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Reliability Analysis of Waste Stabilization Pond under Iran's Climate Conditions

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Abstract

The present paper seeks to comprehensive view on reliability analysis of waste stabilization pond systems under Iran's climate condition in order to shed lights on their efficiency. For this, data on effluents from nineteen waste stabilization ponds treatment plants were collected. Having been determination of effluents statistical distribution in pond stabilization system using goodness of fit tests, data were analyzed and subsequently, coefficient of reliability for qualitative parameters BOD, COD and TSS were calculated. According to the results, a few treatment plants were found to provide reliable performance under operational conditions. The average design concentration of the above parameters in order to meets Iranian discharge standards for effluent discharge into surface water; irrigation and agriculture purpose were obtained. Finally, percent of expected compliance from stabilization ponds system if kept in the same conditions was determined.

Keywords: Coefficient of reliability, performance assessment, stabilization pond treatment plants, coefficient of variation, the effluent quality

Introduction

In recent years, environmental regulatory agencies have stressed substantially urgent needs for evaluation various operation and exploitations of pond stabilization treatments plants. One of the most common issues on waste stabilization pond treatment plants is desirability of design system performance, as wide varieties of factors affects treatment plants performance. Basically, variability is fall into three categories and may influence wastewater treatment system efficiency (Torabian, and Matlabi, 2003)

1. Variability of effluent discharge flow and its properties.
2. Inherent Variability in wastewater process or inherent reliability of system.
3. Variability resulted from mechanical equipment's failure.

At the same time, many sewage treatment plants are designed using only limited information about the nature and extent of these changes. As a result, many of them during operation do not meet specified environmental standards, and in addition to wasting the initial investment costs, causes damage to the surrounding environment to which effluents are discharged. Therefore, the knowledge of how the efficiency and reliability of wastewater stabilization ponds may clarify operation status and can be found useful in the designs and environmental laws that are supposed to be implemented in the future is of great importance. Fundamentals of reliability engineering can be determination of probable quality and quantity during which unpleasant events may occur.

Therefore, the reliability analysis of stabilization pond system provides engineer with opportunities to exploit statistical structure of effluent input and output data and also gives the predicted probability of undesirable events. Variable nature and quality of the incoming wastewater during stabilization pond system lifespan may cause some fluctuations in the efficiency of predicted design efficacy. Hence, the final effluent quality should be selected as stable based on an accepted probability of these obtained values (Sílvia, Oliveira, & Sperling, 2008) . Since there are many uncertainties in the design and operation of wastewater treatment plant, the failure risk is inevitable and the treatment plants should be designed based on an acceptable risk level. In this case, the minimum required reliability should be obtained in order to determine acceptable failure probability. Thus, operating costs and investment in the wastewater treatment process will be expected to directly affect by respective reliability. Also high quality effluent entails for operation at a higher level, installation of sophisticated control systems and, in some cases additional treatment units or processes or long term physical processes. However, probability of treatment systems failure including stabilization pond system effluent is strongly sensitive to sewage concentration distribution. Therefore, it was specified, terms are found to define an interval in which given concentrations exceed treatment standards and as a result, a predicted WTP performance may be predicted. In this regard, Niku et al., (1979), developed a coefficient of reliability (COR) as per distributional functions of effluent quality parameters for wastewater treatment systems, which relates components mean values (e.g., design or operational values) to required environmental standards based on a probabilistic fundamentals (Brepols, 2008).

The main objective for doing the present research is to assess efficiency and behavior of wastewater treatment plant so that its results provide practitioners and stockholders with information to estimate wastewater biological treatment process. In addition, the results and information can be promising to regulatory organizations to prepare or modify reasonable and efficient discharge standards.

Materials and Methods

As mentioned earlier, to the best of our knowledge many studies and papers published on the distribution of effluent concentration data stated that as log-normal distribution gives a good fit for effluent concentrations . In order to verify this assumption, using data from 19 stabilization pond WTP, different distributions for different components were considered. The main reason behind this was to determine the best theoretical probability distribution to describe the behavior of variables BOD, COD and TSS in the effluent of stabilization pond systems using of goodness-of-fit tests. Results of statistical tests such as K-S demonstrated that log-normal distribution is the best representative for behavior of the quality parameters of treated effluent from stabilization ponds confirming the findings of previous studies. As a result, the expansion coefficients given by Niku et al., based on the log-normal distribution of data can be used to determine the reliability of the stabilization pond systems. Therefore, to calculate the COR ratio, the average coefficient of variation (CV) calculated for various quality parameters of stabilization pond effluent systems studied were considered.

