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Performance assessment of centrifuge dewatering unit using multivariate statistical approach: a case study of a centralized sludge treatment facility (CSTF) in Malacca, Malaysia

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ABSTRACT

The performance of the centrifuge dewatering unit in Sungai Udang centralized sludge treatment facility has been studied using multivariate statistical approach. The relationships between bio-solids production and 14 parameters were analyzed using principle component analysis (PCA) and multiple linear regression (MLR) analysis. PCA was used to simplify the complexity among variables affecting the production of bio-solids in the treatment facility. All varimax factor (VF) values obtained from the PCA were used as independent variables in MLR analysis. It was found that VF1 (wet sludge and mixed liquor suspended solids) and VF4 (polymer dosage) had significant linear relationships with bio-solids production, which accounted for 74.32% of variations in the bio-solids production. This approach could be used to precisely estimate the amount of sludge produced by the centrifuge dewatering unit and for better evaluation of system performance that meets the design criteria and future requirements for sludge disposal.

Keywords: Centrifuge dewatering unit; Bio-solids; Principle component analysis; Multiple linear regression; Sludge; Wastewater treatment

1. Introduction

In the recent years, due to extensive development over the world, the numbers of wastewater treatment plants (WWTPs) have been increasing significantly. This has raised many issues and major concerns in proper sludge management. It is expected that a large amount of municipal sewage sludge would be generated in the next decade with the increasing numbers of wastewater treatment facilities currently being developed [1]. The selection of an appropriate technology for sludge management depends not only on the minimization of total capital of operation and maintenance cost, but also depends on other important factors such as local geography, climate, land use, regulatory constraints, as well as public acceptance of various practices [2,3]. The treatment of excess sludge can account for up to 60% of the operational costs of the facility, mainly associated with conditioning, dewatering, disposal [4], and treatment of odor generated during the solids handling processes [5]. The on-site management

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of sludge in wastewater treatment system is a key factor affecting maintenance and operation requirements of the system [6]. Municipal sludge may contain liquid, organic and inorganic solids, in which the quality of the sludge in WWTPs depends on suitable colonization of the flocs by micro-organism activities [7–10]. According to Ødegaard et al. [11], in principal there are three final disposal strategies for wastewater sludge and its components which are deposited on land (e.g. landfills or special sludge deposits), in the sea (e.g. ocean disposal), or to a certain extent in the air (e.g. consequence of incineration).

Many studies have been associated with the determination of sludge accumulation in decentralized wastewater treatment systems [e.g. 12–14]. However, this paper attempts to further analyze and estimate the bio-solids production in a centralized sludge treatment facility (CSTF) before being disposed at trenching site. In view of the pressing needs to formulate suitable strategies to adopt the cradle to grave approach in managing sludge and bio-solids, it is important to determine the actual amount of sludge and bio-solids produced by the sludge facility. This is to make sure that the existing capacity of landfill and trenching site are adequate to cater for the bio-solids production in the future. At the same time, other approaches or strategies could be implemented (e.g. recycling or reusing) for the excess sludge produced as fertilizers. This will help to reduce the negative impacts on the environment due to improper sludge disposal.

According to Hammer [15], Eckenfelder and Santhanam [16] and environmental protection agency [17], sand-drying beds produce sludge cakes within 25–46% solids and can exceed up to 60% solids with additional drying times. However, there are efforts in recent decades to reduce the excess sludge in municipal WWTPs through mechanical dewatering equipment such as centrifuge dewatering unit and filter press [1]. Sludge dewatering process by mechanical dewatering units depends primarily upon the nature of the sludge, its original solids content and whether or not polymer is used [3,9,18]. The enhancement methods such as chemical (e.g. ozone and base treatment), physical (e.g. sonication, mechanical shearing), and biological methods (e.g. extended solids retention time) are usually costly and could also result in poor sludge settling and increased nitrogen concentration in the effluent or filtrate water [19].

The centrifuge dewatering technology has been widely used in Malaysian palm oil-related wastewater but not in sewage treatment processes. Therefore, it is interesting to understand the performance of this technology currently being adopted in sewage treatment plant in Malaysia. The studied CSTF was built in 2008 and it is intended to assess the treatment facility performance over its early years operation since commissioning. Specifically, this study aims to evaluate the performance of the centrifuge dewatering unit in Sungai Udang CSTF and to estimate the amount of bio-solids produced by the centrifuge dewatering unit according to their interrelations with other parameters using multivariate statistical approach. For this purpose, principal component analysis (PCA) of 14 parameters was performed and provided the most meaningful parameters for the production of bio-solids. Then, the new groups of parameters were used as independent variables in multiple linear regression (MLR) models to further analyze the parameters significant for the production of the bio-solids.

2. Methods

2.1. Site description

Sungai Udang CSTF (2˚17´26´´N to 2˚17´38´´N and 102˚8´84´´E to 102˚9´5´´E) is located in Central Malacca District at the western coast of Peninsular Malaysia (Fig. 1) and is approximately 150 km from Kuala Lumpur. It is bordered by the Straits of Malacca to the west, State of Negeri Sembilan to the north, and State of Johor to the south. Sungai Udang CSTF receives tankered sludge from individual septic tanks (IST), sewage treatment plants (STP), and communal septic tanks (CST) mostly from rural and Malacca town conservation areas that generally rely on pour-flush and pit latrines. The site is undulating and dissected by two rivers (Air Batu River and Udang River), the flow that drains to the Straits of Malacca. The facility is designed for 300,000 population equivalents or 190 m^3/day of wastewater. Fig. 2 depicts the sludge treatment process flow in this facility, where the pretreated sludge from sludge holding tank is thickened using polymer and dewatered by centrifuge systems. The CSTF is managed and operated by Malacca Indah Water Konsortium (IWK) Sdn. Bhd., Malaysia.

