Research Article
Performance, Compliance and Reliability of Waste Stabilization Pond: Effluent Discharge Quality and Environmental Protection Agency Standards in Ghana

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Abstract: Measuring performance has been arguerably, one of the metric with many facets with different school of thoughts, as there exist different approaches of measuring it. Several of the existing approaches measure such metric by comparison with standards esherined in policy documents and as a result, takes less look to its compliance and reliability of values being matched to an established standards. This study seeks to integrate reliability and compliance into measuring of performance of Waste Stabilization Pond (WSP) and Treatment Plant (TP) as well as to generate the appropriate standard chart tables using the Ghana Environmental Protection Agency (EPA) approved discharge values for physico-chemical and some biological parameters to account for these shortfalls on over reliance of EPA discharge standards. Probability distribution density function was applied on the lognormal distribution function to establish the relationship between the statistical coefficient of variation and the coefficient of reliability based on r^{th} moment about the origin in the moment of generation function to generate the functions of the mean and standard deviation, properties of the standard Z normal distribution were used to establish the coefficient of reliability relationship depending on the coefficient of variation influenced by the standard of deviation. Discharge values of Physico-chemical Parameters measured from the WSP were found be performing acceptably based on the EPA standards, whereas only four of the TP were acceptable. Discharge Values of physico-chemical and biological parameters which are found to be accepted under comparison with EPA standards were found to have compliance levels below what is generally accepted for Waste Stabilization Ponds (WSP) designed compliance. Based on these shortcomings, reference charts were develop to serve as reference points in assessing the various characteristics of compliance and performance of WSPs in Ghana on (28) physico-chemical and biological parameters. These charts are intended to make it easier to assess the performance of WSPs and its corresponding reliability and compliance level to compensate for overreliance on EPA standards alone.

Keywords: Coefficient of reliability, coefficient of variation, effluent quality discharge, EPA standards, lognormal distribution, performance and compliance, probability of reliability, waste stabilization ponds

INTRODUCTION

The use of Waste Stabilization Ponds (WSPs) as an economical and efficient way of re-cycling water has taken centre stage for the use in agricultural production over the past two decades, it's been noted that, WSPs are usually the most cost effective procedure in dealing with domestic and municipal wastewater treatment for agricultural purposes in Africa due to the condition of favorable climate and low cost of maintenance (Mara, 2004), which are very important factors for tropical countries such as the sub-Saharan Africa.

Owing to the natural process of treatment of water in WSP, the treatment processes are highly dependent on the physical design of the WSPs; conversely these physical designs do not consider the ecological process, which takes place in the system. Purposefully, WSP consist of anaerobic ponds, facultative and maturation ponds in series, or several of these maturation series ponds in parallel (Gawasiri, 2003; Mara, 1996, 2004) with each having a specific purpose, though they sometimes overlap. Specifically, facultative ponds are needed for the removal of Biochemical Oxygen Demand (BOD_5) when the effluent is meant for restricted irrigation and fish pond fertilization as well as

for the discharge of treated water into surface water. For unrestricted irrigation, maturation ponds are needed for the removal of pathogen in order to meet the WHO standard of '<1000 fecal coliform bacteria per 100 mL' (Mara, 2004; WHO, 2006).

Several studies (Haydeh *et al*., 2013; Shah, 2008; Oliveira and Sperling, 2008; Mbwele *et al*., 2003) have evaluated the performance of the WSPs by comparing the percentage of removal of Biochemical Oxygen Demand (BOD$_5$), Total Nitrogen (TN), Total Suspended Solids (TSS), Total Phosphorus (TP), Total Coliform (TC), Faecal Coliform (FC) and Salmonella with design standards, with few focusing on the extend of compliance of the ponds to its design standards. However, few works (Redda, 2013; Oliveira and Sperling, 2008) have compared the percentage of removal of the parameters of evaluation performance of WSPs to the compliance and reliability of the WSPs according to the standards set up by the local policy. However, Oliveira and Sperling (2008) mainly conducted the reliability concentrated on different treatment plants by comparing their reliability level of which a real WSP was excluded. Based on the shortcomings of over relying on EPA standards without due inclusion of compliance level of WSP and treatment plants, performance short fall of accounting for compliance and hence underestimate the effluent discharge values deemed to be acceptable. This study seeks to integrate reliability and compliance into measuring of performance of WSP and treatment plant as well as to generate the appropriate standard chart tables using the Ghana EPA approved discharge values for physico-chemical and some biological parameters to account for these shortfalls on over reliance of EPA discharge standards.

