbidity, conductivity, nitrates, phosphates, chlorides, magnesium, calcium and sodium. TDS and conductivity were determined using a TDS/Conductivity meter, HACH model CO 150, COD, nitrates, phosphates, chlorides, magnesium, calcium and sodium were determined using a portable data logging spectrophotometer, manufactured by HACH, model DR/2010]. Turbidity was determined using a turbidimeter Standard kit model 2100A. All samples were tested according to standard methods [9].

Figure 1: Map of Makurdi Town

Source:https://www.google.com/maps/place/Makurdi,+Nigeria/@7.7290891,8.555926,13z/data=!3m1!4b1!4m2!3m1!1s0x1050805458317acf:0x1acb339fc3ba1a3b.

Plate 1: Reverse Osmosis Unit of one of the Sampling Points

3 RESULTS AND DISCUSSION

The monthly values and means of the various parameters analyzed for the ROC samples are presented Tables 1 and 2 representing physical for the wet and dry seasons respectively, while the chemical properties for the wet and dry seasons are presented in Tables 3 and 4 respectively. The physical parameters determined were temperature, turbidity, and total dissolved solids, while the chemical parameters determined from the ROC samples were pH, COD, calcium, sodium, magnesium, phosphate, nitrate, chloride and electrical conductivity.

The average values of monthly means were used to compare with FAO irrigation standards [10] and the USEPA discharge standards [11]. The results of the comparison for the physical parameters during the wet and dry seasons are as presented in Table 5 and 6 respectively, while that for the chemical parameters for the respective seasons are as presented in Tables 7 and 8.

Table 1: Physical Characteristics of ROC Samples during the Wet Season

Parameter	**Months**								
	August			**September**			**October**		
	SA	**SB**	**Mean**	**SA**	**SB**	**Mean**	**SA**	**SB**	**Mean**
Temp. (^{0}C)	38.4	36.2	**37.2**	37.3	37.0	**37.15**	36.8	36.2	**36.5**
TDS (mg/L)	4680	2030	**3355**	4850	2080	**3465**	5200	2120	**3660**
Turbidity (NTU)	21.8	18.9	**20.4**	44.5	34.9	**39.7**	38.4	32.6	**35.5**

Table 2: Physical Characteristics of ROC Samples during the Dry Season

Parameter	Months								
	November			December			January		
	SA	**SB**	**Mean**	**SA**	**SB**	**Mean**	**SA**	**SB**	**Mean**
Temp. (^{0}C)	32.6	29.3.	**31.0**	31.5	30.0	**30.8**	28.3	26.8	**27.6**
TDS (mg/L)	5028	3430	**4229**	5560	3720	**4640**	5880	3760	**4820**
Turbidity (NTU)	18.2	12.6	**15.4**	21.8	17.4	**19.6**	28.6	21.7	**25.2**

Note:
SA = Sample A (Ground Water ROC)
SB = Sample B (Pre-treated Surface Water ROC)

3.1 Physical Characteristics of ROC

The physical characteristics of ROC from drinking water reclamation companies in the study area were determined for the wet season and the results are presented in Table 1. Those for the dry season are presented in Table 2. The results revealed that Temperature ranged between 36.2 – 38.4 ^{0}C for the wet season, while it ranged between 26.8 – 31.5 ^{0}C during the dry period. The TDS ranged from 2030 – 5200 mg/L and 3430 – 5880 mg/L for the wet and dry seasons respectively. Similarly, the turbidity values of the ROC ranged between 18.9 – 44.5 µs/cm and 12.6 -28.6 µs/cm for the wet and dry seasons respectively.

It was observed that the temperature was highest in the month of August in sample A (38.4 ^{0}C) and the lowest was observed with sample B in the month of January (26.8 ^{0}C). this is likely due to the influence of the ambient temperature of the study area which is usually higher during the dry seasons as compared to the wet season. Generally, the temperature of the ROC from sample A was observed to be higher than that for sample B throughout the period covered in the study. This can be attributed to the difference in the sources of raw water as well as the pressure generated in the reverse osmosis units during operations that lead to the generation of the ROC [5].

The TDS was observed to be higher in sample A as compared to sample B for each month covered in the study, with the highest (5880 mg/L) value occurring in the month of

December. The lowest TDS value (2030 mg/L) was observed in the month of August. This observation could be influenced by the source of the raw water used and also by the seasonal effects of rainfall. It is obvious that since sample A is a by- product of groundwater treatment, the TDS especially as it relates to the geology of the study area is expected to be higher than that from sample B which is a by-product of pre-treated surface water treatment. The high value of TDS in sample A was likely due to increase in dissolved salt content of the raw water during the wet season.

