A paradigm Shift in the Compliance Monitoring of Wastewater Quality and Reporting in the Oil and Gas Industry.

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Abstract
A paradigm shift in the Compliance Monitoring (CM) reporting for management decision to assess sustainability and compliability instead of the present method of indicating individual parameter approach was carried out in the treated oily waste water of a flow station in Delta State, Nigeria. For a period of six months, treated oily waste water was sampled weekly and subjected to standard methods of analysis for some quality parameters. Water quality indexing (WQI), which expresses the overall water quality at a specific location and time based on the various quality parameters, was used to analyse the data obtained. The outcome of the analysis indicated "Excellent water" that can be released into the environment, suggesting that the flow station's operational activities did not adversely affect the environment of the region and time period under study. In order to improve Compliance Monitoring (CM) reporting in the oil and gas industry, it is recommended that a critical examination and potential adoption of this approach be conducted.

Key words: Compliance Monitoring, Quality Parameters, Water Quality Index, oil and gas.

1. Introduction
Compliance Monitoring of effluents (waste water) is a routine exercise carried out monthly in the oil and gas industry to safe guard the quality of the different segments of our environment in all oil and gas locations in Nigeria. In line with the Department of Petroleum Resources (DPR) green book – Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN), (Section E, Subsection 3.6.3.1 which states that disposal of oily waste water shall be permitted in Inland/Near shore areas, if treated to meet the limitations as on Table III.1 and others.[1] The implication of this is that before oily waste water is discharged into the environment, be it onshore, near shore or offshore there is need to carry out a quality analysis of such waste waters that will be discharged into the environment in a way of safeguarding the immediate environment, seeking for compliance to the regulation and sustainability of their operations. The effects of such waste waters on the terrestrial and aquatic resources of the immediate environment and beyond are common knowledge to all, how devastating and sometimes annoying it can be and in line with international best practices in the industry, operators must endeavour to keep their work places and the environment in its natural state for sustainability.

Good as the policy is the communication line of the outcome of the environmental monitory exercise still looks vague especially to an unprofessional and the general public, sometimes even to some management staff. [2-5] Presently, we have a reporting system (Table 1) were we compare the respective values of the outcome of the analysis to the various regulatory standards and try to point out particular parameter(s) which is/are above the stated standard guideline(s). This looks a bit absurd scientifically without indicating the general quality of the waste water in question to the understanding of the general public.

Table 1: Present reporting system of wastewater (effluent) analysis to the Department of Petroleum Resources

S/N	PARAMETERS	Week				Monthly Average	(DPR /FMEnv) Limits
		1	2	3	4		
1	pH	8.3	6.5	5.8	6.8	6.9	**6.5**
2	Temp(^oC)	31.2	29.8	28.8	28.6	29.6	35.0
3	TDS (mg/l)	165.0	90.3	184.0	174.0	153.3	600.0
4	EC (µS/cm)	256.0	180.5	275.0	263.0	243.6	10000.0
5	Turb(NTU)	2.4	4.2	3.7	3.3	3.4	2000.0
6	TSS(mg/l)	4.0	6.0	6.0	5.0	5.3	5000.0
7	DO (mg/l)	1.4	1.7	1.2	3.8	2.0	(6.0)
8	BOD (mg/l)	1.5	1.3	1.3	1.4	1.4	10.0
9	COD (mg/l)	2.7	2.4	2.4	2.7	2.5	10.0
10	THC (mg/l)	6.7	7.9	9.2	7.7	7.9	10.0
11	Pb^{2+} (mg/l)	0.000	0.001	0.005	0.020	0.007	0.050
12	Fe (mg/l)	0.002	0.007	0.005	0.011	0.006	1.000
13	Zn^{2+}(mg/l)	0.003	0.005	0.003	0.005	0.004	0.500
14	Cu^{+2} (mg/l)	0.006	0.000	0.002	0.000	0.002	1.500
15	Cr (mg/l)	0.000	0.000	0.002	0.000	0.001	0.300

Source: data from the first months' (January) field trip.