LITERATURE REVIEW

Statistical effluent data distribution: Exploratory Data Analysis (EDA) gives overview of how data analysis is done, by first fitting the appropriate distribution to describe the data through making distributional assumptions about the data (Thode, 2002); this could be done by plotting the dataset and finding the classical or traditional distribution, which fits the dataset. Most statistical tests assume data to be normally distributed (Ott, 1995), but this is not necessary true. Failing to understand the appropriate statistical distribution of data may lead to invalid assumptions and consequently incorrect conclusions (Thode, 2002). Several studies (Niku and Schroeder, 1981; Niku *et al*., 1979, 1981, 1982; Oleiveira and Sperling, 2006, 2008; Redda, 2013) have all reported that, lognormal distribution gives a good overall fit to effluent values, but there are some cases where neither normal nor lognormal seems to approximately fit the distribution of the observed data, in such cases the distribution of effluent values should be treated independently to fit its own distribution as such (Niku *et al*., 1979). Niku *et al*. (1979) and Hovey *et al*. (1977)

developed a linear model through the use of simple regression analysis to determine the percentile values for the distributions of effluent parameters concentrations exceeding various percentages of the time related to the mean values. Their approach could be used if the effluent concentration is not known or does not follow a classical distribution function.

Recent work by Redda (2013) attempts to use the logistic regression model to find the level of compliance as a function of other independent parameters of the treatment plants which influences the parameters of measuring performance and give rise to the reliability level without using the distribution function of effluent concentration. Oliviera and Sperling (2010) explained that due to variation in performance, treatment plants should be designed to produce effluent quality below the discharged standards. This suggests a mean value should be used to guarantee an effluent concentration consistency and which should be less than standard with a certain reliability and compliance level. To meet such high standards especially with WSPs which do not have any adjustable controls once in operation, the onus is placed on the design stage and regular maintenance; hence design engineers must be able to estimate the expected effluent quality and its variations for a given time as well as know the efficiency of each WSP portions. Besides, Mbwele *et al*. (2003) and Redda (2013) concluded that, care should be taken in the interpretation of performance data, as some performance variations likely result from biotic and abiotic factors other than design standard values alone.

Process of reliability: Several studies have defined reliability as the ability to perform the specified requirements free from failure (Niku *et al*., 1979); e.g., the percentage of times a wastewater treatment plant complies to discharge standards (McBride and Ellis, 2001; Smith *et al*., 2001). The WSPs will be completely reliable if the process performance does not violate the target standards of the regulatory bodies specifications (Oliveira and Sperling, 2008), Hence mathematically:

$$Failure = effluent\ concentration >\ effluent\ requirements \qquad (1)$$

Due to the numerous uncertainties underlying the design and operation of a wastewater treatment plant, a risk of failure is always unavoidable and the wastewater treatment plant should be designed based on an acceptable risk or degree of violation. Hence the mean operational effluent quality and the coefficient or reliability developed by Niku *et al*. (1979) is based on the assumption of the lognormal distribution to assess the reliability of the treatment plants. The minimum reliability requirements must be determined to establish the failure-probability magnitude that can be accepted'. Niku *et al*. (1979) model as follows:

$$Reliability = 1 - P(failure) \quad (2)$$

By Eq. (1) and (2) becomes:

Reliability = 1-*P* (effluent concentration > effluent requirement) (3)

The lognormal distribution owning to deviation in symmetry measured by the skewness coefficient, has positive skewness since there is usually a lower bound for effluent concentration, but there are no upper bounds:

$thus(0 \le x$
$\le \infty$, where x is values for the effluent concentration)

The probability density function of the lognormal distribution of effluent quality is given as:

$$f_X(x) = \frac{1}{x\sigma_{\ln X}\sqrt{2\pi}}Xexp\left\{-\frac{1}{2}\left[\frac{1}{\sigma_{\ln X}}ln\left(\frac{x}{\widetilde{m}_X}\right)\right]^2\right\}x \ge 0 \quad (4)$$

where,
X = Effluent variable concentration
$\sigma_{\ln X}$ = Standard deviation of the natural logarithm of X
$\widetilde{m}_X$ = Median of X

For the rth moment of about the origin in the moment generation function:

$$E(X^r) = (\widetilde{m}_X)^r exp\left(\frac{1}{2}r^2\sigma^2{}_{\ln X}\right) \quad (5)$$

Hence:

$$m_X = \widetilde{m}_X exp\left(\frac{1}{2}\sigma^2{}_{\ln X}\right) \quad (6)$$

$$\sigma^2{}_X = m^2{}_X[exp(\sigma^2{}_{\ln X}) - 1] \quad (7)$$

where, m_X and $\sigma^2{}_X$ represent the mean and variance of the original data, respectively from the moment function. Re-arranging Eq. (6) and (7) accounting for the relationship of parameters of probability density function of lognormal distribution in terms of moment of variable X are:

$$\sigma^2{}_{lnX} = ln\left(\frac{\sigma^2{}_X}{m^2{}_X} + 1\right) \quad (8)$$

$$m_{lnX} = lnm_X - \frac{1}{2}\sigma^2{}_{lnX} \quad (9)$$

where, m_{lnX} is the average natural logarithm of X.
For some probability of failure at α, the lognormal distribution will have a property of X, thus:

$$P(X \le X_s) = 1 - \alpha \quad (10)$$

Table 1: Value of standard normal distribution

Cumulative probability $1 - \alpha$	Percentiles $Z_{1-\alpha}$
50	0.000
60	0.253
70	0.525
80	0.842
90	1.282
92	1.405
95	1.645
98	2.054
99	2.326
99.9	3.090

where, X_s is the effluent concentration standard fixed for policy assessment. Hence choosing the parameters of the lognormal distribution, Eq. (10) becomes:

$$P\left(Z \le \frac{lnX_s - m_{\ln X}}{\sigma_{\ln X}}\right) = 1 - \alpha \quad (11)$$