The overall reliability coefficient relates mean values of design concentrations in terms of probabilistic basis to discharge standards so that it can be expressed as follows (Niku et al, 1979; Metcalf and Eddy, 2003:

$$m_x = (COR) X_S \quad (1)$$

m_m: The average effluent concentration (operational or design values) (mg/l)

X_s: The concentration of the effluent specified discharge standards (mg/l).

COR: Coefficient of reliability in active sewage system

These coefficients can be extended using the following equation developed by Niku et al (1979) calculated.

$$COR = \sqrt{CV^2+1} \times \exp\left\{ -Z_{1-\alpha}\sqrt{Ln(CV^2+1)} \right\} \qquad (2)$$

CV: Coefficient of variation in parameters of interest

α: Standard Failure probability

$Z_{1-\alpha}$: Standardized normal variable

Some values related to the probability of 1- α and percentages related to $Z_{1-\alpha}$ are shown in Table 1 (Montgomery, & Runger,1999) .

Table 1: $Z_{1-\alpha}$ Values in Standard Normal Distribution

1-α	$Z_{1-\alpha}$
99	2.326
98	2.054
95	1.645
90	1.282
80	0.842
70	0.525
60	0.253
50	0

Thus, using calculated reliability coefficients, the design parameters that required meeting discharge standards are determined.

A- Determining the expected percentages to meets the discharge standards

Expected percentages to satisfy the discharge standards are calculated using real effluent concentrations values and coefficient of variation (CV) for all stabilization pond systems. This is done to show how stabilization pond systems can be utilized in terms of maintaining and efficiency of systems expected to be operated.

Von Sparling and Oliveira (2008), developed an equation by which expected favorable percentages for a specified discharge standards by integrating the probability density function (PDF) log normal distribution is obtained (Montgomery and Runger, 1999; Sílvia et al, 2009).

$$\int \left(\frac{1}{\sqrt{2\mu X\sigma_y}}\right) e^{\frac{-(\ln x-\mu y)^2}{2\sigma^2 y}} dx \rightarrow \frac{1}{2} erf\left(\frac{1}{2}\frac{\sqrt{2}}{\sigma_y} Ln(x) - \frac{1}{2}\frac{\mu_y}{\sigma_y}\sqrt{2}\right) \qquad (3)$$

Niku et al (1979) purposed alternative way to achieve the same results without the need to integration. They took relationships between log normal and normal distributions to develop equation 4 (Landsteiner, & Lempert, 2007) .

$$Z_{1-\alpha} = \frac{LnX_s - \left[Lnm_x - \frac{1}{2} Ln(CV^2+1) \right]}{\sqrt{Ln(CV^2+1)}} \qquad (4)$$

m_x: The average concentration of effluent (actual values) (mg/l)

Having been 1-α values calculated, equal amounts of the cumulative probability of the standard normal distribution (the distribution Z) is needed. This can be done using existing statistical tables in statistical book or software.

B- Interpreting coefficient of reliability (COR) in waste stabilization pond systems

To help interpret concept COR, Table I and Fig 1 for different levels of reliability and for a wide range of CV values was prepared. The discussion on estimate and change COR values are given in Table 2 below.

