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ORIGINAL RESEARCH ARTICLE

ANALYSIS OF GROUNDWATER POLLUTION FROM AN UNLINED CONSTRUCTED WETLAND SLUDGE DRYING BED

A. E. Adeniran[1*], O. I. Ajibola[2] and A. T. Aina[3]

[1]Department of Civil and Environmental Engineering, University of Lagos, Lagos, Nigeria
[2]Lagos State Building Control Agency, Ikeja, Lagos, Nigeria
[3]Works & Physical Planning Department, University of Lagos, Lagos, Nigeria

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ABSTRACT

Sludge drying beds (SBDs) are part of wastewater treatment processes where dewatering and reduction of water content from the substrate sludge take place to enhance caking and thus facilitate handling and disposal. In this study, the effect of the operation of an unlined drying bed of a constructed wetland for domestic wastewater treatment on the adjourning groundwater was investigated. Experimental boreholes for water quality monitoring were constructed downstream of the SBD prior to its operation. Preliminary investigations of the quality of water in the boreholes were carried out before the operation of the SBD. The concentration levels of pH, Conductivity, Total Dissolved Solids, Colour, Mn, Fe, SO_4, NO_3, Total Coliform and e-coli were used to empirically and statistically determine the level of pollution of the ground water during the operation of the SDB. The 2-way ANOVA at (α =0.05) showed that the operation of the SBD had statistically significant impact on the quality of the groundwater on all the observed parameters. For the parameters observed, $p<0.05$ ($p=0.00$ for the averages of pH, EC, TDS, Turbidity, Colour, Mn^{+2}, Fe^{+2}, SO_4 and NO_3), while $p=0.0028$ and 0.0018 for the averages of Total coliform and E.coli respectively in all the boreholes. The distances from the discharge point of the SDB were at 15m, 20m, 25m, 30m, 35m, 40m and 50m for boreholes 1, 2, 3, 4, 5, 6 and 7 respectively. Also, comparison of the means of the quality parameters with the allowable limits set by the Nigerian National Environmental Surface and Groundwater Quality Control Regulations (NSGQCR) indicated that the operation of the SBD rendered the quality of the groundwater unacceptable

1.0 Introduction

Pollution of water at any point in the hydrological cycle could prevent its availability in good quality for other users in the cycle (Tundisi, 2008, Varade *et al.,* 2017). Potential sources of groundwater pollution include untreated wastewater effluent, seepage from leaking sewers; shoddily built septic tanks, landfill leachate seepage, burial sites, unregulated animal husbandry sites, farming practices and solid waste dumping on the ground. These pollutants include liquids, organic substances, chemical substances and bacteria. Groundwater that is close to the surface, as obtained in unconfined aquifers, is more susceptible to pollution (Naseh et al., 2018).

Constructed wetlands are engineered systems that use natural functions of vegetation, soil, and organisms to treat wastewater. Depending on the type of wastewater the design of the constructed wetland has to be adjusted accordingly. Constructed wetlands have been used to treat both centralized and on-site wastewater. Similar to natural wetlands, constructed wetlands also act as a bio-filter and can remove a range of pollutants such as organic matter, nutrients, pathogens, heavy metals from the water (Maiga *et al.*, 2017). Constructed Wetlands (CW) have emerged as a natural form of wastewater treatment. CWs operations mimic nature and research has confirmed their suitability for effective and economic treatment of wastewater especially in the tropical regions (Mairi *et al.*, 2012; Olukanni and Kokumo, 2013 and de Anda *et al.*, 2018). Like all wastewater treatment processes, sludge is a by-product of CW wastewater treatment. Sludge contains low concentration of solids compared to its much higher water content. Dewatering aims at reducing the water content to enhance sludge handling for composting, land application and disposal purposes. SDB are the oldest method of sludge dewatering and are still used extensively in small to medium sized plants. This dewatering method easily produces a sludge cake with 25 – 40 percent solids and can exceed 60 percent solids with additional drying time (Qiao *et al.*, 2010).