Table 1 above looks ambiguous to the ordinary eyes hence difficult to understand and interpret to the understanding of the general public. This paper therefore seeks to propose a reporting system that has to do with the overall quality of the said water that will assure the general public and management about the status of the waste water to be discharged into the environment.

In any industrial process especially in the oil and gas industry, large volumes of water are constantly extracted and used as coolants or co-produced (Produced Water) in the production processes [1,6,7] and these water are ultimately discharged into the environment as wastewater. Imagine a situation were such waste water are not treated, tested in the laboratory for its quality, the report documented and made known in such a way that is understandable to all and sundry, the issues that will arise. The laws guiding the oil and gas industry, which is under the Department of Petroleum Resources (DPR) of the Federal government of Nigeria stipulates that such used or waste waters must be treated, subjected to laboratory analysis and the result properly documented and reported periodically so that the general public and off cause the host communities will be aware of the safe management of the water and other natural resources. Where this is not done or the report not properly communicated to the understanding of all, it could lead to civil crises and ultimately shutting down of such production facility as is in the case of Ogoni land in Rivers State. [8,9] Revenue coming from that axis to the national purse and employment opportunities for the teaming population of the country is now stopped out for some years now. [10]

This study therefore seeks a paradigm shift in the reporting system that has to do with the general quality of the said water that will assure the general public and management about the status of the waste water discharged into the environment. The reporting system being proposed here is 'water quality indexing'. The specific objectives of this study are as required by EGASPIN [1] weekly wastewater samples was obtained from a flow station under the Nigerian Petroleum Development Company (NPDC) Benin in Edo State and analysed in the laboratory for six months; results obtained at the end of each month was subjected to quality indexing using national and international standards and report was stated in an easily comprehendible manner at the end of each month and also the end of the study.

Water quality refers to the chemical, physical and biological characteristics of water. [5,11,12] It is a measurement of the state of water in relation to the needs of one or more biotic species and/or any human need or purpose.[13] In order to keep the health of any aquaculture system at an optimal level, certain water quality indicators or parameters (pH, Temperature (^oC), Salinity (as Chloride), Total dissolved solids, Turbidity, Total suspended solids, Chemical oxygen demand, Biochemical oxygen demand, Total hydrocarbon, Cu^{2+}, Zn^{2+}, Fe (total) and Cr^{6+}, etc.) must be monitored and controlled.[1] Water quality index (WQI) provides a single number that expresses the overall water quality (e.g., excellent, good, poor, etc.) at a certain location and time based on several water quality parameters.[5,12,14-16] The objective of WQI is to turn complex water quality data into information that is understandable and usable by management and the general public. A number of indices have been developed to summarize water quality data in an easily expressible and easily understood format.[5,17-19] The WQI which was first developed by Horton in the early 1960s is basically a mathematical means of calculating a single value from multiple test results. [5,15,19,20,] The index result represents the level of water quality in a given water system, such as lake, river or stream, water treatment facility etc. After Horton, a number of workers all over the world developed WQI based on rating of different water quality parameters.[5,15,20] Basically a WQI attempts to provide a mechanism for presenting a cumulatively derived, numerical expression defining a certain level of water quality. [5,19,21,22]

The use of water quality index (WQI) simplifies the presentation of results of an investigation related to a water system as it summarises in one value or concept a series of parameters analysed. In this way, the indices are very helpful for transmitting information about water quality to the wider populace, and they give a good idea of how water quality evolves over time. A single WQI value makes information more easily and rapidly understood than a long list of numerical values for a large variety of parameters; it assist policy makers and the public to avoid subjective assessments and subsequent biased opinions; additionally, WQI also facilitates comparison between different sampling sites and events. [23,24] Inadequate management of water resources directly or indirectly results in the degradation of hydrological environment which is not sustainable.