The wastewater produced during sludge dewatering is highly polluted. A biological treatment system with a long sludge age and total nitrification capability such as extended aeration (EA) activated sludge system complemented with anoxic zones for denitrification process is provided to treat the filtrate water. There are, however, no specific design criteria in Malaysia for CSTF. The basic treatment processes are essentially the same as adopted for typical sewage treatment. The effluent from clarifier of Sungai Udang CSTF is discharged by gravity to Air Batu River and must be in compliance with Standard B, Third Schedule of Environment Quality Act (EQA) 1974 [20].

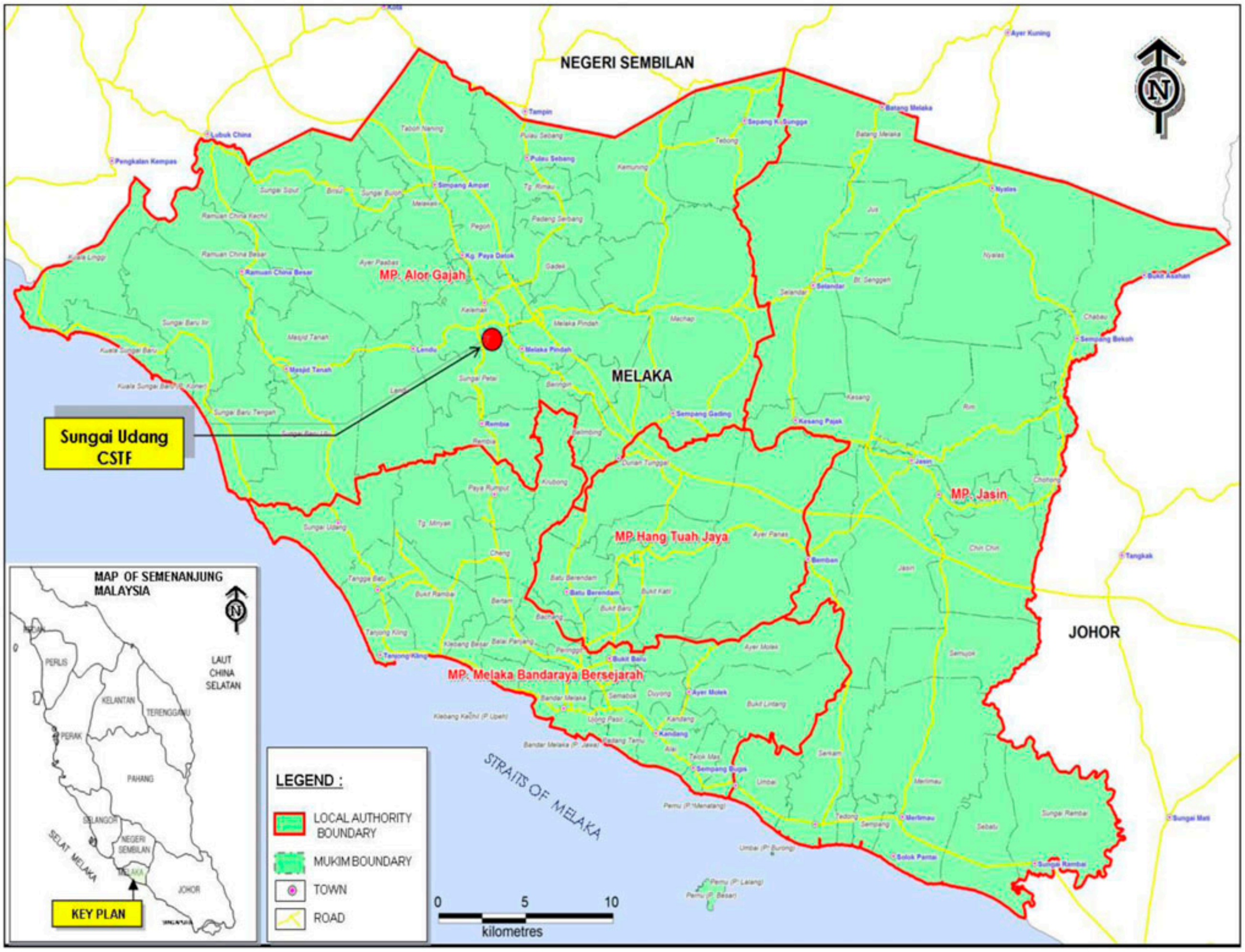

Fig. 1. Location of Sungai Udang CSTF in Malacca (adapted from Indah Water Konsortium Sdn. Bhd. Malacca).