Groundwater pollution poses a major threat whilst employing the sludge drying bed method, as the drained fluid percolates into the soil profile. Lagos State is increasingly dependent on groundwater for domestic and industrial water supplies (Balogun et al., 2017). According to Longe (2011), groundwater occurrence in the coast of Lagos can be classified as confined, semi-confined to unconfined dominated by sand and clay formations. Sandy unconfined aquifers have been reported to be susceptible to pollution (Odukoya et al., 2013, Naseh et al., 2018). The University of Lagos, where this study was carried out, takes 60% of its domestic water supply from groundwater aquifers both confined and unconfined (Adeniran, et al., 2013). The objective of this study was to investigate the effect of the operation of an unlined drying bed attached to a constructed wetland domestic wastewater treatment on the adjourning groundwater resources.

2. Materials and Methods

2.1 The study area

This study was carried out at the precinct of the constructed wetland located in the Service Area of the University of Lagos, Lagos, Nigeria. The study area lies between longitudes 3º 23′ 44″ E – 3º 23′ 48″ E and latitude 6º 31′ 7″ N – 6º 31′ 12″ N (Figure 1). The area falls within the Dahomey basin, which underlies a combination of inland, coastal and offshore regions that stretch through Ghana, Togo, Benin and Southwestern Nigeria. The region is characterized by high water tables within shallow aquifers with tropical weather conditions, lots of sunshine and excessive rainfall (Obaje, 2009). The University is bounded on the East by the Lagos Lagoon which empties into the Atlantic Ocean.

2.2 Constructed wetland wastewater treatment system

The SDB studied is part of the constructed wetland wastewater system for the treatment of part of the domestic wastewater generated in the University of Lagos main campus. The wastewater generated within the University community is conveyed through a network of sewers to the central sewage pumping station. The wastewater is then processed through the various unit operations including screening, aeration, anaerobic digestion, phytoremediation and slow sand

Corresponding author's e-mail address: eadeniran@unilag.edu.ng, engrea54@gmail.com

filtration (Figure 1). Sludge dislodging operation was carried out fortnightly from the anaerobic digester and the CW beds to the sludge drying bed and left to dry naturally by evaporation and drainage through the underlying sand. The dried sludge cakes are evacuated for disposal and land application. Prior to the introduction of the sludge drying bed and wetland treatment system, the sludge from the anaerobic chamber were openly discharged, without treatment, on the adjourning soil. The discharged sludge led to further degradation of the lagoon thus endangering human and aquatic life as observed by Longe and Ogundipe (2010).

2.3 The sand drying bed and observation wells

The sand drying bed lies about 10m downstream of the anaerobic digester with dimensions 15 x 20 x 1.5 m (Figure 1). The sidewalls were constructed in concrete to ensure stability and prevent collapse. A sand layer of 450 mm depth was placed over the bed. To monitor the groundwater pollution (if any), seven (7) down gradient experimental boreholes of 150 mm diameter (with screen casings) were drilled as part of the constructed wetland project by the University. The depth of each of the experimental boreholes was 10 m. The distances from the discharge point of the SDB were at 15m, 20m, 25m, 30m, 35m, 40m and 50m for boreholes 1, 2, 3, 4, 5, 6 and 7 respectively The constructed wetland and the observation boreholes were completely fenced to avoid anthropogenic activities influence.