Similarly the turbidity of the tested ROC was observed to be higher in sample A as compared to sample B. The highest value (44.5 NTU) was recorded in the month of September, while the lowest value (12.6 NTU) was obtained in the month of November. The high value of turbidity in sample A during the peak of the wet season may also be as a result the increased dissolution of salts and organics in the raw water (groundwater) from where the ROC was generated. The low value obtained in sample B is likely because sample B was obtained from a pre-treated surface water reverse osmosis treatment process, which would have taken care of most of the constituent that would have contributed to turbidity values most especially during the dry season, when even the raw surface water is relatively not turbid.

3.2 Comparing Physical Characteristics of ROC with Wastewater Standards

The average values of the physical characteristic of ROC samples considered in the current study were compared with the USEPA Effluent Discharge Limits and also with the FAO Water Quality Standards for Irrigation. This was done for both the wet (Table 5) and dry seasons (Table 6).

It was observed that the ROC samples were highly polluted and as such, in all the months covered in the study, most of the physical parameters were extremely higher than the set limits for either discharge into the environment of for re-use for irrigated agriculture.

Most specifically, the average temperature of 37^0C in the wet season is more than 3^0C from the ambient and as such is not suitable for discharge into surface water bodies or even for re-use for irrigation purposes. This suggests that ROC obtained during the wet seasons must be cooled to acceptable limits before discharge of re-use for the purpose of irrigation. However, an average value of 29.8^0C was obtained in the dry season, which was found to be suitable for both irrigation and discharge purposes. Similarly, average turbidity values of 31.9 and 20.1 NTU for the wet and dry seasons respectively, were found to be higher than the stipulated range of 4 – 11 NTU for water meant for the purpose of irrigation. This again calls for the need to further treat ROC samples in the study area to remove pollutants of concern before they can be discharge into the environment of re-used in irrigated agriculture.

3.3 Chemical Characteristics of ROC

The chemical characteristics of the ROC samples during the wet season are presented in Table 3, while those for the dry season are presented in Table 4. From Table 3, it was observed that the values of COD, pH, electrical conductivity, nitrate, phosphate, calcium, magnesium, sodium and chloride in the wet season ranged between 450.6 – 826.7 mg/L, 8.0 – 8.9, 148 -288 µs/cm, 12.3 – 28.6 mg/L, 0.33 – 1.05 mg/L, 432 – 726 mg/L, 112 – 181 mg/L, 648 – 1786 mg/L and 628 – 1439 mg/L respectively.

Similarly the chemical characteristic of the studied ROC samples during the dry spell (Table 4) ranged between 584.8 -725.4 mg/L, 8.6 – 9.4, 145 -291 µs/cm, 9.5 – 18.9 mg/L, 0.22 -0.82 mg/L, 471 – 826 mg/L, 132 – 206 mg/L, 747 – 2425mg/L and 668 – 1622 mg/L for COD, pH, electrical conductivity, nitrate, phosphate, calcium, magnesium, sodium and chloride respectively.

It was generally observed that the values of the chemical parameters were higher during the dry season except for phosphorus and nitrate which had the highest values in the wet season. This observation may be as a result of the increase in nutrient content of runoff to the surface water bodies and the leaching of nutrients into the groundwater during the wet season from where the raw water was abstracted. The higher concentration of other chemical parameters in the ROC during the dry season may be as a result of the reduced water volumes during such periods, which further concentrates the pollutants in the source water as a result of reduced dilution effects [5].

Table 3: Chemical Characteristics of ROC Samples during the Wet Season

Parameter	Months								
	August			September			October		
	SA	SB	Mean	SA	SB	Mean	SA	SB	Mean
COD (mg/L)	450.6	680.2	**565.4**	520.3	630.9	**575.6**	465.0	826.7	**645.9**
pH	8.6	8.4	**8.5**	8.7	8.0	**8.4**	8.9	8.5	**8.7**

Elect. Cond. (µs/cm)	243	148	**195.5**	287	169	**228**	288	160	**224**
Nitrate (mg/L)	12.3	28.6	**20.5**	14.3	26.9	**20.6**	14.8	27.4	**21.1**
Phosphate (mg/L)	0.41	0.72	**0.57**	0.33	0.69	**0.51**	0.46	1.05	**0.76**
Calcium (mg/L)	625	432	**528**	628	491	**559.5**	726	621	**673.5**
Magnesium (mg/L)	156	112	**134**	168	129	**148.5**	181	128	**154.5**
Sodium (mg/L)	1238	648	**943**	1704	678	**1191**	1786	782	**1284**
Chloride (mg/L)	1382	628	**1005**	1439	658	**1048.5**	1395	684	**1039.5**