2.2. Data

The data were recorded daily from October 2008 to February 2012 for 14 parameters by the plant operator of the CSTF. These include the amount of wet sludge received, influent readings of biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), ammonia (NH_3), mixed liquor suspended solids (MLSS), pH from receiving station, and effluent readings of BOD, COD, SS, and NH_3 which were taken after an EA treatment system. Other parameters measured from centrifuge dewatering unit such as polymer dosage, percent of solids concentration, and bio-solids production were recorded weekly. The raw data were arranged and transformed accordingly where data below detection limit were set off or displaced as values to halve the detection limit [21,22]. Normal distribution tests were carried out using W (Shapiro–Wilk), A2 (Anderson-Darling) and D (Lilliefors test). In order to present a large data-set, a univariate statistical analysis was applied to represent the data in the form of mean and standard deviation [22–24]. All statistical analysis was performed using XLSTAT 2012.6.02 application and other add-ins applications in Microsoft Excel 2007.

2.3. Principal component analysis

PCA was used, as this method shows linear relationships between variables. Barttlet's sphericity test, χ^2 with degrees of freedom = ½ $[p(p-1)]$ was used to verify the applicability of PCA to raw data [33]. The principle components (PCs) can be expressed as:

$$Z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + a_{im}x_{mj} \quad (1)$$

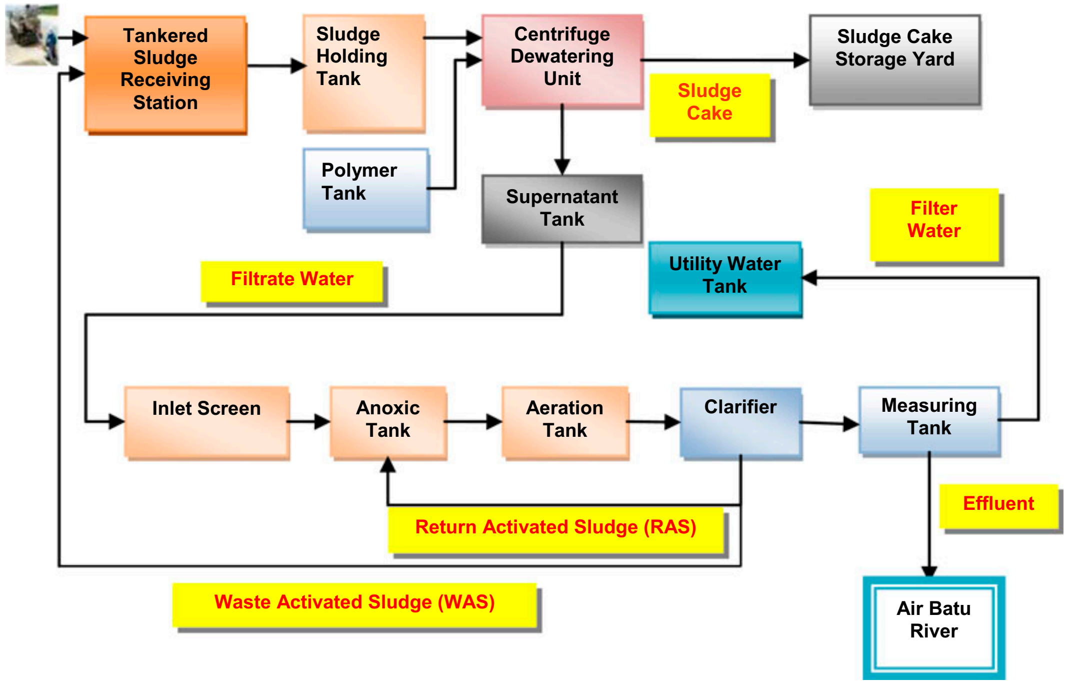

Fig. 2. Flow diagram of process design of Sungai Udang CSTF.

where z is the component score, a is the component loading, x is the measured variable, i is the component number, and m is the total number of variables. The equation provides a correlation matrix which has a linear relationship among variables that can classify the original set of data based on eigen analysis of the correlation [25]. PCs generated by PCA are sometimes not readily interpreted; therefore, it is advisable to rotate the PCs. For PCs with eigen value more than one, it is rotated using varimax rotation. This rotation is applied to reduce variables with less contribution by increasing the participation of variables with higher contribution without changing the percentage of total variance [26]. The new numbers of variables or varimax factors (VFs) can explain more information related to the intended data. Factor loadings after the varimax rotation can show how much the variable contributes to the particular PC. The factor loadings that are greater than 0.7 are considered to be "strong" and from the corresponding loading plot, responsible variables are easily detected and those below than 0.3 can be considered as "weak" significant factor loadings [27].

2.4. Multiple linear regression analysis

MLR analysis was used to predict the bio-solids production from the best predictor of PC scores using add-ins applications in Microsoft Excel. In this approach, five selected PCs with eigen value more than one were included as independent variables. According to Çamdevýren et al. [28], Chen et al. [33] and Liu et al. [34], the MLR models can be written as:

$$\textit{Bio-solids}\ (Y) = a + b_1 s_1 + b_2 s_2 + b_3 s_3 + b_4 s_4 + b_5 s_5 + e \tag{2}$$

where a is the constant term, b_k is the regression coefficient of scores value of kth PC; s_k is the scores value of kth, and e is the error of the model. This mathematical relationship expresses the output variable as a function of the value of input variables. t-test was used in testing the performance of the treatment processes.