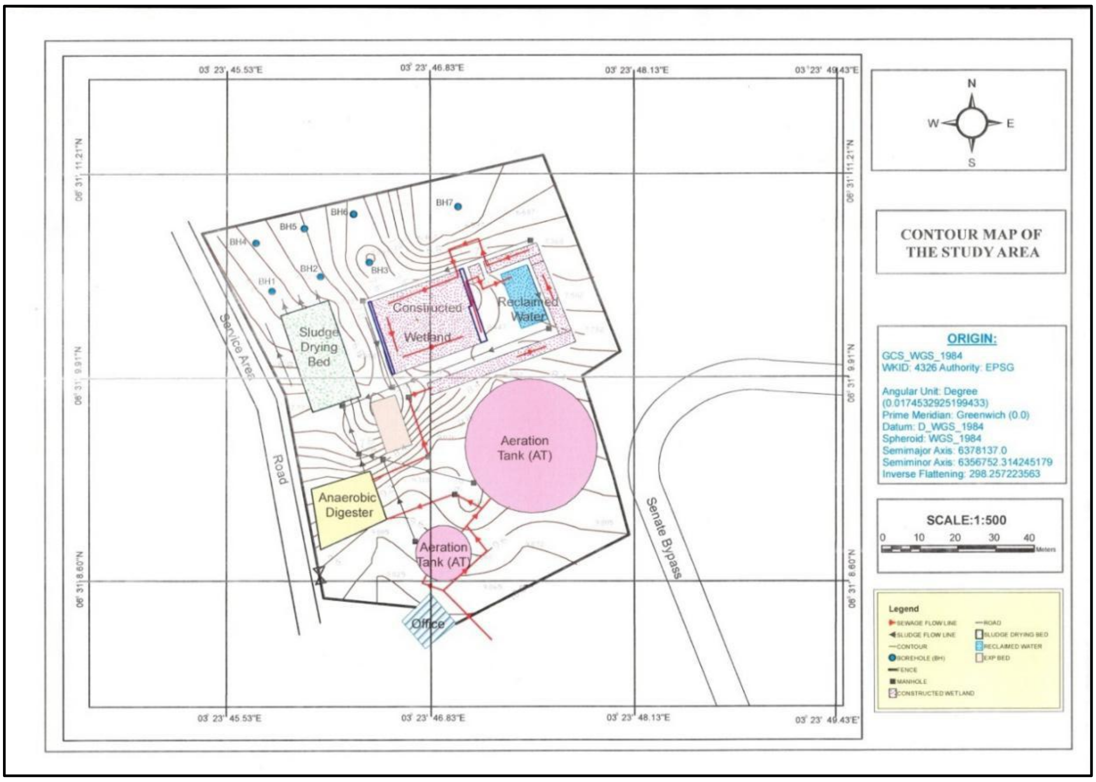

Figure 1: Contour Map of Study Area including Monitoring Boreholes

2.4 Collection and analysis samples

2.4.1 Experimental Boreholes

The experimental boreholes were monitored with preliminary samples collected for thirty (30) days and analysed to determine the quality of the groundwater before the operation of the SDB. During the operation of the SDB, groundwater samples were collected from the boreholes in accordance with US-EPA (2013) between the hours of 08.30 and 09.30 am. Sampling, at 5 m depth, was done daily for 50 days for physicochemical parameters while sampling for bacteriological parameters was carried out weekly for 8 weeks. The parameters monitored and analysed were pH, Electrical Conductivity, Total Dissolved Oxygen, Turbidity, Colour, Manganese, Ferrous, Sulphate, Nitrate, Coliform and e-coli.

2.4.2 Analysis of Samples

2.4.2.1 Laboratory Analyses

Analyses of samples were carried out using the American Public Health Association (APHA, 2012) Standard method for examination of water and wastewater (Eaton et al., 2012). All pH measurements were made using an Accumet XL50, Dual channel pH/ion/conductivity meter. Conductivity meter was calibrated with reference solution just prior to measurement of electrical conductivity (EC). The materials for the reference solution were deionized water, calibration standard, plastic cup and a thermometer. The temperature of the solution was adjusted to be in conformity with the standard calibration value provided by the manufacturer. TDS was measured using HM digital TDS meter. Turbidity was measured using Hach Dr 900 photometer. Colour was measured using Hanna HI83200 multi-parameter photometer. The concentration levels of Mn^{+2}, Fe^{+2}, SO_4 and NO_3 of the samples were measured with Thermo-Scientific X-Series2 ICP-MS spectrophotometer. Coliform and e-coli count were enumerated with pour plate method and identified using morphological and biochemical tests in accordance with APHA (2012).