The standard Z normal distribution can also be defined from Eq. (10) as:

$$P(Z \le Z_{1-\alpha}) = 1 - \alpha \quad (12)$$

Hence at a reliability level of $1 - \alpha$ of a failure level of α, a known standard of effluent concentration level could be calculated given a coefficient variation, the $Z_{1-\alpha}$ values were obtained using the *NORMDIST* function in Microsoft excel (Table 1) for the cumulative probability at $1 - \alpha$ and its percentiles. It should be noted that, the higher the normal variate value the higher the corresponding compliance level (cumulative probability) hence by Eq. (8) and (9) into (11) results in:

$$\frac{lnX_s - \left[\ln m_x - \frac{1}{2}ln(V_x{}^2+1)\right]}{[ln(V_x{}^2+1)]^{\frac{1}{2}}} = Z_{1-\alpha} \quad (13)$$

Making the mean value the subject of Eq. (13) results in the following:

$$m_x = [(V_x{}^2 + 1)]^{\frac{1}{2}}Xexp\left\{-Z_{1-\alpha}[ln(V_x{}^2 + 1)]^{\frac{1}{2}}\right\}(X_s) \quad (14)$$

By simplification, Eq. (13) results:

$$Z_{1-\alpha} = -\frac{ln\left[\frac{m_x}{X_s}(V_x{}^2+1)\right]^{-\frac{1}{2}}}{[ln(V_x{}^2+1)]^{\frac{1}{2}}} \quad (15)$$

The statistical parameters used in the reliability to relate the mean constituent value m_x to standard X_s defines the Coefficient of Variation (CV) as V_x:

$$V_x = CV = \frac{\sigma_x}{m_x} \quad (16)$$

From Eq. (14), hence Coefficient of Reliability (COR) is given as:

Table 2: Coefficient of reliability as a function of coefficient of variation and percentiles

Reliability (%)	Coefficient of Variation (CV)														
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.6	1.8
50	1.00	1.00	1.02	1.04	1.08	1.12	1.17	1.22	1.28	1.35	1.41	1.56	1.72	1.89	2.06
60	1.00	0.98	0.97	0.97	0.98	0.99	1.01	1.04	1.07	1.11	1.15	1.23	1.32	1.42	1.52
70	1.00	0.95	0.92	0.89	0.88	0.87	0.87	0.88	0.89	0.90	0.91	0.95	1.00	1.04	1.10
80	1.00	0.92	0.86	0.82	0.78	0.75	0.73	0.72	0.71	0.70	0.70	0.71	0.72	0.73	0.75
90	1.00	0.88	0.79	0.72	0.66	0.61	0.57	0.54	0.52	0.50	0.49	0.47	0.45	0.44	0.44
92	1.00	0.87	0.77	0.69	0.63	0.58	0.54	0.50	0.48	0.46	0.44	0.41	0.40	0.39	0.38
95	1.00	0.85	0.74	0.64	0.57	0.51	0.47	0.43	0.40	0.38	0.36	0.33	0.31	0.30	0.29
98	1.00	0.82	0.68	0.57	0.49	0.42	0.37	0.33	0.30	0.28	0.26	0.22	0.20	0.19	0.17
99	1.00	0.80	0.64	0.53	0.44	0.37	0.32	0.28	0.25	0.22	0.20	0.17	0.15	0.14	0.13
99.9	1.00	0.74	0.55	0.42	0.33	0.26	0.21	0.17	0.15	0.12	0.11	0.08	0.07	0.06	0.05

Table 3: Environmental protection agency standard values for effluent discharge in Ghana

EPA parameter	Standard value	Unit
Biochemical Oxygen Demand (BOD$_5$), Total Suspended Solids (TSS) and Total Nitrogen (TN), trichloroethylene, benzene	50	mg/L
Carbon Oxygen Demand (COD), chloride and total residual chlorine	250	mg/L
	50	mg/L
Total Phosphate (TP)	2.0	mg/L
Total Coliform (TC)	400	MPN/100 mL
Total Dissolved Solids (TDS)	1000	mg/L
Dissolve oxygen, total cyanide, phenol, selenium and ammonia	1.0	mg/L
Conductivity	1500	µS/cm
pH	6-9	
Temperature	<30.0	ºC
Turbidity	75	NTU
E. coli	10	
Soluble arsenic, lead and silver	0.1	mg/L
Total arsenic, total chromium and nickel	0.5	mg/L

$$COR = [(V_x{}^2 + 1)]^{\frac{1}{2}} X exp\left\{-Z_{1-\alpha}[ln(V_x{}^2 + 1)]^{\frac{1}{2}}\right\} \quad (17)$$

Putting Eq. (16) into (17):

$$COR = [CV^2 + 1]^{\frac{1}{2}} X exp\left\{-Z_{1-\alpha}[ln(CV^2 + 1)]^{\frac{1}{2}}\right\} \quad (18)$$