3. Results and discussion

3.1. Performance of centrifuge dewatering unit

The descriptive statistics of the Sungai Udang CSTF performance data for 14 parameters are summarized in Table 1. The mean pH value is 6.82, indicating that all influent discharge is within optimum pH range of 6–9 and suitable for aerobic and anaerobic bacterial growth. Temperature is not taken as one of the variables due to no variation in data and Malaysia has stable weather and sufficient sunlight year round. Optimum temperatures for bacterial activity are in the range of 25–35˚C [29]. The average values of incoming BOD, COD, NH_3, SS, and MLSS are 1,538, 14,625, 123, 15,130, and 8,404 mg/l, respectively. The values were relatively high when compared to typical sewage due to the wet sludge originating from the existing ISTs, STPs, and CSTs. The high concentration of solids in the sludge indicates low dewaterability and high specific resistance to filtration [9]. Hydraulic retention time (HRT) is another important variable in the performance assessment of such a treatment system [3,30,31]. Minimum HRT design limits for sludge stabilization and dewatering is 30 days [32], and the IST must be desludged every two years to ensure that the tank is able to meet 24 h HRT. However, for most cases in Malacca, the accumulations of sludge volume are more than two years period. Conversely, the effluent readings of BOD, COD, and SS complied with the standard limits of Standard B, Environment Quality Act 1974 (Revised 2009) except for the maximum value of COD and SS. The average removal efficiency of BOD, COD, NH_3, and SS are 98.86, 98.02, 73.27, and 98.75%, respectively. All parameters showed reduction efficiency within satisfactory limits and were significantly different (p-value < 0.05).

The operating parameters of the centrifuge unit were varied systematically to achieve the driest percentage of dry cake [9]. The performance data of the centrifuge dewatering unit are summarized in Table 2. The average loading received in the CSTF is 2.58 m^3/h and the capacity of the dewatering equipment is 32.20 m^3/h. The centrifuge unit produced approximately 22.70–34.80% of solids content using in average 3.62 kg/m^3 of polymer dosage. The data shows that the solids content produced from the centrifuge unit are relatively dry when compared to other centrifuge performance e.g. in Jahra treatment plant, Kuwait [9]. The bio-solids produced from Sungai Udang CSTF is ready to be used for recycling application or directly sent to nearby landfills without any additional drying time. Generally, the performance of the centrifuge dewatering unit was considered good. The sludge cake concentration has achieved the design criteria which is 20% of dryness and above 25% that is suitable for landfill and/or trenching disposal. Overall, the centrifuge dewatering unit has produced 2,532 metric tons of bio-solids from September 2008 until February 2012 (Fig. 3). The production of the bio-solids varies every month depending on the amount of wet sludge received.

3.2. Principle component analysis

Correlation coefficient matrix between the variables was performed using PCA and the results are shown in Table 3. Correlation matrix is useful to show strong relationships between variables where overall coherence of data-set and participation of the variables in several influencing factors can be shown [33]. Value of χ^2 that is calculated as 277.5 by Barttlett's sphericity test (df = 91 and p-value < 0.0001) implies that PCA is applicable to the data. Out of the 14 parameters, only 5 PCs have eigen value of more than one as shown in Table 4. The five selected PCs explained 71.24% of total variation of variables in PCA. Then, the five selected PCs were rotated by varimax method and the results are shown in Table 5. These PCs were rotated to obtain the absolute value of varimax loadings by

Table 1
Descriptive statistics of daily average of Sungai Udang CSTF data (October 2008–February 2012)

Variables	Ave.	Min.	Max	Med.	Std. Dev.
Wet sludge (m^3/d)	63.86	9.68	120.04	63.19	22.93
BOD influent (mg/l)	1,538.17	120.00	8,251.00	634.00	2,023.13
COD influent (mg/l)	14,625.93	701.00	61,901.00	8,864.00	16,237.81
NH_3 influent (mg/l)	123.61	2.00	406.00	114.00	59.07
SS influent (mg/l)	15,130.36	524.00	70,200.00	8,847.00	16,902.60
MLSS (mg/l)	8,404.17	16.00	21,646.00	8,053.00	5,357.08
pH	6.82	4.00	7.80	7.00	0.79
BOD effluent (mg/l)	5.72	2.00	37.00	3.00	7.19
COD effluent (mg/l)	66.23	20.00	137.00	63.00	27.49
NH_3 effluent (mg/l)	18.15	1.00	73.00	12.00	19.08
SS effluent (mg/l)	36.43	3.00	106.00	27.00	28.93
Polymer (kg/m^3)	3.62	1.05	12.54	3.16	1.85
Concentration (%)	28.66	22.70	34.80	28.73	2.47
Capacity of dewatering unit (kg/m^3)	66.71	20.50	118.00	61.50	24.87

Table 2
Centrifuge dewatering unit performance data

Description	Unit	Value		
		Ave.	Max.	Min.
Loading	m^3/h	2.588	3.950	1.446
Capacity of dewatering unit	m^3/h	32.20	42.7	25.0
Concentration solids	kg/h	173.5	222.2	128.0
Disposed sludge cake	ton/d	1.2	2.3	0.7
Dewatering sludge	%solids	28.66	34.80	22.7
Polymer dosage	kg/m^3	3.62	12.54	1.05

determining values greater than 0.67 as strong correlation between the varimax factors (VFs) [34]. The bold marked values indicate strong correlation between the variables and corresponding PCs.

Group VF1 with 20.59% of total variance has positive loadings on wet sludge and MLSS. These variables positively related to each other and directly contributed to the amount of sludge production. The solids accumulation rate depends on the quantity of these variables. MLSS represent the organic and inorganic solids in the wet sludge received which is measured from sludge receiving station and could be a significant indicator of dead bacteria. A better way to control MLSS is through evaluation of food/microorganisms (F/M) ratio. Group VF2 explains 19.88% of total variance with strong positive loadings on influent BOD, COD, and SS readings. These variables are the dominant parameters for the design of CSTF.