2.4.2.2 Statistical Analysis

Data were analysed at $\alpha = 0.05$ using a two-way analysis of variance (ANOVA) on EXCEL^R Data Analysis to compare the means samples from preliminary investigation (samples obtained and analysed prior to the operation of the SDB) with the means results obtained during the operation of the SDB. The results obtained were compared with data in literature (where available). The means of the groundwater quality parameters obtained during the operation of the SDB were also compared with Nigerian National Environmental (Surface and Groundwater Quality Control Regulations, 2011 (NSGQCR, 2011) for surface and groundwater discharges, irrigation and reuse.

3. Results and Discussion

The results of means of the observed parameters before and during the operation of the SDB are presented in Tables 1 and 2 respectively. The summary of means, deviations and range of the observed parameters are presented in Table 3. In Table 4 the mean of the replicate concentrations of the quality parameters during the operation of the SDB are presented along with the maximum allowable limits by the Nigerian National Environmental (Surface and Groundwater Quality Control Regulations, 2011 (NSGQCR, 2011) for surface and groundwater discharges, irrigation and reuse. Table 4 shows that the observed concentrations of most of the physical, chemical and bacteriological parameters were beyond the limits specified by the regulatory authority. The operation of the SDB had seriously polluted the groundwater. Table 5 shows the output of ANOVA analysis of observed parameters (α=0.05). It is observed from the ANOVA that the operation of the SDB significantly affected the groundwater quality statistically.

Corresponding author's e-mail address: eadeniran@unilag.edu.ng, engrea54@gmail.com

Table 1: Mean of quality parameters in experimental boreholes before the operation of SDB

Parameters	Units	BH1	BH2	BH3	BH4	BH5	BH6	BH7
pH		4.48	4.59	4.54	4.43	4.43	4.43	4.64
Cond.	µS/cm	257.44	257.76	257.78	257.66	257.34	257.47	257.57
TDS	mg/l	80.57	79.82	79.65	79.53	79.48	79.45	79.41
Turbidity	FTU	0.51	0.42	0.52	0.55	0.48	0.45	0.45
Colour	PCU	30.47	31.16	31.06	30.46	30.63	31.14	31.24
Mn^{+2}	mg/l	0.51	0.60	0.53	0.52	0.55	0.41	0.47
Fe^{+2}	mg/l	0.04	0.05	0.05	0.05	0.05	0.04	0.05
SO_4	mg/l	2.89	2.87	2.88	2.88	2.88	2.88	2.87
NO_3	mg/l	2.53	2.65	2.71	2.61	2.74	2.72	2.73
Coliform	fu/100ml	2	1	2	1	1	1	0
e-Coli	cfu/100ml	0	0	0	0	0	0	0

Note: BH1, BH2, BH3, BH4, BH5, BH6, BH7 are Experimental Boreholes 1, 2, 3, 4, 5, 6 and 7 respectively.

Table 2: Weekly means of quality parameters in experimental boreholes during the operation of SDB

Parameters	Units	BH1	BH2	BH3	BH4	BH5	BH6	BH7
pH		6.83	6.88	6.81	6.66	6.68	6.42	6.82
Cond.	µS/cm	617.28	664.66	651.30	548.60	555.22	512.14	477.12
TDS	mg/l	543.90	551.98	533.04	527.58	495.66	496.74	395.56
Turbidity	FTU	24.48	26.78	25.55	24.15	24.70	23.69	21.89
Colour	PCU	335.76	368.32	362.76	273.50	284.04	345.96	242.12
Mn^{+2}	mg/l	2.37	2.46	2.30	1.88	1.58	1.70	1.13
Fe^{+2}	mg/l	36.63	39.15	31.01	24.67	21.26	20.88	10.90
SO_4	mg/l	61.93	67.01	60.52	58.43	57.99	56.97	46.83
NO_3	mg/l	65.55	71.04	46.77	49.07	40.24	28.26	23.65
Coliform	cfu/ml	942	1047	975	960	984	1036	776
e-Coli	cfu/100ml	14	13	18	16	19	14	12

Note: BH1, BH2, BH3, BH4, BH5, BH6, BH7 are Experimental Boreholes 1, 2, 3, 4, 5, 6 and 7 respectively