Table 2: COR Values Based on the Coefficient of Variation (CV) for Different Levels of Reliability

Reliability	coefficient of variation														
	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.5	3	3.5	4
50	1	1.02	1.08	1.17	1.28	1.41	1.56	1.72	1.89	2.06	2.24	2.69	3.16	3.64	12.4
60	1	0.97	0.98	1.01	1.07	1.15	1.23	1.32	1.42	1.52	1.62	1.89	2.15	2.42	2.69
70	1	0.92	0.88	0.87	0.89	0.91	0.95	1	1.04	1.1	1.15	1.29	1.43	1.57	1.7
80	1	0.86	0.78	0.73	0.71	0.7	0.71	0.72	0.73	0.75	0.77	0.82	0.88	0.94	1
90	1	0.79	0.66	0.57	0.52	0.49	0.47	0.45	0.44	0.44	0.44	0.44	0.45	0.46	0.48
95	1	0.74	0.57	0.47	0.4	0.36	0.33	0.31	0.3	0.29	0.28	0.27	0.26	0.26	0.26
98	1	0.68	0.49	0.37	0.3	0.26	0.22	0.2	0.19	0.17	0.17	0.15	0.14	0.13	0.13
99	1	0.64	0.44	0.32	0.25	0.2	0.17	0.15	0.14	0.13	0.12	0.1	0.09	0.09	0.08

For example, the average effluent concentrations with coefficient of variation CV = 0.6 and reliability level 95%, the $Z_{1-\alpha}$ value is obtained from the standard normal distribution tables (α=0.05. $1-\alpha=0.95 \rightarrow Z_{1-\alpha=}$ 1.645). Then COR can then be obtained according to Equation 5. The calculated reliability coefficient that is COR=0.47 which can be obtained using TABLE 2 for CV=0.6 and the level of reliability 0.95.

$$COR = \sqrt{0.6^2+1} \times \exp\left\{-1.645\sqrt{In(0.6^2+1)}\right\} = 0.47 \qquad (5)$$

This means that to meet the treatment standards in 95% from system efficiency monitoring period, average effluent concentrations can be calculated according to equation 1:

$m_x = CORX_S = 0.47\ X_S$

For example, according to standard effluent into the surface water in Iran for the parameter COD=60 (mg/l), the design effluent concentration 28 (mg/l) was calculated.

$m_x = 0.47 \times 60 = 28$ mg/l

For a lower level of reliability of 80% and the same coefficient of variation values CV =0.6 From TABLE 2, COR =0.73 is derived. Therefore, to meet the discharge standards of 80% in the period, the average effluent concentration 44 (mg/l) is required.

$m_x = 0.73 \times 60 = 44$ mg/l

Therefore,, as it can be seen, the less levels of reliability, the more average concentration of effluent will be. But for the reliability level of 95% if the value of the coefficient of variation is increased, i.e. CV=1.2 then the coefficient of reliability COR=0.33 from table and effluent design concentration of 20 (mg/l) will be obtained.

$m_x = 0.33 \times 60 = 20$ mg/l

Thus, as system's coefficient of variation increases, COR and hence average design concentration decreases accordingly.

Results and Discussion

In order to determine the reliability coefficient of stabilization pond systems under Iran's climate among the cities characterized with wastewater treatment plant, 19 stabilization pond systems across Iran were evaluated according to the different climatic conditions as well as the homogeneity of temperature with different discharges. General features of such systems include operational discharges along with population are given in Table 3.

Table 3: Characteristics of Stabilization Pond Systems

No	Province	City	Wastewater treatment	population	discharge (1000m^3/year)
1	Khozestan	Sosangerd	sosangerd	46000	7300
		Hoveyzeh	North hoveyzeh	6000	2190
		Hoveyzeh	south hoveyzeh	9000	3285
2	Isfahan	Foladshahr	foladshahr	62000	4270
		Baharestan	baharestan	35000	1690
		Shahreza	shahreza	37000	1120
		Varzaneh	varzaneh	12850	654
		Naein	naein	13000	595
		Kohpayeh	kohpayeh	4900	263
		Anarak	anarak	1200	168
3	Khorasan razavi	Mashhad	olang	125000	2326
		Mashhad	parkandabad	300000	10493
4	Bushehr	Bushehr	bushehr	89836	7553
5	Semnan	Mahdishahr	mahdishahr	15400	1658
6	Markazi	Delijan	delijan	7940	491
		Khomeyn	khomeyn	26303	383
		Arak (1)	Arak (1)	51927	120
		Arak (2)	Arak (2)	182788	-
7	Yazd	Yazd	yazd	63360	6497