Group VF3 shows a total variance of 13.37% with strong positive factor loadings on effluent BOD, COD, and SS. This factor was found to be significant on the quality of effluent discharge using an EA system. Group VF4 shows the total variance of 9.16% with positive loading of polymer dosage. This factor might be associated with the use of the lubricant substance in the dewatering equipment. The total variance of group VF5 with 8.25% shows a positive loading on pH and negative loading on NH_3 influent readings. This could be attributed to the suitable environmental condition for the bacterial growth and related to denitrification and nitrification processes. These variables from PCA were then used as independent variables in MLR to estimate the sludge production from the centrifuge dewatering units.

3.3. Multiple linear regressions

As discussed earlier, strong correlations between variables and corresponding components were evaluated as a group (VF1–VF5). All the five groups were then included in the MLR for further analysis of the variables significant for the bio-solids production. The results of the R^2 and p-values are shown in Table 6. Group VF1–VF5 show the R^2 values of less than 30% variation in bio-solids production. However, if VF1 and VF4 were included in the model, coefficient determination would rise up to 74.32%. Group VF1 and VF4 showed a significant linear relationship with bio-solids production (i.e. p-value < 0.0001).

Group VF1 (wet sludge and MLSS) showed a positive relationship and would lead to increased amount of bio-solids production as the variable values increase. However, group VF4 (polymer dosage) has negative relationship with bio-solids production. This means that the amount of bio-solids production will decrease when the amount of VF4 is increased. Note that typically an optimum polymer dosage is applied for the intended amount of sludge. Thus, it is important to determine the exact (optimum) amount of

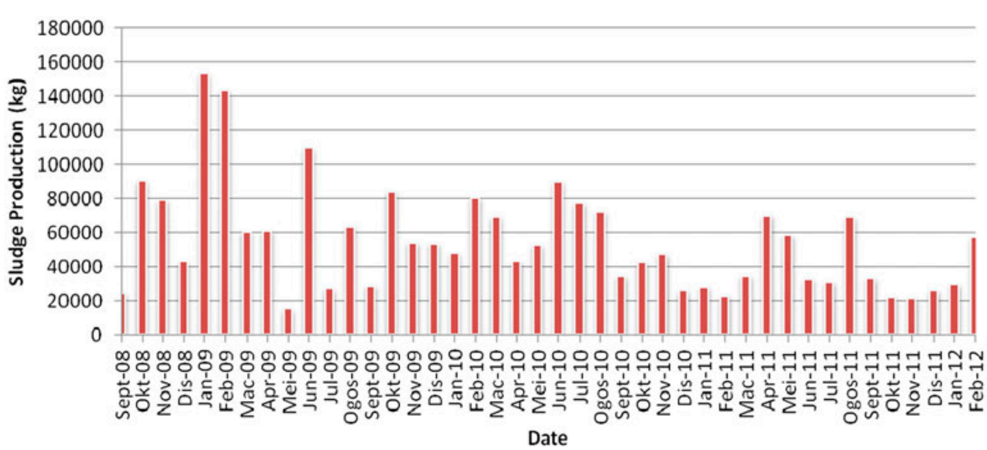

Fig. 3. Sludge production in centrifuge dewatering unit from September 2008 to February 2012.

Table 3
Pearson correlation coefficients for 14 parameters

Variables	Wet sludge	BOD influent	COD influent	NH3 influent	SS influent	MLSS	pH	BOD effluent	COD effluent	NH3 effluent	SS effluent	Polymer	Concentration	Capacity of dewatering unit
Wet sludge	1	−0.107	−0.230	−0.049	−0.068	0.384	0.322	−0.230	−0.250	0.414	−0.156	0.281	0.338	0.402
BOD influent	−0.107	1	0.821	−0.252	0.727	0.097	0.167	−0.134	−0.049	0.077	0.026	0.318	−0.110	−0.029
COD influent	−0.230	0.821	1	−0.214	0.802	−0.068	0.090	−0.075	0.012	−0.110	0.173	0.143	−0.085	−0.186
NH3 influent	−0.049	−0.252	−0.214	1	−0.243	−0.127	−0.445	0.084	0.158	−0.173	0.267	0.018	−0.056	−0.130
SS influent	−0.068	0.727	0.802	−0.243	1	0.104	0.049	−0.027	0.107	−0.020	0.249	0.079	−0.062	−0.008
MLSS	0.384	0.097	−0.068	−0.127	0.104	1	0.053	−0.155	−0.035	0.265	−0.159	−0.026	0.148	0.238
pH	0.322	0.167	0.090	−0.445	0.049	0.053	1	0.114	−0.070	0.146	0.066	0.129	0.074	0.247
BOD effluent	−0.230	−0.134	−0.075	0.084	−0.027	−0.155	0.114	1	0.639	0.012	0.455	−0.139	−0.007	−0.087
COD effluent	−0.250	−0.049	0.012	0.158	0.107	−0.035	−0.070	0.639	1	−0.107	0.710	−0.103	−0.053	−0.009
NH3 effluent	0.414	0.077	−0.110	−0.173	−0.020	0.265	0.146	0.012	−0.107	1	−0.394	0.085	0.174	0.319
SS effluent	−0.156	0.026	0.173	0.267	0.249	−0.159	0.066	0.455	0.710	−0.394	1	0.046	−0.004	−0.039
Polymer	0.281	0.318	0.143	0.018	0.079	−0.026	0.129	−0.139	−0.103	0.085	0.046	1	−0.012	−0.228
Concentration	0.338	−0.110	−0.085	−0.056	−0.062	0.148	0.074	−0.007	−0.053	0.174	−0.004	−0.012	1	−0.020
Capacity of dewatering unit	0.402	−0.029	−0.186	−0.130	−0.008	0.238	0.247	−0.087	−0.009	0.319	−0.039	−0.228	−0.020	1