2. Methodology

2.1 Sample collections and preservation

In line with Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN, 2018), oily wastewater known in the industry as Produced water (or effluents) was collected from the oily waste water treatment facility once in a week on a monthly basis from a flow station (Ughelli) which is under the auspices of National Petroleum Development Company in Benin, Edo State and brought to the laboratory for analysis using recommended list of Standard Method of analysis approved by American Public Health Association [25] and American Standard of Testing Materials (ASTM) [26] as stipulated in Part VIII (D) Section 2.0 of EGASPIN [1]. Sampling cans were properly washed with detergent (apart from the ones for Biochemical oxygen demand) and rinsed copiously with tap water and distilled water. Containers (500 ml plastic cans) for metal ion determinations were later soaked in 1:10 nitric acid for 48 hours after which they were rinsed with deionised/distilled water. Samples for total hydrocarbon (THC) were collected in clean 500ml glass bottles with screw caps. At the point of collection each of the sample cans were rinsed twice with sample. In order to prevent sample misidentification, specific details on sample identification were entered on a permanent label and attached to each sampling cans. Samples were preserved and transported according to the recommended procedures [1] in order to avoid sample degradation and transformation. Samples for the determination of physico-chemical parameters were preserved and transported in iced chest at 4°C while those collected for the determination of THC, were preserved with 1-mL 1+1 sulphuric acid per liter to pH <2 before inserting them in the ice chest. Samples for the determination of metal ions were preserved with 1-mL 1+1 nitric acid per liter to pH <2 before inserting them in the ice chest.

2.2 Analytical methods

The pH, temperature, dissolved oxygen (DO), total dissolved solids (TDS), electrical conductivity (EC), and salinity as chloride of the samples were determined in-situ at the station using pre-calibrated and rinsed standard meters - Palintest/Wagtech Models [27] according to the various stipulated methods in EGASPIN [1]. Results of such analysis were recorded in the field logbook. Turbidity of collected samples were analysed the same day (in the field) using a Wagtech turbidimeter as described in [25]. Total suspended solids were determined with a Hach Spectrophotometer at a wavelength of 810nm. The digital displayed value was recorded in mg/l (APHA 208D – [25]). Chemical oxygen demand (COD) was determined using the closed reflux method (APHA 5220-D- [25]), where 2 mL of the sample is refluxed and digested in a strongly acidic solution with a known amount of excess of potassium dichromate ($K_2Cr_2O_7$). After digestion, the excess un-reacted potassium dichromate was read with a spectrophotometer at 600-nm. Biochemical oxygen demand (BOD_5) was determined by the respiromatory method of Velp Scientifica 2003 using BOD sensor [28], Total hydrocarbon (THC) was determined according to ASTM D3921 [28] method. The whole sample 500ml was poured into a separatory funnel and extracted three times with 30 mL of the extracting solvent (xylene). The combined extract was filtered through 10g of anhydrous sodium suphate and the spectrophotometer reading taking which gives the THC value. Each of the values was then calculated from the calibration graph into mg/l in line with the method. The metal/metal ions (Lead ions (Pb^{2+}), Copper ions (Cu^{2+}) , Zinc ions (Zn^{2+}), total Iron (Fe) and Chromium ions (Cr^{6+})) were determined with the aid of flame Atomic Absorption Spectrometer - Buck Scientific 205 Model.

The regulatory standard for each of these parameters used is that of the Federal Ministry of Environment of Nigeria and that of Department of Petroleum Resources. Laboratory results (Quality data) for each of these parameters from the flow station was subjected to data analysis using 'Microsoft Excell 2003' and the new method of reporting given below.

2.3 Computation of Water Quality Index

The calculation of the WQI was done using weighted arithmetic water quality index which was originally proposed by [29], developed by [30] and used by several workers. [5,11,16,19,31-35] in reporting water quality. The weighted arithmetic water quality index (WQI) is in the following form:

$$WQI = \frac{\sum Wnqn}{Wn} \quad (1)$$

where *n* is the number of variables or parameters,
Wn is the relative weight of the *i*th parameter (water quality parameters e.g. pH, Temperature, etc.) and

qn is the water quality rating of the *ith* parameter.

The unit weight (*Wn*) of the various water quality parameters are inversely proportional to the recommended standards (S_n) for the corresponding parameters.

$$Wn = \frac{k}{s_n} \tag{2}$$

Proportionality constant " k " value using the formula

$$k = \left(\frac{1}{\frac{1}{\sum_{n=1}^{n} s_n}} \right) \tag{3}$$

where s_n is standard permissible for nth parameter.