The COR values are obtained as a function of coefficient of variation and reliability level (Table 2), the different values of the coefficient of variation suggests the different mean and standard deviation parameters of measuring reliability might produce of which are mainly less than 1.0 in practices (Niku *et al*., 1979; Oliveira and Sperling, 2008). Hence by Eq. (18) into (14) simplifications becomes:

$$m_x = CORX_s \quad (19)$$

where,
X_s = The effluent quality standard
COR = The coefficient of reliability
m_x = The mean effluent concentration needed to achieved a certain compliance level of effluent quality standard

Study site and data: Data was obtained through two separate studies on each of the two different sites, all the sites are located within the Kumasi metropolis which is located latitude (6°35' to 6°40'N) 1'30 W and on longitude (1°30' to 1°35') 60 W, 40 N. It has a climate which falls within the wet sub-equatorial type with an average minimum temperature of 22.5°C and a maximum average of 30.7°C. The two study sites were the KNUST treatment plant and Ahinsan WSP. The KNUST treatment plant was constructed to receive wastewater from residential facilities within the university campus and its design was based on the conventional designs of WSPs. The Ahinsan Estate WSP was designed to receive wastewater from the residential areas which includes Ahinsan and Chirapatre estates.

EPA's discharge standards used in the study: The Ghana Environmental Protection Agency discharge standards were adopted for the Coefficient of Reliability (COR) study, the parameters included (Table 3) correspond to other developing countries standards which are considered as more realistic as well as areas which falls within the tropical regions such as Brazil and elsewhere (Oakley *et al*., 2000; Ragas *et al*., 2005; Oliveira and Sperling, 2006). These standards are set as local guideline for discharge of effluents into either stream for irrigation or for replenishing aquifers.

RESULTS AND DISCUSSION

Reliability and compliance: Two statistical parameters characterize the Coefficient of Reliability (COR) the mean and the standard deviation. These two values

determines the nature of the coefficient of variation and hence influences the COR express. As presented in several studies (Niku *et al.*, 1979; MetCalf and Eddy, 2003; McBride and Ellis, 2001; McBride, 2003; Olieveira and Sperling, 2008; Oakley *et al.*, 2000; Redda, 2013) the COR tells the values of the mean design concentrations to the standard that should be achieved, on a probability basis according to the desired level of the operators of the treatment plant, while the standard normal variate calculates the expected percentage of compliance with the discharge standards. The expected percentage of compliance can be used to access the performance of the different segment of the plant as well as for the overall performance, which helps to identify critical points of malfunction i.e., points out discharge standards having unexpected values according to design parameters.

Various standard values of the EPA Ghana were used to find the different compliance level given different levels of coefficient of variation. Twenty eight parameters were selected to develop a reference chart (See baxzes for charts) and used to ascertain the level of compliance at different CVs. Result of effluent discharge performance are much to be desired when the effluent discharge is compared to the fixed standard value only and where it is assume that if the discharge concentration is less than the standard value, the performance is good and indicates a better compliance level of the WSPs. However as shown in the reference chart (See baxzes for charts), such assumption is not always true.

For example, the required standard of effluent discharges concentration of BOD_5 or TSS is 50 mg/L (EPA, Ghana Standard). If a sample taken from a specified WSP gives a mean effluent quality of 48.00 and with standard deviation of 14.4 will have a CV value of 0.3, by referencing to Chart 1 (See baxzes for charts) corresponds to a compliance level (COR) of

60% i.e., less than the required less stringent compliance level of 80% for WSPs (Oliveira and Sperling, 2008; Redda, 2013), This is despite the fact that the mean effluent concentration from the WSP as compared to the EPA standard falls below the standard value of 50 mg/L and can be classified as a good discharged value. Nevertheless, the WSP is underperforming, its effluent discharge value is just less than that of a compliance level of 60%, hence its compliance level is below what's generally accepted (even in a less stringent level of 80%), such information, if available can trigger a further check to be done to identify the segment of the pond (Anaerobic, facultative and maturation) that is underperforming, which could support the routine maintenance of the ponds.

The same procedure could be used by comparing the expected mean effluent concentration of the segments of the pond to its samples using its design compliance and hence finding the compliance level of effluent to check for malfunctioning of pond segments, this is necessary due to the different expected work to be done by each segment to enhance the maintenance of the ponds regularly, Nonetheless, a critical look should be taken because CV values directly relate to reliability and inversely to COR values, hence CV value with high standard deviation and lower mean of an effluent can have the same value as a CV of high mean and low standard deviation value of an effluent, the later shows a more consistent discharge. This shows that, a lower value of CV does not necessarily indicate better results.