As it is clear from the table, these systems are characterized with wide ranges of discharges from 120 (1000 m^3/year) to 10,493(1000 m^3/year) in turn led to great variability in the wastewaters quality and quantity. Overall based on performed statistical analysis, a great variability on effluent concentrations and removals of quality parameters stabilization pond systems were observed. In order to determine the coefficient of reliability of stabilization pond systems in Iran, such systems efficiency for a three years (2008) was evaluated. First about 5300 recorded data were collected from provinces water and wastewater companies and data were analyzed for quality and the outliers (caused by human error or laboratory) were eliminated. In order to verify the data collected from the T-test statistical software was used. The results confirmed the accuracy of the collected data. As it was stated in the previous section, the method developed by Niku et al to calculate (COR) wastewater treatment systems, effluent parameters distribution was considered as log normal one.

To verify and confirm this hypothesis, the parameters BOD, COD and TSS effluent of all stabilization pond systems were analyzed using SPSS software such as KS and goodness-of-fit like K-S. Results showed that in up to 75% of the studied stabilization pond systems, the distribution of BOD, COD and TSS in effluent followed Log normal. Thus, the method developed by Niku et al can be used to calculate COR coefficient of stabilization pond systems under Iran's climate condition.

COR Values Obtained in Study

Coefficient of reliability values (COR) for wastewater parameters (BOD, COD and TSS) is calculated considering coefficient of variation of stabilization pond system 95% confidence level. The average values of the coefficient of variation (CV) and coefficient of reliability (COR) for the stabilization pond system for different levels of reliability are presented in Table 4. Fig 2 shows average values of the coefficient of variation (CV) and coefficient of reliability (COR) to the box - whisker graph showing maximum and minimum percentages of 25% and 75%, and the median values.

Table 4: Coefficients of Reliability (COR) For Stabilization Pond Systems in Terms of the Coefficient of Variations

Confidence level	CV			COR		
	BOD	COD	TSS	BOD	COD	TSS
%99	0.488	0.492	0.556	0.380	0.495	0.342
%98	0.488	0.492	0.556	0.431	0.541	0.394
%95	0.488	0.492	0.556	0.520	0.617	0.487
%90	0.488	0.492	0.556	0.615	0.695	0.588
%80	0.488	0.492	0.556	0.754	0.802	0.739
%70	0.488	0.492	0.556	0.873	0.889	0.871
%60	0.488	0.492	0.556	0.990	0.971	1.003
%50	0.488	0.492	0.556	1.112	1.054	1.144

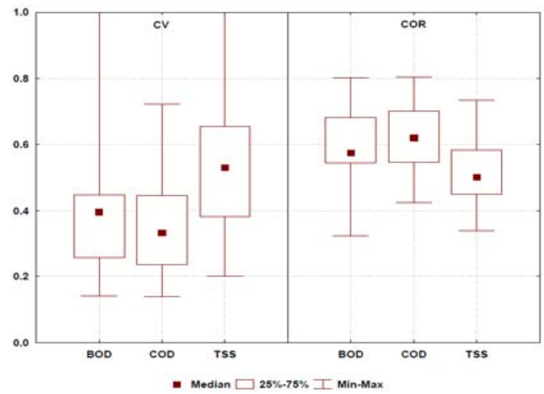

Figure 2: The Coefficients of Variation (CV) and Coefficient of Reliability (COR) For Stabilization Pond Systems in Iran

As it can be seen in Fig 2, the coefficient of variation values for the parameters BOD, COD and TSS is lower than 1. Although equal coefficient of variation for all three parameters expected, but as it is illustrated in figure 2, BOD parameter is of the maximum range for the CV. The above figure shows a general trend so that for level of reliability (95%) larger values of coefficient of variation (CV) leads to small coefficient of reliability (COR), so that most treatment plants have the least variation for COD parameter, as a result most of them are characterized with reliability coefficient greater than two others. average reliability coefficient obtained for the COD parameter is higher compared to the other two parameters.

It should be noted that the low values of the coefficient of variation (CV) and thus High values of reliability coefficient (COR) does not imply necessarily the proper operation of the treatment plant (since concentration of effluent for quality parameters are not considered), but simply it shows stable operation conditions. The smaller COR value, the lower levels of the design concentration, obtained through multiplying COR by discharge standards.