Table 4
Results of principle components analysis

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
Eigenvalue	**2.883**	**2.783**	**1.872**	**1.282**	**1.154**	0.980	0.893	0.714	0.451	0.338	0.273	0.166	0.118	0.093
Variability (%)	20.590	19.875	13.371	9.157	8.245	7.001	6.377	5.102	3.223	2.411	1.950	1.187	0.845	0.666
Cumulative (%)	20.590	40.466	53.837	62.994	71.239	78.240	84.617	89.718	92.941	95.352	97.303	98.489	99.334	100.000

Note: Bold values represent PCs with eigenvalue more than one.

Table 5
Factor loading after varimax rotation

Variables	VF1	VF2	VF3	VF4	VF5
Wet sludge	**0.772**	−0.169	−0.149	0.356	0.182
BOD influent	0.019	**0.907**	−0.076	0.135	0.121
COD influent	−0.172	**0.921**	0.023	0.076	0.055
NH3 influent	−0.023	−0.265	0.244	0.189	**−0.737**
SS influent	0.073	**0.911**	0.131	−0.042	0.014
MLSS	**0.719**	0.146	−0.094	−0.156	−0.129
pH	0.151	0.042	0.094	0.164	**0.862**
BOD effluent	−0.129	−0.145	**0.779**	−0.104	0.198
COD effluent	−0.016	0.036	**0.897**	−0.135	−0.087
NH3 effluent	0.608	−0.034	−0.175	−0.035	0.237
SS effluent	−0.104	0.151	**0.865**	0.137	−0.100
Polymer	0.051	0.178	−0.068	**0.858**	0.057
Concentration	0.414	−0.144	0.057	0.296	0.026
Capacity of dewatering unit	0.588	−0.063	0.014	−0.435	0.252

Note: Bold values represent strong correlation between variables and PCs.

Table 6
Results of R^2 and p-values of multiple linear regressions

Group	Variables	p-value	R^2
VF1	Wet sludge and MLSS	0.0015	0.2560
VF2	BOD influent, COD influent, and SS influent	0.7763	0.0250
VF3	BOD effluent, COD effluent, and SS effluent	0.1217	0.1249
VF4	Polymer	0.0066	0.1526
VF5	NH_3 influent and pH	0.1009	0.0990
VF1 + VF4	Wet Sludge, MLSS, and polymer	<0.0001	0.7432

VF4 during the operation of centrifuge sludge dewatering system in order to avoid excess sludge production. Whilst as previously discussed, the variables of VF2, VF3, and VF5 have no significant relationship with bio-solids production and were excluded in the regression analysis. Predicted amount of bio-solids production was then obtained from the model as follows:

$$\text{Bio-solids } (Y) = 44.7534 + 1.1226(VF1) - 12.5481(VF4) \tag{3}$$

By using the variables in PCA analysis, 74.32% of variations in bio-solids production in the CSTF since the beginning of its operation have been precisely determined. Notably, the amount of wet sludge and MLSS are critical variables in such a system together with the aid of polymer addition for the production of bio-solids that meet the criteria for final disposal. For this CSTF, the observed and predicted bio-solids productions are shown in Table 7 for comparison.

It is known that sludge dewatering and digestion would be essential for the reduction of excess sludge production often associated with the utilization of activated sludge process for wastewater treatment [35]. There are various factors that may influence the quality of the dewatered sludge. Operating condition is an important factor in many cases. A study found that dewaterability of sewage sludge might be improved by sludge disintegration for the production of biogas [36]. Sludge pre-treatment with alkali–ozone was able to reduce 30% of SS and resulted in 40% COD solubilization for domestic wastewater being treated in a membrane bioreactor (MBR) ultimately leading to a reduced sludge [35]. The MBR was operated with MLSS concentrations in the range of 7,000–7,200 mg/l (*cf.* average of 8,404 mg/l in the studied CSTF). A hydrothermal process coupled with mechanical expression process at increased temperature may also help to enhance the dewatering process of excess sludge with relatively lower energy input [37]. The type of sludge, i.e. primary or secondary sludge