Moreover, with the use of the charts (See baxzes for charts) for various parameters of WSPs in Ghana, once an effluent concentration average is known and its compliance level at design is also known, a quick reference point can be made to find what was expected to be discharging and compare to its current discharge to be assure of its compliance without necessary

Table 4: Performance of physical conditions (Ahinsan estate WSP)

	pH	Temp.	Conductivity	Total dissolved solids	Total suspendid solids
Anaerobic pond					
Influent	7.50	26.80	1419.00	728.00	323.00
Effluent	7.20	26.20	679.00	339.00	91.00
Remove (%)	4.00	2.24	52.15	53.43	71.83
Facultative pond					
Influent	7.20	26.20	679.00	339.00	91.00
Effluent	7.10	26.30	605.00	302.00	88.00
Remove (%)	1.39	-0.38	10.90	10.91	3.30
Maturation pond I					
Influent	7.10	26.30	605.00	302.00	88.00
Effluent	7.30	26.40	542.00	270.00	38.00
Remove (%)	-2.82	-0.38	10.41	10.60	56.82
Maturation pond II					
Influent	7.30	26.40	542.00	270.00	38.00
Effluent	7.30	26.60	484.00	242.00	52.00
Remove (%)	0.00	-0.76	10.70	10.37	-36.84
Overall					
Influent	7.50	26.80	1419.00	728.00	323.00
Effluent	7.30	26.60	484.00	242.00	52.00
Remove (%)	2.67	0.75	65.89	66.76	83.90

Table 5: Performance chemical conditions (Ahinsan estate WSP)

	NO$_3$-N	NO$_2$-N	NH$_3$-N	TP	DO
Anaerobic pond					
Influent	0.20	0.47	0.75	18.40	1.40
Effluent	0.05	0.08	0.46	10.40	0.30
Remove (%)	75.00	82.98	38.67	43.48	78.57
Facultative pond					
Influent	0.05	0.08	0.46	10.40	0.30
Effluent	0.03	0.06	0.43	11.00	0.30
Remove (%)	40.00	25.00	6.52	-5.77	0.00
Maturation pond I					
Influent	0.03	0.06	0.43	11.00	0.30
Effluent	0.02	0.04	0.37	9.40	0.70
Remove (%)	33.33	33.33	13.95	14.55	-133.33
Maturation pond II					
Influent	0.02	0.04	0.37	9.40	0.70
Effluent	0.01	0.06	0.36	6.10	0.80
Remove (%)	50.00	-50.00	2.70	35.11	-14.29
Overall					
Influent	0.20	0.47	0.75	18.40	1.40
Effluent	0.01	0.06	0.36	6.10	0.80
Remove (%)	95.00	87.23	52.00	66.85	42.86

Table 6: Performance of biological conditions (Ahinsan estate WSP)

	E. coli	TC	BOD$_5$	COD
Anaerobic pond				
Influent	2.3×10^9	6.8×10^9	554.00	933.00
Effluent	3.8×10^7	3.3×10^8	95.00	187.00
Remove (%)	98.35	95.15	82.85	79.96
Facultative pond				
Influent	3.8×10^7	3.3×10^8	95.00	187.00
Effluent	3.1×10^7	1.2×10^7	83.00	178.00
Remove (%)	18.42	96.36	12.63	4.81
Maturation pond I				
Influent	3.1×10^7	1.2×10^7	83.00	178.00
Effluent	2.4×10^6	4.3×10^7	37.00	68.00
Remove (%)	92.26	-258.33	55.42	61.80
Maturation pond II				
Influent	2.4×10^6	4.3×10^7	37.00	68.00
Effluent	7.1×10^5	1.7×10^8	38.00	99.00
Remove (%)	70.42	-295.35	-2.70	-45.59
Overall				
Influent	2.3×10^9	6.8×10^9	554.00	933.00
Effluent	7.1×10^5	1.7×10^8	38.00	99.00
Remove (%)	99.97	97.50	93.14	89.39

comparing it to fixed standard values, due to the unaccounted for information on compliance the EPA fixed standard gives, These reference charts were develop to serve as reference points in assessing the various characteristics of compliance and performance of WSPs in Ghana. These tables are intended to make it easier to assess the performance of WSPs and its corresponding reliability and compliance level without going through the task of using the log-normal procedure as shown above.

Performance analysis: The influent and effluent conditions of the different pond cells or portions of water quality in terms of physical parameters (Table 4), chemical parameters (Table 5) and biological parameters (Table 6) of the Ahinsan WSP are given below. The physical condition performance (Table 4) in terms of removal percentage were as follows; conductivity (52.15%), total dissolved solids (53.43%) and total suspended solids (71.83%) in the anaerobic

pond, the facultative pond continued the removal efficiency of the physical parameters except for temperature which recorded negative percentage (-0.38) indicating a temperature rise from the anaerobic pond into the facultative pond and a continued rise in the maturation pond as well. However, the rise in temperature was insignificant and fell within the level essential for algae growth. Moreover, TSS also increased in the maturation pond as well. Notably, the cumulative efficiency removal was high for both anaerobic and facultative ponds which are specially designed to remove most of the physical properties WSPs (Mara, 2004). Nevertheless, the maturation pond also helps in the reduction of all of the physical parameters of the Ahinsan pond with the exception of the temperature, pH and TSS.