The quality rating for nth parameter (qn) where there are n parameters is calculated as

$$qn = 100 \left\{ \frac{(v_n - v_{io})}{(s_n - v_{io})} \right\} \tag{4}$$

Where v_n = Estimated value of the nth parameter of the given sampling station.

v_{io}= Ideal value of nth parameter in pure water (i.e., 0 for all other parameters except the parameters pH and Dissolved oxygen [7.0 and 14.6 respectively])

s_n = Standard permissible value of the nth parameter.

Table 2: Classification of water quality based on weighted arithmetic WQI method

Water quality Index Level	Water quality Status
0 – 25	Excellent
26 – 50	Good
51 – 75	Poor
76 – 100	Very Poor
Above 100	Unsuitable

Sources: [5,36]

A working template for each month's data and the six months data was generated in "Microsoft Excel 2003" using equations 1 to 4 and equation 1. With this template (file attached as an addendum) all that is required is to key in the laboratory data (Vn) into the template by the environmental officer or consultant and the respective WQI will be obtained.

2.4 Percentage compliance

The percentage compliance was obtained from the weekly report e.g. supposing from the field work we have Week 1 = good water, week 2 = good water, week 3 = excellent water and week 4 = poor water, then the compliance level can be stated as thus

$$\frac{4-1}{4} \times 100 = 75\%$$

3. Results and Discussion

The monthly result of the compliance monitoring of wastewater quality from the crude oil flow station is as presented (in the proposed reporting system) in Table 3, while that of the six months results is as presented (in the proposed reporting system) in Table 4 below.

Table 3: WQI of the first monthly oily waste water of the flow station of the study

S/N	PARAMETERS	Week 1	Week 2	Week 3	Week 4	Monthly Average	Sn (FMEnv) /DPR	[1]Computer template for calculation of water quality status
1	pH	8.3	6.5	5.8	6.8	6.9	**6.5**	
2	Temp(^{o}C)	31.2	29.8	28.8	28.6	29.6	35.0	
3	TDS (mg/l)	165.0	90.3	184.0	174.0	153.3	600.0	
4	EC (µS/cm)	256.0	180.5	275.0	263.0	243.6	10000.0	
5	Turb(NTU)	2.4	4.2	3.7	3.3	3.4	2000.0	
6	TSS(mg/l)	4.0	6.0	6.0	5.0	5.3	5000.0	
7	DO (mg/l)	1.4	1.7	1.2	3.8	2.0	6.0	
8	BOD (mg/l)	1.5	1.3	1.3	1.4	1.4	10.0	
9	COD (mg/l)	2.7	2.4	2.4	2.7	2.5	10.0	
10	THC (mg/l)	6.7	7.9	9.2	7.7	7.9	10.0	
11	Pb^{2+} (mg/l)	0.000	0.001	0.005	0.020	0.007	0.050	
12	Fe (mg/l)	0.002	0.007	0.005	0.011	0.006	1.000	
13	Zn^{2+}(mg/l)	0.003	0.005	0.003	0.005	0.004	0.500	
14	Cu^{+2} (mg/l)	0.006	0.000	0.002	0.000	0.002	1.500	
15	Cr (mg/l)	0.000	0.000	0.002	0.000	0.001	0.300	

WQI = SWnqn/SWn	2.2	3.1	9.6	34.4
Monthly Ave of WQI	12.3			
Water quality status	**Excellent water**			
Percentage compliance	**100%**			

[1] Template in 'Microsoft Excel' is attached as an addendum

The raw weekly data obtained from the laboratory for each month (the columns marked in blue colour) as presented in Table 1 were subjected into the developed template (Microsoft Excel file attached as an addendum) derived from equations 1 to 4 which simply gives the final result as indicated in the last row of Table 3 (Excellent, Good, Poor, Very Poor, and Unsuitable water) below. For the whole study duration (six months) the report can also be represented as shown in Table 4 where each monthly average is entered into the template (the columns marked in blue colour) and the result obtained as Excellent, Good, Poor, Very Poor, or Unsuitable water to be discharged into the environment. The coloration of the water quality status (which will be green if it is Excellent or good, Red if it is Poor and very Poor and Dark red if it is Very Poor or Unsuitable) and percentage compliance (Green if it is 100% -50% and red it is 49%- 0%) from the template will also give more meaning and understanding of the report.