Table 7
Observed and predicted bio-solids for centrifuge sludge dewatering unit

Observations	Observed values (kg/h)	Predicted values (kg/h)
1	124.80	118.72
2	109.33	111.47
3	59.64	85.53
4	198.85	131.41
5	83.37	94.82
6	84.40	101.52
7	20.52	70.23
8	151.62	136.94
9	37.04	89.62
10	88.07	98.37
11	39.38	70.46
12	116.67	78.87
13	74.90	77.80
14	74.24	100.44
15	65.83	41.82
16	111.04	78.08
17	95.43	89.82
18	59.53	70.43
19	72.65	77.67
20	124.21	114.18
21	106.98	109.14
22	99.78	110.71
23	47.57	58.87
24	59.02	79.02
25	64.95	70.64
26	35.52	52.89
27	38.17	38.75
28	31.50	43.21
29	47.95	62.10
30	96.76	98.72
31	80.54	80.07
32	45.20	78.48
33	95.15	96.78
34	45.82	53.95
35	30.71	26.28
36	29.58	33.42
37	35.89	29.92
38	40.59	31.61
39	79.20	61.42
40	65.76	58.63
41	54.35	56.44
42	56.26	57.72
43	57.23	57.39

involved in the sequence of treatment processes and treatment configuration may also influence the sludge production. It was found that insufficient primary treatment would result in sludge with relatively high water content (poor dewaterability), lower energy content, and decreased bio-solids production [38]. The study observed the sludge cake production in the range of 12,000–22,500 m^3/year (raw sludge production between 3,000 and 5,500 tonnes per annum).

The effect of polymer addition into wastewater has also been investigated in many studies. Niu et al. [39] found that the type of coagulant for chemical conditioning (e.g. $FeCl_3$, polyaluminum chloride (PACl), and high performance PACl (HPACl)) would have impact on the size of flocs formation and hence the sludge dewaterability. Peeters et al. [40] found that PACl addition to waste sludge would be very effective to avoid fouling problems in sludge decanter centrifuge. They also found that a dose ranging from 50 to 150 g PACl/kg MLSS would mitigate the stickiness of partially dried sludge with a dry solid content between 25 and 60% dry solids.

4. Conclusion

The concentration of the bio-solids in Sungai Udang CSTF has achieved the design criteria which are above 20% of dryness and is ready to be reused or disposed without extension time. From the MLR analysis, only VF1 (wet sludge and MLSS) and VF4 (polymer dose) have significant relationships with the production of bio-solids with 95% confidence level. In conclusion, the amount of bio-solids production in the CSTF have been precisely estimated by taking into account of significant variables affecting the sludge production and to make sure of adequate space availability for the disposal of sludge in the future.

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References

[1] F. Liu, L. Zhou, J. Zhou, X. Song, D. Wang, Improvement of sludge dewaterability and removal of sludge-borne metals by bioleaching at optimum pH, J. Hazard. Mater. 221–222 (2012) 170–177.
[2] G.J. Hatziconstantinou, H. Efstathiou, Sludge dewatering and disposal practices for small activated sludge wastewater treatment plants, J. Environ. Sci. Health A. 38(10) (2003) 2401–2412.
[3] F.M. Kusin, A review of the importance of hydraulic residence time on improved design of mine water treatment systems, World Appl. Sci. J. 26(10) (2013) 1316–1322.
[4] S. Saby, M. Djafer, G.-H. Chen, Effect of low ORP in anoxic sludge zone on excess sludge production in oxic–settling–anoxic activated sludge process, Water Resour. 37 (2003) 11–20.
[5] D.H. Chon, M.N. Rome, H.S. Kim, C. Park, Investigating the mechanism of sludge reduction in activated sludge with an anaerobic side-stream reactor, Water Sci. Technol. 63 (1) (2011) 93–99.
[6] H. Lossing, P. Champagne, J. McLellan, Examination of sludge accumulation rates and sludge characteristics for a decentralized community wastewater treatment systems with individual primary clarifier tanks located in Wardsville (Ontario, Canada), Water Sci. Technol. 62 (12) (2010) 2944–2952.
[7] E. Steel, T. McGhee, Water Supply and Sewage, McGraw Hill, New York, NY, 1979.
[8] P. Innocenti, Techniques for handling water treatment sludge, J. Am. Water Works Assn. 14 (1988) 1–4.
[9] S. Al-Muzaini, A comparative study of sludge dewatering units for sludge management, J. Environ. Sci. Health A. 39(2) (2012) 473–482.
[10] L. Arregui, R. Liebana, E. Rodriguez, A. Murciano, F. Conejero, B. Perez-Uz, S. Serrano, Analysis of the usefulness of biological parameters for the control of activated sludge wastewater treatment plants in an interlaboratory study context, J. Environ. Monit. 14(5) (2012) 1444–1452.
[11] H. Ødegaard, B. Paulsrud, I. Karlsson, Wastewater sludge as a resource: Sludge disposal strategies and corresponding treatment technologies aimed at sustainable handling of wastewater sludge, Water Sci. Technol. 46 10) (2002) 295–303.
[12] H. Philip, S. Maunoir, A. Rambaud, L. Philippi, Septic tank sludges: Accumulation rate and biochemical characteristics, Water Sci. Technol. 28(10) (1993) 57–64.
[13] N. Gray, The influence of sludge accumulation rate on septic tank design, Environ. Technol. 16(8) (1995) 795–800.
[14] C. Kinsley, A. Crolla, D. Joy, Impact of Water Softer on Septic Tanks Field Evaluation Study, Ontario Rural Wastewater Centre-University of Guelph, 2005.
[15] M.J. Hammer, Water and Wastewater Technology, Wiley, New York, NY, 1975.
[16] W.W. Eckenfelder Jr., C.J. Santhanam, Sludge Treatment, Pollution Engineering and Technology, Series No. 14, Marcel Dekker Inc., New York, NY, 1981.
[17] USEPA, Process Design Manual for Dewatering Municipal Wastewater Sludges, US Environmental Protection Agency, EPA-625/1-82-014, 1982.
[18] T.D. Reynold, Unit Operation and Processes in Environmental Engineering, California Brooks, Cole Engineering Division, New York, NY, 1982.
[19] E.W. Low, H.A. Chase, Reducing production of excess biomass during wastewater treatment, Water Resour. 33(5) (1999) 1119–1132.
[20] EQA, Environmental Quality Act (Act 127), EQ (Sewage and Industrial Effluents) Regulations 1979, Laws of Malaysia, Percetakan Nasional Malaysia Berhad, Kuala Lumpur, 1974, pp. 111–121.
[21] H. Juahir, S. Md Zain, A.Z. Aris, M.K. Yusoff, Spatial assessment of Langat River water quality using chemometrics, J. Environ. Monit. 12(1) (2010) 287–295.
[22] S. Carrer, R. Leardi, Characterizing the pollution produced by an industrial area chemometric methods applied to the lagoon of Venice, Sci. Total Environ. 370(1) (2006) 99–116.
[23] O.O. Omo-Irabor, S.B. Olobaniyi, K. Oduyemi, J. Akunna, Surface and groundwater water quality assessment using multivariate analytical methods: A case study of the Western Niger delta Nigeria, Phys. Chem. Earth 33(8–13) (2008) 666–673.