The chemical parameters saw an efficient removal in the anaerobic and facultative ponds and most of the removal was done before the effluent entered the maturation pond. TP increased in the facultative pond,

Table 7: Physico-chemical properties including BOD_5 (KNUST PLANT)

	Temp.	PH	TURB	TSS	TP	TN	BOD_5
Primary pond							
Influent	28.95	7.90	478.38	370.69	44.92	36.65	271.13
Effluent	28.78	7.73	342.69	342.69	41.16	33.29	231.69
Remove (%)	0.59	2.15	28.36	7.55	8.37	9.17	14.55
Dosing and trickling filter							
Influent	28.78	7.73	342.69	342.69	41.16	33.29	231.69
Effluent	24.35	7.13	114.06	162.63	26.87	22.21	172.75
Remove (%)	15.39	7.76	66.72	52.54	34.72	33.28	25.44
Secondary pond							
Influent	24.35	7.13	114.06	162.63	26.87	22.21	172.75
Effluent	22.99	7.09	84.56	80.00	19.11	12.93	116.13
Remove (%)	5.59	0.56	25.86	50.81	28.88	41.78	32.78
Tertiary pond							
Influent	22.99	7.09	84.56	80.00	19.11	12.93	116.13
Effluent	24.66	6.78	59.69	51.63	12.20	10.83	81.75
Remove (%)	-7.26	4.37	29.41	35.46	36.16	16.24	29.60
Overall							
Influent	28.95	7.90	478.38	370.69	44.92	36.65	271.13
Effluent	24.66	6.78	59.69	51.63	12.20	10.83	81.75
Remove (%)	14.82	14.18	87.52	86.07	72.84	70.45	69.85

but declined in the maturation ponds I and II, On the other hand, dissolved oxygen removal was predominant only in the anaerobic pond, whereas the DO content increased in the maturation pond, leading to the recording of negative percentage. This is due to the high removal activity in the anaerobic pond (78.57%) whereas microbiological activities in the other ponds use oxygen due to the algae growth. The nitrate family continued to decline, indicating that there was no limitation to nitrification in the Ahinsan Estate Pond.

On the biological parameters (Table 6) BOD_5 and COD efficiency of removal was very high in the anaerobic pond as well (82.85 and 79.96%, respectively). This removal efficiency was also evident in the facultative pond and maturation pond I. In maturation pond II, a reverse efficiency was recorded, confirming that the anaerobic and facultative ponds are essential for the removal of (TN, TP, BOD_5, COD, Conductivity, pH), whereas the anaerobic pond is essentially for DO. The *E. coli* and TC were having a high efficiency of removal in the anaerobic pond and the TC increased further in the facultative, but increased considerably in the maturation ponds resulting in negative percentages. Still, the overall removal efficiency was high.

In respect of the KNUST plant, the physico-chemical parameters (Table 7) showed a continuous removal of BOD_5, TN, TP, TSS, TURB, pH and Temperature, indicating that the BOD_5 content declines as the wastewater passes through the primary chamber up to the secondary chamber from which wastewater can be used for restricted irrigation. The percentage efficiency of the removal trend was not different from the Ahinsan WSP, though the latter has higher percentage removal.

The average values of removal efficiency percentages of the physical, chemical and biological parameters of the Ahinsan plant as well as the physico-

chemical parameters of the KNUST plant are all presented in the respective Table 4 to 7. The overall removal efficiency of the Ahinsan WSP were 2.6% for pH, 83.90% for TSS, 87.23% for NO_2-N, 52.00% for NH_3-N, 66.86% for TP, 42.86% for DO, 97.50% for TC, 93.14% for BOD_5 and 89.39% for COD. Whereas that of the KNUST Plant were 14.18% for pH, 86.07% for TSS, 72.84%% for TP, 70.45% for TN and 69.85% for BOD_5, the removal efficiency of BOD_5 in the Ahinsan WSP was higher than the KNUST plant.

Effluent discharge and EPA standards: From the comparison of the various discharge qualities to the standards of EPA, it is very evident that, some of the parameters for the KNUST plant do not conform to EPA standards (Table 8). Though some exceptions like the temperature (24.66), TN (10.83), TC (79.69), pH (6.78) and turbidity (59.69) level, which recorded a lower discharge values than the EPA standard, all other parameters such as TSS (51.53), TP (12.2), BOD_5 (81.75) and *E. coli* (26.50) were higher than the standard. In contrast, the Ahinsan WSP was performing better in terms of discharge values than the KNUST plant. This WSP had most of its effluent discharge values lower than the EPA which included; temperature (26.6), pH (7.3), TN (0.01), Ammonia (0.36), BOD_5 (38), COD (99), Conductivity (484), TDS (242). The performing discharge values of the Ahinsan WSP is attributed to some form of maintenance during the trial work of aqua-culture in the ponds, whereas, the KNUST plant did not receive any form of maintenance over quite a number of years, which can explain its under-performance.