Table 4: A summary of the six months wastewater result for the flow station

		Monthly						Sn	
S/N	PARAMETERS	Jan	Feb	Marh	Apr	May	Jun	(FMEnv)/DPR	
1	pH	6.9	7.4	7.2	6.5	6.6	6.1	**6.5**	[1]Computer template for calculation of water quality
2	Temp(°C)	29.6	31.9	30.6	31.1	31.1	31.0	35.0	
3	TDS (mg/l)	153.3	116.6	27.4	25.1	21.1	19.6	600.0	
4	EC (µS/cm)	243.6	179.4	41.2	40.9	36.9	31.6	10000.0	
5	Turb(NTU)	3.4	2.6	1.5	2.6	1.5	2.5	2000.0	
6	TSS(mg/l)	5.3	5.5	3.3	4.5	3.8	5.8	5000.0	
7	DO (mg/l)	2	2.6	3	3.6	3.2	2.8	6.0	
8	BOD (mg/l)	1.4	1.6	1.2	1.3	1.3	1.5	10.0	
9	COD (mg/l)	2.5	3.2	2.3	2.8	2.4	2.9	10.0	
10	THC (mg/l)	7.9	0.0	0.0	0.0	0.0	0.3	10.0	
11	Pb^{2+} (mg/l)	0.010	0.000	0.000	0.000	0.000	0.000	0.1	
12	Fe (mg/l)	0.006	0.000	0.000	0.000	0.000	0.010	1.0	
13	Zn^{2+}(mg/l)	0.004	0.000	0.000	0.000	0.000	0.000	0.5	
14	Cu^{+2} (mg/l)	0.002	0.000	0.000	0.000	0.000	0.000	1.5	
15	Cr (mg/l)	0.001	0.000	0.000	0.000	0.000	0.000	0.3	

WQI = SWnqn/SWn	1.26	1.31	1.16	0.82	0.89	0.74
Monthly WQI	**EW**	**EW**	**EW**	**EW**	**EW**	**EW**
Percentage compliance	100%					
6 Months WQI	1.14					
6 Months Water quality status	**Excellent water (EW)**					

[1] Template is attached as an addendum

In practice in the oil and gas industry, **t**he environmental officer keys in the laboratory data in to the blue coloured columns only and obtains the Water Quality Index of the duration (weekly, monthly, quarterly, half yearly or yearly) and then communicates in plain language (the treated waste water is Excellent , Good, Poor, Very Poor, or Unsuitable water to be discharged into the environment) to the Manager of Environment (of the Oil Company) who will then communicate same to the Management and Department of Petroleum Resources) for appropriate decision. From the foregoing, this new approach will be beneficial not only to the oil and gas industry, but also to the host communities, public water management and the general public as a whole. And finally, this method of reporting can also be applicable to other uses of water e.g. potable water, water for aquaculture, surface water quality etc.

Based on the example given above and the results from the flow station, it can be observed that the status of the waste water to be discharged into the environment can be classified as Excellent water for the first month and also the six months of this study hence communicating this to the general public and management becomes easier than the clumsy comparison of the result obtained in Table 1 above with the regulatory standards. It can be categorically stated or communicate to whosoever that is concerned that the operational activities has not negatively impacted the terrestrial and aquatic resources of the area.

4. Conclusion

Assembling different parameters into one single number leads an easy interpretation of water quality index, thus providing an important tool for management purposes. A water quality index is a useful tool for "communicating water quality information to the public and to management and legislative decision makers;" it is not "a complex predictive model for technical and scientific application". The results indicate that the treated waste water samples analysed from the flow station are safe for discharge in the environment which implies that the operational activities of the flow station have not negatively impacted the environment of the area under study. This method will be faster for management to review the operations of the station without necessarily looking at individual parameter for compliance which is a bit cumbersome. A critical look into and possible adoption of this approach for a better Compliance Monitoring (CM) reporting in the oil and gas industry is hereby recommended.

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