[24] A.S. Shihab, A. Hashim, Cluster analysis classification of groundwater quality in wells within and around Mosul City, Iraq, J. Environ. Hydrol. 14(1) (2006) 1–11.

[25] Y.H. Huang, C.P. Yang, Y.C. Lee, P.K. Tang, W.M. Hsu, Variation of groundwater quality in seawater intrusion area using cluster and multivariate factor analysis, Proceedings of the sixth International Conference on Natural Computation, Yantai, China, August 10–12, IEEE catalog No. 6 (2010) 3021–3025.

[26] E.M. Andrade, H.A.Q. Palacio, I.H. Souza, R.A. OliveiraLeao, M.J. Guerreiro, Land use effect in groundwater composition of Anlluvial Aquifer (Trussu River, Brazil) by multivariate techniques, Environ. Res. 106 (2) (2008) 170–177.

[27] E. Marengo, M.C. Gennaro, E. Robotti, A. Maiocchi, G. Pavese, A. Indaco, A. Rainero, Statistical analysis of groundwater distribution in Alessandria Province (Piedmont-Italy), Microchem. J. 88(2) (2008) 167–177.

[28] H. Çamdevýren, N. Demýr, A. Kanik, S. Keskýn, Use of principle component scores in multiple linear regression models for prediction of Chlorophyll-*a* in reservoirs, Ecol. Model. 181(4) (2005) 581–589.

[29] Metcalf and Eddy, G. Tchobanoglous, F.L. Burton, H.D. Stensel (Eds.), Wastewater Engineering Treatment and Reuse, fourth ed., McGraw-Hill, New York, NY, 2003.

[30] F.M. Kusin, A.P. Jarvis, C.J. Gandy, Hydraulic performance assessment of passive coal mine water treatment systems in the UK, Ecol. Eng. 49 (2012) 233–243.

[31] F.M. Kusin, A.P. Jarvis, C.J. Gandy, Hydraulic performance and iron removal in wetlands and lagoons treating ferruginous coal mine waters, Wetlands 34(3) (2014) 555–564.

[32] SPAN, Malaysian Sewerage Industry Guidelines for Sewage Treatment Plants, Third ed., National Water Services Commission (SPAN), vol. 4, p. 139, 2009.

[33] K. Chen, J.J. Jiao, J. Huang, R. Huang, Multivariate statistical evaluation of trace elements in groundwater in a coastal area in Shenzhen, China, Environ. Poll. 147(3) (2007) 771–780.

[34] C.W. Liu, C.S. Jang, C.P. Chen, C.N. Lin, K.L. Lou, Characterization of groundwater quality in Kinmen Island using multivariate analysis and geochemical modeling, Hydrol. Proc. 22(3) (2008) 376–383.

[35] M.S.K. Kumar, T.K. Kumar, P. Arulazhagan, S.A. Kumar, I. Yeom, J.R. Banu, Effect of alkaline and ozone pretreatment on sludge reduction potential of a membrane bioreactor treating high-strength domestic wastewater, Desalin. Water Treat. (2014, in press). doi:10.1080/19443994.2014.92333.

[36] T. Elsäßer, L. Houdková, P. Bělohradský, P. Stehlík, Disintegration of sewage sludge for improved dewaterability, Chem. Eng. Trans. 29 (2012) 1273–1278.

[37] L. Wang, L. Zhang, A. Li, Hydrothermal treatment coupled with mechanical expression at increased temperature for excess sludge dewatering: Influence of operating conditions and the process energetics, Water Res. 66 (2014) 85–97.

[38] W.P.F. Barber, Influence of wastewater treatment on sludge production and processing, Water Environ. J. 28(1) (2014) 1–10.

[39] M. Niu, W. Zhang, D. Wang, Y. Chen, R. Chen, Correlation of physicochemical properties and sludge dewaterability under chemical conditioning using inorganic coagulants, Bioresource Technol. 144 (2013) 337–343.

[40] B. Peeters, R. Dewil, L. Vernimmen, B. Van den Bogaert, I.Y. Smets, Addition of polyaluminiumchloride (PACl) to waste activated sludge to mitigate the negative effects of its sticky phase in dewatering-drying operations, Water Res. 47(11) (2013) 3600–3609.