Compliance and reliability analysis:
EPA's discharge standards to be achieve in operation concentration: The current reliability of the KNUST treatment plant and Ahinsan WSP (Table 9)

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Table 8: Effluent discharge values and the EPA standard

Parameter	EPA standard	KNUST plant	Ahinsan WSP
Temperature (°C)	<30	24.66	26.60
pH	6-9	6.78	7.30
TSS (mg/L)	50	51.63	52.00
TP (mg/L)	2	12.20	6.10
Turbidity (NTU)	75	59.69	-
TN (mg/L)	50	10.83	0.01
Ammonia/ammonium (mg/L)	1	-	0.36
BOD_5 (mg/L)	50	81.75	38.00
COD (mg/L)	250	-	99.00
Conductivity (μS/cm)	750	-	484.00
TDS (mg/L)	1500	-	242.00
DO (mg/L)	1	-	0.80
TC (MPN/100 mL)	400		1.7×10^8
E. coli (MPN/100 mL)	10	26.50	7.1×10^5

Table 9: Actual mean effluent discharge, reliability and its compliance

	KNUST treatment plant			AHINSAN WSP		
Parameters	Mean effluent discharge	Reliability	Compliance	Mean effluent discharge	Reliability	Compliance
Temperature (°C)	24.66	0.63	73.60	26.60	0.51	69.50
pH	6.78	-0.03-0.84	48.80-80.00	7.30	-0.05-0.65	48.00-74.20
TSS (mg/L)	51.63	0.35	63.70	52.00	0.36	64.10
TP (mg/L)	12.20	-2.11	1.70	6.10	-1.38	8.40
Turbidity (NTU)	59.69	0.68	75.20	-	-	-
TN (mg/L)	10.83	2.21	98.65	0.01	17.09	99.90
Ammonia/ammonium (mg/L)	-	-	-	0.36	1.84	96.70
BOD_5 (mg/L)	81.75	0.34	63.30	38.00	0.75	77.30
COD (mg/L)	-	-	-	99.00	1.66	95.20
Conductivity (μS/cm)	-	-	-	484.00	2.12	98.30
TDS (mg/L)				242.00	2.09	98.20
DO (mg/L)	-	-	-	0.80	0.67	74.90
TC (MPN/100 mL)				1.7×10^8	-13.17	00.00
E. coli (MPN/100 mL)	26.50	-0.47	31.90	7.1×10^5	-14.92	00.00

Table 10: Mean design effluent concentration to achieve 95% compliance with the standard and observed actual effluent concentrations

	KNUST				AHINSAN			
Parameters	CV	COR	Mean design conc.	Observed actual mean conc.	CV	COR	Mean design conc.	Observed actual mean conc.
Temperature (°C)	0.57	0.48	14.40	24.66	0.72	0.43	12.90	26.60
pH	0.49	0.52	3.12	6.78	0.63	0.46	2.76	7.30
TSS (mg/L)	0.92	0.37	18.50	51.63	0.98	0.36	18.00	52.00
TP (mg/L)	0.84	0.39	0.78	12.20	0.73	0.42	0.84	6.10
Turbidity (NTU)	0.73	0.42	31.50	59.69	-	-	-	-
TN (mg/L)	1.04	0.35	17.54	10.83	0.54	0.49	24.50	0.01
Ammonia/ammonium (mg/L)	-	-	-	-	0.77	0.41	0.41	0.36
BOD_5 (mg/L)	2.41	0.27	13.50	81.75	0.69	0.44	22.00	38.00
COD (mg/L)	-	-	-	-	0.81	0.40	100.00	99.00
Conductivity (μS/cm)	-	-	-	-	0.69	0.44	660.00	484.00
TDS (mg/L)	-	-	-		1.03	0.35	350.00	242
DO (mg/L)				-	0.85	0.39	0.39	0.80
TC (MPN/100 mL)					1.21	0.33	132.00	1.7×10^8
E. coli (MPN/100 mL)	1.32	0.32	3.20	26.50	0.84	0.39	3.90	7.1×10^5

shows different compliance level of the discharge values to the standard values used for the design. Only three discharge values (TC; 99.4%, TN (98.65%) and pH; 48.8-80.0%) met the less stringent design specification of 80% compliance on the KNUST plant and as well recorded an observed value less than its mean design concentration value (Table 10). The different compliance levels of the actual effluent discharge were: Temperature (73.6%), TSS (63.7%), TP (1.7%), Turbidity (75.2%), BOD_5 (63.3%) and *E. coli* (31.9%) and although discharge values for temperature, pH, turbidity and TC were all lower than the EPA standards, but fall short of meeting the design compliance of 95%.

The Ahinsan WSP had five of its discharge values (TN, 99.9%; Conductivity 98.3%; Ammonia, 96.7%; COD, 95.2% and TDS, 98.%) conforming to the standard compliance of 95% compliance and achieving its observed effluent discharge being less than the mean design concentration with the required compliance level (Table 10), whereas the rest were not complying with the design compliance level. These included;

Temperature (69.5%), pH (48.0 to 74.2%), TSS (64.1%), TP (8.4%), BOD_5 (77.3%), DO (74.9%), TC (0.00%) and *E. coli* (0.00%). Again, temperature, pH, BOD_5, conductivity and DO effluent discharge meet the EPA standard but its compliance level does not meet the design specification.