Table 4: Chemical Characteristics of ROC Samples during the Dry Season

Parameter	**Months**								
	November			**December**			**January**		
	SA	**SB**	**Mean**	**SA**	**SB**	**Mean**	**SA**	**SB**	**Mean**
COD (mg/L)	640.2	725.4	**682.8**	618.6	639.2	**628.9**	584.8	649.6	**617.2**
Ph	8.8	8.6	**8.7**	9.2	8.7	**9.0**	9.4	8.8	**9.1**
Elect. Cond. (µs/cm)	288	145	**216.5**	283	166	**224.5**	291	164	**227.5**
Nitrate (mg/L)	9.5	18.6	**14.1**	9.8	18.0	**13.9**	10.3	18.9	**14.6**
Phosphate (mg/L)	0.22	0.49	**0.36**	0.35	0.63	**0.49**	0.41	0.82	**0.62**
Calcium (mg/L)	739	471	**605**	802	611	**706.5**	826	569	**697.5**
Magnesium (mg/L)	184	132	**158**	206	147	**176.5**	198	129	**163.5**
Sodium (mg/L)	2348	821	**1584.5**	2385	747	**1566**	2425	756	**1590.5**
Chloride (mg/L)	1472	684	**1060**	1601	692	**1146.5**	1622	668	**1145**

More specifically, pH, electrical conductivity, calcium, magnesium, sodium and chlorides were found to be consistently higher in sample A throughout the period of the study. Conversely, COD, nitrate and phosphates were found to be consistently higher in sample B over the period covered. The more elevated values of COD obtained in sample B may be attributed to the use of chemicals such as polyelectrolyte, chlorine and alum during the pre-treatment of surface water, from which sample B was obtained. While the reason for the high values of phosphates and nitrate in sample B is as earlier explained. In the same vein, the higher values of calcium, magnesium, sodium, conductivity, pH and chlorides in sample a can be linked to the geology of the study area which is known to contain inorganics that are soluble in water. These soluble inorganics are found more in groundwater and are also responsible for the conductivity and pH values of ground water from where sample A is derived.

3.4 Comparing Chemical Characteristics of ROC with Wastewater Standards

Again the comparison of the ROC sample chemical characteristics with the USEPA Wastewater Discharge Limits and the FAO Irrigation Water Standards revealed that, the ROC samples were highly polluted and largely unsuitable for discharge into the environment or re-use for irrigation of crops.

More specifically, it was observed that only the electrical conductivity, magnesium and phosphate values of the ROC in both the wet (Table 7) and dry (Table 8) seasons conformed to both standards. All other parameters especially sodium and COD were extremely higher than the set limits for irrigation or discharge for each period covered in the study. This points to the fact that, ROC from drinking water reclamation industries hold great potentials for environmental pollution if they are not treated to acceptable limits before discharge or re-use.

Table 5: Comparing Physical Characteristics of ROC Samples during the Wet Season with Standards

Parameter	Months							
	August	**September**	**October**	**Range**	**Average**	**USEPA Diischarge Limits**	**FAO Irrigation Standards**	**Remark**
Temp. (^{0}C)	37.2	37.15	36.5	36.2-38.4	37	< 3^{0}C higher than ambient	Depend on season, location and sampling time	NS for both
TDS (mg/L)	3355	3465	3660	2030 - 5200	3493	30	0-2000	NS for both
Turbidity (NTU)	20.4	39.7	35.5	18.9 – 44.5	31.9	NA	4 – 11	NS for irrigation

Table 6: Comparing Physical Characteristics of ROC Samples during the Dry Season with Standard

Parameter	Months							
	November	**December**	**Janauary**	**Range**	**Average**	**USEPA Diischarge Limits**	**FAO Irrigation Standards**	**Remark**
Temp. (^{0}C)	31.0	30.8	27.6	26.8 – 31.5	29.8	< 3^{0}C higher than ambient	Depend on season, location and sampling time	S for both
TDS (mg/L)	4229	4640	4820	3430 - 5880	4563	30	0-2000	NS for both
Turbidity (NTU)	15.4	19.6	25.2	12.6 – 28.6	20.1	NA	4 – 11	NS for irrigation