Table 3: Summary of observations before and during operation of SDB

Parameters		*Mean Before SDB*	*Mean During SDB*
pH		4.51±0.09	6.73±0.16
Cond.	*µS/cm*	257.57±0.17	575.19±71.03
TDS	*mg/l*	79.70±0.41	506.35±53.44
Turbidity	*FTU*	0.48±0.04	24.61±1.61
Colour	*TCU*	30.88±0.34	316.07±49.16
Mn^{+2}	*mg/l*	0.51±0.06	11.54±3.81
Fe^{+2}	*mg/l*	0.05±0.00	26.30±9.17
SO_4	*mg/l*	2.88±0.01	58.53±6.15
NO_3	*mg/l*	2.67±0.08	46.22±16.16
Total Coliform	*cfu/100ml*	1±0.05	960±83
e-Coli	*cfu/100ml*	0.0±0.0	15±2

Table 4: Comparison of observed parameters with Nigerian standard for drinking water

Parameters	Units	Observed Pollutant Level	NSGQCR, 2011	Comments
pH		6.73±0.16	6.5-8.5	Acceptable
Cond.	*µS/cm*	575.19±71.03	1000	Acceptable
TDS	*mg/l*	506.35±53.44	500	Marginally Acceptable
Turbidity	*FTU*	24.61±1.46	5	Not Acceptable
Colour	*TCU*	316.07±49.16	5	Not Acceptable
Mn^{+2}	*mg/l*	11.54±3.81	40	Acceptable
Fe^{+2}	*mg/l*	26.30±9.17	0.5	Not Acceptable
SO_4	*mg/l*	58.53±6.15	500	Acceptable
NO_3	*mg/l*	46.22±16.16	40.0	Not Acceptable
Total Coliform	*cfu/100ml*	960±83	10	Not Acceptable
e-Coli	*cfu/100ml*	15±2	0	Not Acceptable

Table *5:* Output of ANOVA analysis of observed parameters (α=0.05)

Parameter	SS	df	MS	F	P-value	F crit	Observation	Inference
pH	82.548	1	82.548	487.852	0.0000	4.1830	F>Fcrit; P<α	Statistically Significant
EC	1782476.355	1	1782476.355	303.070	0.0000	4.1830	F>Fcrit; P<α	Statistically Significant
TDS	2393786.247	1	2393786.247	678.072	0.0000	4.1830	F>Fcrit; P<α	Statistically Significant
Turbidity	8408.549	1	8408.549	70.876	0.0000	4.1830	F>Fcrit; P<α	Statistically Significant
Colour	1414055.224	1	1414055.224	317.001	0.0000	4.1830	F>Fcrit; P<α	Statistically Significant
Mn	1793.557	1	1793.5566	313.953	0.0000	4.1830	F>Fcrit; P<α	Statistically Significant
Fe	11377.843	1	11377.8427	29.814	0.0000	4.1830	F>Fcrit; P<α	Statistically Significant
SO_4	50672.420	1	50672.4202	201.470	0.0000	4.1830	F>Fcrit; P<α	Statistically Significant
NO_3	33075.1899	1	33075.1899	147.902	0.0000	4.1830	F>Fcrit; P<α	Statistically Significant
Coliform	3680938.373	1	3680938.373	20.2609	0.0028	5.5914	F>Fcrit; P<α	Statistically Significant
e-coli	894.952	1	894.952	23.5641	0.0018	5.5914	F>Fcrit; P<α	Statistically Significant

3. 1 *pH*

The mean pH of 4.51±0.09 was observed before the operation of the SBD. During the operation of the SDB, the mean pH values in the observation boreholes ranged from 6.42 to 6.88 (Table 2) with a mean of 6.73±0.16 (Table 3). The pH values in the observation boreholes were consistent with each other and ranged between 4.43 and 4.64 (Table 1). The pH level of the groundwater was altered through the operation of the SDB from an initial acidic level ranging from 4.51±0.09 to an almost neutral level of 6.73±0.16. This may be due to the alkalinity of the sewage sludge

Corresponding author's e-mail address: eadeniran@unilag.edu.ng, engrea54@gmail.com

(Table 3). A two-way ANOVA returned F=487.85 while F-critical=4.18; p=0.000<0.005, hence statistically significant (Table 5). The operation of the SDB altered the level of the ground water pH, though the observed levels are within acceptable limits recommended by the NSGQCR (Table 4). This is consistent with Kengne et al. (2014) who reported groundwater pH level of 6.91 after unplanted drying bed leachate percolation.