Calculation Design Concentrations using the Coefficients (COR)

According to table 5, COR coefficients obtained for the parameters BOD, COD and TSS, were COR_{TSS}=0.487, COR_{COD}=0.617, COR_{BOD}=0.520 respectively. If the standards concentration of effluent according to Iranian standards for surface water discharge parameters be 30, 60 and 40 (mg/l) and for irrigation and agriculture purposes it set , 100, 200 and 100 (mg/l), using equation 1, average design concentration is obtained by environment experts while designing stabilization pond systems in Iran. Table 5 presents average concentrations designed to achieve discharge standards specified for the parameters BOD, COD and TSS, the average effluent concentrations for the parameters BOD, COD and TSS from stabilization pond treatment plants.

Table 5: Average Values for Coefficients Obtained Using the Calculated COR

	BOD_{total}	COD_{total}	*TSS*
COR	0.520	0.617	0.487
average design concentration for discharge into surface water(mg/L)	16	37	19.5
The average design concentrations (For irrigation and agriculture purposese) (mg/L)	52	124	49
Average observed effluent concentration (mg/L)	29.30	59.231	47.24

Figures 3 and 4' show design concentrations for parameters BOD, COD and TSS for standards discharge into surface waters, Irrigation and agriculture purposes against concentrations from 19 wastewater stabilization ponds respectively. Design concentrations using an equation, the coefficient of variation each treatment system and $\alpha = 0/05$ were calculated.

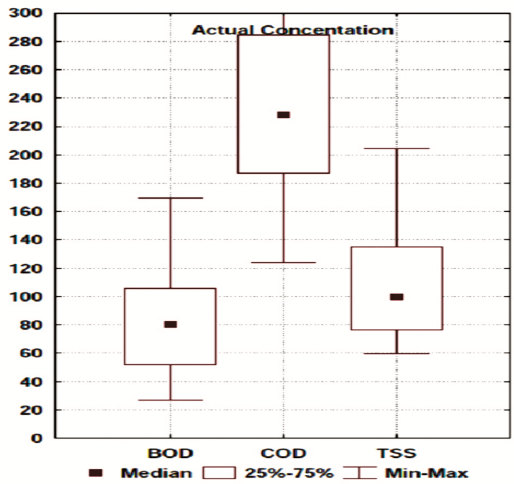

Figure 3: **Actual and Observed Concentrations versus Design Concentrations Calculated For the Standard Discharge into Surface Waters**

According to this table for ratio actual/real equal to one, the concentration of effluent with design concentration required to estimate that 95% of the results are consistent with meeting the discharge standards. But according to tables, such ratio for surface water discharge standards and all three parameters is less than 1 ranged 0.65 to 0.75, indicating a large gap exists between the actual concentrations to that standard. This means that discharge standards surface for 95 percent of a period, according to the present treatment plants is not sufficient and hence they have to be improved. Of course, such ratio for drinking and agriculture purposes standards is much larger than one and effluent concentrations met the discharge standards But it should be noted that the values are higher than 1 and if existent treatment plant designed as per standards for agriculture and drinking purposes they would poorly designed and will not be cost and time-effective.

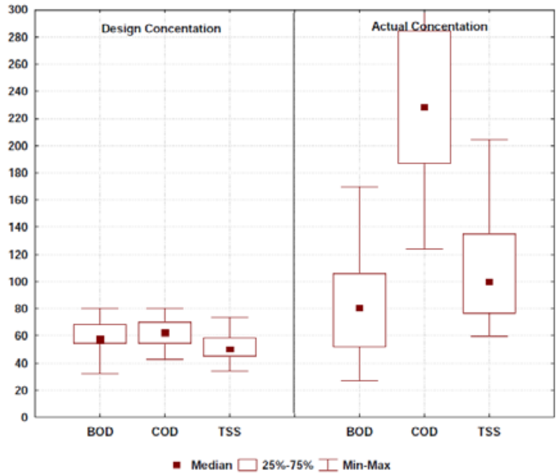

Figure 4: **Actual and Observed Concentrations versus Concentrations Calculated For Standard Agriculture and Irrigation Purposes**