Table 7: Comparing Chemical Characteristics of ROC Samples during the Wet Season with Standards

Parameter	Months							
	August	September	October	Range	Average	USEPA Discharge Limits	FAO Irrigation Standard	Remark
COD (mg/L)	565.4	575.6	645.9	450.6–826.7	595.6	150	NA	NS for discharge
pH	8.5	8.4	8.7	8.0 – 8.9	8.5	6 -9	6.5 – 8.4	NS for irrigation
Elect. Cond. (µs/cm)	195.5	228	224	148 – 288	215.8	NA	0 – 2000	S for irrigation
Nitrate (mg/L)	20.5	20.6	21.1	12.3 – 28.6	20.7	20	0 -10	NS for both
Phosphate (mg/L)	0.57	0.51	0.76	0.33 – 1.05	0.61	5	0 – 2	S for both
Calcium (mg/L)	528	559.5	673.5	432 – 726	587	0 - 500	0 – 400	NS for both
Magnesium (mg/L)	134	148.5	154.5	112 – 181	145.7	0 - 300	0 – 200	S for both
Sodium (mg/L)	943	1191	1284	648 – 1786	1139.3	0 - 500	0 – 920	NS for both
Chloride (mg/L)	1005	1048.5	1039.5	628 - 1439	1031	0 -50	0 -142	NS for both

Table 8: Comparing Chemical Characteristics of ROC Samples during the Dry Season with Standards

Parameter	Months							
	November	December	January	Range	Average	USEPA Discharge Limits	FAO Irrigation Standards	Remark
COD (mg/L)	682.8	628.9	617.2	584.8 – 725.4	643	150	NA	NS for discharge
pH	8.7	9.0	9.1	8.6 – 9.4	8.9	6 -9	6.5 – 8.4	NS for irrigation
Elect.	216.5	224.5	227.5	145 –	222.8	NA	0 - 2000	S for

Cond. (µs/cm)				291				irrigation
Nitrate (mg/L)	14.1	13.9	14.6	9.5 – 18.9	14.2	20	0 -10	NS for irrigation
Phosphate (mg/L)	0.36	0.49	0.62	0.22 – 0.82	0.49	5	0 – 2	S for both
Calcium (mg/L)	605	706.5	697.5	471 – 826	669.7	0 – 500	0 – 400	NS for both
Magnesium (mg/L)	158	176.5	163.5	132 – 206	166	0 – 300	0 – 200	S for both
Sodium (mg/L)	1584.5	1566	1590.5	747 – 2425	1580.3	0 – 500	0 – 920	NS for both
Chloride (mg/L)	1060	1146.5	1145	668 - 1622	1117.2	0 -50	0 -142	NS both

Note:
SA = Sample A (Ground Water ROC)
SB = Sample B (Pre-treated Surface Water ROC)
NA means “Not available”, NS means “Not satisfactory”, S means “Satisfactory”

4 CONCLUSIONS

In the present study, reverse osmosis concentrate (ROC) from two drinking water reclamation industries in Makurdi metropolis of Benue state-Nigeria were characterized over a period of six (6) consecutive months, covering both the wet and dry season. One of the companies obtain its raw water from a borehole (groundwater: sample A) while the other obtains its raw water from pre-treated surface water (Water works: sample B).

The study observed that ROC from both sources varied widely in terms of its physical and chemical characteristics. The ROC were found to be greatly polluted throughout the period of monitoring and were largely unsuitable for discharge into surface water bodies nor re-use for irrigation purposes based on the USEPA Wastewater Discharge Limits and the FAO Irrigation Water Standards. Generally, sample A was found to be more polluted as compared to sample B as a result of high level of dissolved inorganics in the raw water from were sample A was derived. It is therefore recommended that drinking water corporations in the study area should endeavor to treat their ROC before discharge or re-use for irrigation in other to avert the impending pollution crisis as a result of rising number of water companies in the area, which currently discharge their ROC to the environment without any form of treatment.

Also, further studies on the characterization of ROC in the study area should be conducted to cover the other months not covered in the current study, with a view to providing a more reliable data that will be useful for sustainable management of ROC generated in the area. Such studies could involve the characterization of ROC for micro and emerging contaminants such as pesticides, herbicides, phenols, endocrine disruptors, pharmaceuticals etc.

In the same vein, laboratory and pilot-scale studies on sustainable technologies for the treatment of ROC generated in the study area should be conducted in order to pave way for the full scale installation of such technologies.

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