3.2 *Electrical Conductivity (EC)*

Electrical conductivity (EC) is a measure of the capacity of water to conduct electric current. It is an indication of the presence of high level of organic and inorganic nutrients in the water body. The conduction of current through a water solution is primarily dependent on the concentration of dissolved ionic substances such as salts. High amounts of dissolved substances can prevent the use of waters for irrigation and drinking, hence conductivity ranks as one of the most important inorganic water quality parameters. The lower the EC of a water sample, the better the quality of the water. Mean conductivity value of 575.19 ± 71.03µS/cm was obtained during the operation of the SDB, while a mean value of 257.64 ± 0.17µS/cm was obtained from preliminary investigations (Table 3). The deviation in the EC values were significant; F=303.07>F-critical (4.18), p=0.000<0.05 (Table 5). The levels of EC during the operation of the SDB were acceptable by NSGQCR standards (Table 4). The results are consistent with results obtained by Kengne et al. (2014), Sanko et al. (2014) and Pande et al. (2015) who obtained after pollution ground water qualities ranging from 6.61 to 523.6 µS/cm.

3.3 *Total dissolved solids (TDS)*

Total Dissolved Solids (TDS) are the total amount of inorganic salts and organic matter dissolved in a given volume of water. A high level of TDS is an indication of inorganic salts and organic matter pollution. A mean TDS value of 506.35±53.44 mg /l was obtained during the operation of the SDB while a mean value of 79.70 ± 0.41 mg/l prior to the operation (Table 3). The initial values of TDS in the boreholes range from 79.41 mg/l to 80.57 mg/l and were acceptable by NSO standards (Table 1). The TDS values ranging from 395.56 mg/l to 551.98 mg/l observed during the operation of the SDB (Table 2) were slightly higher than the regulatory value of 500mg/l (Table 4). Pande et al. (2015) reported TDS pollution values ranging from 789.6-811.4 mg/l. The concentration TDS in the observation boreholes during the operation of the SDB was marginally acceptable within the limits recommended by the NSGQCR standards (Table 4) though the analysis of variance indicated the change in the level of TDS that occurred during the operation of the SDB was statistically significant (Table 5).

3.4 *Turbidity*

Turbidity is the measure of relative clarity of a liquid, as turbidity makes water cloudy or opaque. Materials that caused turbidity include clay, silt and microscopic organisms. The mean turbidity value was 0.48 ± 0.04 FTU before the operation of the SDB, whereas the level during operation was 24.61 ± 1.46 FTU (Table 3). The Turbidity level of the groundwater during the operation of the SDB was observed to be higher than the regulatory value of 5 FTU (Table 4) hence the aesthetic quality of the groundwater has been altered by the operation of the SDB. Analysis of variance showed that the Turbidity level was statistically significant (Table 5). The turbidity level of the groundwater was significantly altered due to the operation of the SDB. Pande et al. (2015)

obtained values that ranged from 11.1 to 12.5 for groundwater quality after leachate percolation for the city of Dhanbad.

3.5 *Colour*

Colour is an aesthetic requirement for water. The initial perception of the consumer and acceptability of water for consumption or use will normally derive from the colour. Before the operation of the SDB, the colour of the groundwater of the study area was acceptable at a level of 30.88 ± 0.34 PCU and is less than the regulatory standard of 50 PCU (Table 1). The colour variation in of the groundwater was consistent and ranged between 29.5 and 31.9 PCU. During the operation of the SDB, the colour of the groundwater became clouded and not aesthetically acceptable. The trends of colour in the observation boreholes (BH) ranged between 93 PCU and 497 PCU with peak points around dislodging days. The mean value of colour was an unacceptable figure of 316.07 ± 49 PCU in accordance with NSGQCR standard (Table 4). Analysis of variance showed groundwater was significantly polluted (in respect to colour) as a result of the operation of the SDB (Table 5). Pande et al. (2015), using visual observation, reported alteration of groundwater from "very clear" to "pale yellow" and "light brown."