Expected Percentages as per Discharge Standards

In this research percentages of individual wastewater stabilization pond in compliance with discharge standards, if they kept under same operating conditions was calculated using Equation 4. The results obtained for the qualitative parameters of BOD, COD and TSS are shown in fig 5, 6 and 7. For example, according to figure 5, as expected percentage of compliance to the standard BOD=30 mg/lit, it was found that 50% percent of the treatment plants to achieve compliance over 85% will fail. Or in other words, only 40% of the treatment plants showed 90% compliance. Fig 6 shows the percentage of compliance expected for discharge standards COD=60(mg/l). Fig 7 also shows the percentage of compliance expected for discharge standards TSS=40 (mg/l).

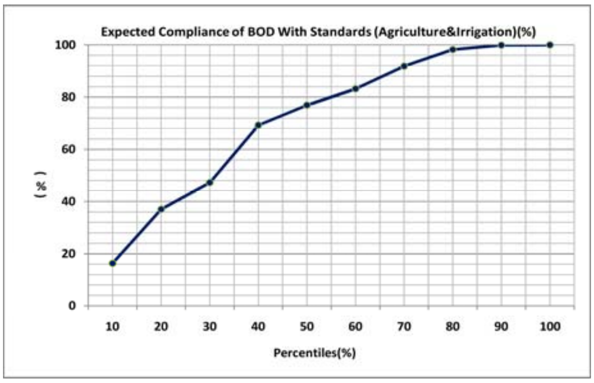

Figure 5: Percentage of the parameter compliance from expected stabilization pond for BOD parameter

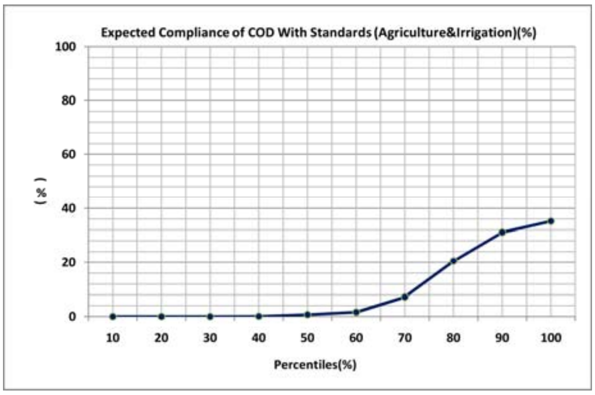

Figure 6: Percentage of the Parameter Compliance from Expected Stabilization Pond for COD Parameter

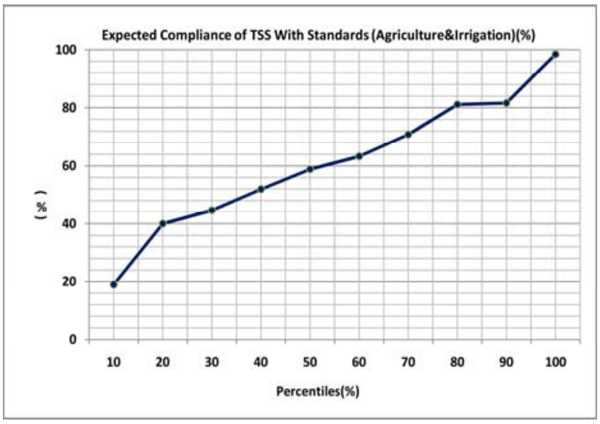

Figure 7: Percentage of the Parameter Compliance from Expected Stabilization Pond for TSS Parameter

Conclusion

Here, a comprehensive study on coefficient of reliability in stabilization pond system under Iranian climate condition was conducted. For this, an extended method by Niku et al., (1979) was used. Therefore first stabilization pond system effluent data were collected in annual using statistical methods and subsequently verified and validated. Then reliability coefficient of stabilization pond system for output quality parameters BOD, COD and TSS was calculated about 0.520, 0.617 and 0.487 respectively.in addition, using data obtained, expected percentages according to discharge standards into surface water and agriculture and irrigations were obtained as graphs. The results and information can be promising to regulatory organizations to prepare or modify reasonable and efficient discharge standards.

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