CONCLUSION

From this study, it was observed that, measuring performance of WSP and treatment plants using effluent discharge values in a comparison to standards alone is sufficient only for knowing effluent quality but cannot be used to evaluate compliance of the WSP or treatment plant. It is evident that compliance because it considers both effluent quality discharge as well as design capability in its performance measure is more appropriately than the use of removal efficiency and fixed standard values alone. In this study, we developed reference charts (Table 1 to 3: Supplementary Results) which can be used for assessing effluent discharge qualities. These were done for different compliance levels from the Ghana EPA standard discharge values. Nevertheless, the importance of a stable operation and thus low CV should be remembered at all time, so that the WSP or treatment plant should not need to be designed to achieve very low mean effluent concentration. The effluent discharge values of the sites used for the study were not complying fully with the design specification (for the less stringent specifications of WSP and treatment plant). However, the Ahisan WSP had some of its water quality parameters (TN, Ammonia, TDS and COD) meeting both the compliance level of 95% and the EPA discharge standards. However, irrespective of the presence of two maturation ponds in series for the Ahinsan WSP, it could not meet the pathogen reduction standard values expected.

REFERENCES

Gawasiri, C.B., 2003. Modern design of waste stabilization ponds in warm climates: Comparison with traditional design methods. M.Sc. Thesis, University of Leeds, UK.

Haydeh, H., M. Doosti and M. Sayadi, 2013. Performance evaluation of waste stabilization pond in Birjand, Iran for the treatment of municipal sewage. Int. Acad. Ecol. Environ. Sci., 3(1): 52-58.

Hovey, W.H., E.D. Schroeder and G. Tschobanoglous, 1977. Optimal Size of Regional Wastewater Treatment Plants. California Water Resources Centre, Contribution No. 161, University of California, Davis.

Mara, D., 1996. Waste stabilization ponds: Effluent quality requirements and implications for process design. Water Sci. Technol., 33(7): 23-33.

Mara, D., 2004. Domestic Wastewater Treatment in Developing Countries. Earthscan, USA.

Mbwele, L., M. Rubindamayugi, A. Kivaisi and G. Dalhammar, 2003. Performance of a samll wastewater stabilization system in tropical climate in Dar Es Salaam, Tanzania. Water Sci. Technol., 48(11-12): 187-191.

McBride, G.B., 2003. Confidence of compliance: Parametric versus nonparametric approaches. Water Res., 37: 3666-3671.

McBride, G.B. and J.C. Ellis, 2001. Confidence of compliance: A Bayesian approach for percentile standards. Water Res., 35(5): 1117-1124.

Metcalf and Eddy, 2003. Wastewater Engineering: Treatment and Reuse. 4th Edn., Metcalf & Eddy Inc., New York, pp: 1819.

Niku, S. and E.D. Schroeder, 1981. Factors affecting effluent variability from activated sludge processes. J. Water Pollut. Control Assoc., 53(5): 546-559.

Niku, S., E.D. Schroeder and F.J. Samaniego, 1979. Performance of activated sludge process and reliability-based design. J. Water Pollut. Control Assoc., 51(12): 2841-2857.

Niku, S., E.D. Schroeder and R.S. Haugh, 1982. Reliability and stability of trickling filter processes. J. Water Pollut. Control Assoc., 54(2): 129-134.

Niku, S., E.D. Schroeder, G. Tchobanoglous and F.J. Samaniego, 1981. Performance of activated sludge process: Reliability, stability and variability. Environmental Protection Agency, EPA Grant No. R805097-01, pp: 1-124.

Oakley, S.M., A. Pocasangre, C. Flores, J. Monge and M. Estrada, 2000. Waste stabilization pond use in Central America: The experiences of El Salvador, Guatemala, Honduras and Nicaragua. Water Sci. Technol., 42(10/11): 51-58.

Oliveira, S.C. and M.V. Sperling, 2008. Reliability analysis of wastewater treatment plants. J. Water Res., 42: 1182-1194.

Oliveira, S.M.A.C. and M.V. Sperling, 2006. Wastewater characteristics in a developing country, based on a large survey (166 treatment plants). Proceeding of the 5th IWA World Water Congress, Beijing, China.

Ott, W.R., 1995. Environmental Statistics and Data Analysis. Lewis Publishers, New York, pp: 313.

Ragas, A.M.J., P.A.G.M. Scheren, H.I. Konterman, R.S.E.W. Leuven, P. Vugteveen, H.J. Lubberding, G. Niebeek and P.B.M. Stortelder, 2005. Effluent standards for developing countries: Combining the technology- and water quality-based approach. Water Sci. Technol., 52(9): 133-144.

Redda, M.A., 2013. Studies of the performance, stability and reliability of various configuration of the activated sludge process at full scale municipal wastewater treatment plants. Ph.D. Thesis, University of Texas at Arlington, US.

Shah, T.S.K., 2008. Performance evaluation of central wastewater treatment plant: A case study of Hetauda industrial district, Nepal. Environ. Nat. Resour. J., 6(2): 36-51.

Smith, E.P., K. Ye, C. Hughes and L. Shabman, 2001. Statistical assessment of violations of water quality standards under section 303(d) of the clean water act. Environ Sci. Technol., 35:606-612.

Thode, H.C., 2002. Testing for Normality. Marcel Dekker, New York.

WHO, 2006. Guidelines for the Safe Use of Watewater, Excreta and Greywater. Volume 2: Wastewater Use in Agricluture. WHO, Geneva.