3.6 *Fe*

High presence of iron ions (Fe^{+2}) in water causes discolouration of sanitary wares and stains laundry. Iron concentrations in naturally occurring surface waters are normally low (< 0.1 mg/l) but can be higher in groundwater. A mean iron value of 26.30 ± 9.17 mg/l was obtained from the experimental boreholes during the operation of the SDB, while a mean value of 0.05 ± 0.00 was obtained from preliminary investigation (Table 3). The concentration of Fe^{+2} of the groundwater before the operation of the SDB was between 0.0 and 0.10 mg/l. The iron concentrations changed significantly during the operation of the SDB and ranged from1.5 and 14.7 mg/l. ANOVA analysis (Table 5) showed significant alteration to the iron concentration in the groundwater during the operation of the SDB. These concentration values in the groundwater during the operation of the SDB exceeded the NSGQCR maximum permissible level of 20.0 mg/l (Table 4) hence not acceptable. Pande et al. (2015) and Ohwoghere-Asuma and Aweto (2013) reported groundwater pollution levels for iron ranging from 17.28 to 18.60 due to sludge leachate.

3.7 *Manganese (Mn^{+2})*

Manganese ions (Mn^{+2}) is a chemical quality parameter in water. High concentration of Mn^{+2} in water has health implication including neurological disorder. The mean Mn^{+2}concentration of the experimental boreholes during the operation of the SDB was 11.54 ± 3.81 mg/l, while a mean of 0.51 ± 0.06 mg/l was obtained from preliminary data (Table 3). The levels of Mn^{+2} during the preliminary investigation were within the limits of NSGQCR standards and ranged between 0.0 and 0.99 mg/l while the observed. Manganese values from the experimental boreholes during the operation of the SDB varied widely between 2.40 and 29.70 mg/l and were below the NSGQCR standard of 40mg/l (Table 4). Krithika et al. (2017) obtained similar results. Analysis of variance, however, indicated statistical significance (Table 5) in view of the wide difference that occurred between the observation before and during the operation of the SDB.

Corresponding author's e-mail address: eadeniran@unilag.edu.ng, engrea54@gmail.com

3.8 *Sulphate (SO_4)*

Sulphate minerals can cause scale build up in water pipes similar to other minerals and may be associated with a bitter taste in water that can have a laxative effect on humans and young livestock. High level of sulphate is not desirable in water for domestic and industrial uses. A mean sulphate value of 58.53 ± 6.15 mg/l was obtained from the experimental boreholes, while a mean value of 2.88± 0.11 mg/l was obtained prior to the implementation of the sludge drying bed (Table 3). Before the operation of the SDB the observed concentrations of SO_4 ranged from 2.83 to 2.92 mg/l and were within the NSGQCR specified standard (Table 4). During the operation of the SDB, high values of 117, 119, 121, 125, 129 mg/l which were observed, though these were below the NSGQCR standard of 500 mg/l (Table 4), the operation of the SDB altered the level of SO_4 in the groundwater significantly (Table 5). Lower figures that ranged from 43.36-47.99 were reported for sludge leachate percolation by Pande et al. (2015).

3.9 *Nitrate*

Unpolluted natural waters usually contain only minute amounts of nitrate (Jaji *et al.,* 2007). In essence, nitrate is responsible for eutrophication. A mean Nitrate value of 46.22 ± 16.16 mg/l was obtained from the experimental boreholes during the operation of the SDB, while a mean value of 2.67 ± 0.08 was obtained from preliminary investigation (Table 3). The experimental borehole samples displayed show high fluctuation of NO_3 concentration reaching peak values during dislodging operation. The mean value of 46.22 ± 16.16 mg/l is not acceptable by NSGQCR standard (Table 4) and it is an indication of groundwater pollution. Analysis of variance showed that the operation of the SDB had statistically significance on the nitrate level of the groundwater (Table 5). Łuczkiewicz and Quant (2007) obtained NO_3 value in groundwater of 80 ±10.0 after land application of sewage sludge.

3.10 *Total Coliforms*

Coliforms are a large group of bacteria that inhabit the intestinal tract of humans and animals that may cause disease. Coliform presence is an indicator of faecal or sewage pollution in water, which impact negatively on odour, taste and turbidity. A mean coliform value of 960 ± 83 cfu/100ml was obtained from the experimental boreholes during the operation of the SDB, while a mean of 1.00±0.05cfu/100ml was obtained from preliminary observations (Table 3). Before the operation of the SDB the Total Coliform concentration in the ground water was acceptable and was between 0 and 5.0 cfu/100ml. The experimental borehole Coliform levels, during the SDB operation, ranged from 105 to 1,800 cfu/100ml, which exceeds the NSGQCR limits (10 cfu/100ml) for drinking and recreational purposes (Table 4). Valenzuela et al. (2009) and Adeyemi et al. (2007) reported Total Coliform groundwater pollution raging from a mean of 225 to 440 cfu/100ml and 140 to 271 cfu/100ml respectively due to sludge leachate. As shown in Table 5, ANOVA showed that the operation of the SDB significantly altered the Total coliform level of the groundwater. The implication is that the groundwater has become unsuitable for use or discharge into

3.11 *E. Coli*

E. coli is a species of diseases causing coliform bacteria specific to faecal material from humans and other warm-blooded animals. E.coli is widely preferred above other coliform as an indicator of faecal contamination of water sources. A mean E-coli value of 0±0 cfu/100ml was observed during the preliminary investigation before the introduction of the SDB. However, during the operation of the SDB an unacceptable high level of E.coli pollution was observed in all the monitoring boreholes (Table 2). The value of E.coli during the operation of the SDB is consistent with dislodging operation and ranged from 3 cfu/100ml to 31 cfu/ml. The E.coli in the observation wells during the operation of the SDB was 15.0±2.0 cfu/100ml (Table 3). Mendoza et al. (2017) obtained similar results of (3.6-23 cfu/100ml E.coli groundwater pollution due to leachate percolation. The concentration of E.coli in the ground water exceeded the NSGQCR limits of 0 cfu/100ml (Table 4). Analysis of variance showed that the operation of the SDB had statistically significance E. coli concentration level in the groundwater (Table 5). As a result of its operation, the groundwater at the precinct of the SDB was no longer safe for discharge into water bodies or for direct usage.

4.0 Conclusion

Groundwater pollution induced by the operation of the sludge drying bed attached to the constructed wetland domestic sewage treatment plant of the University of Lagos was investigated. Samples were taken from seven down gradient boreholes downstream of the sludge drying bed for various physicochemical and biological analyses. The obtained water quality parameters were compared with the results from preliminary data obtained from the boreholes before the implementation of the sludge drying bed. Increase in the various parameters was observed in the borehole samples when the SDB was in operation. Analysis of variance was carried out for each of the water quality parameters investigated. It was observed that, statistically, the operation of the SDB significantly altered the ground quality parameters. In almost all the parameters investigated, the values were in excess of the Nigerian regulatory body (NSGQCR) standard for drinking water. The concentration values of the parameters during the operation of the SDB were much higher than those obtained from the boreholes prior to the operation of the SDB. The NSGQCR standards for the parameters were exceeded (indicating groundwater pollution), with the exception of pH, Mn and SO_4. It is recommended that a layer of well compacted clay should be provided to avoid groundwater pollution. Also, before the construction of drinking water boreholes in the precincts of sludge drying beds, septic tank soak pits etc., thorough groundwater quality investigations including physical, chemical and biological analysis should be conducted.

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Corresponding author's e-mail address: eadeniran@unilag.edu.ng, engrea54@gmail.com

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Corresponding author's e-mail address: eadeniran@unilag.edu.ng, engrea54@gmail.com

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Corresponding author's e-mail address: eadeniran@unilag.edu.ng, engrea54@gmail.com