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Cluster analysis of some ecological properties in Al-Rustamiyah wastewater treatment plant 3rd expansion at Baghdad city, Iraq through (2006-2011)

التحليل العنقودي لبعض المتغيرات البيئية في محطة الرستمية لمعالجة مياه الصرف الصحي (التوسع الثالث) في بغداد، العراق للفترة من 2006 ولغاية 2011

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Abstract

The present study aimed to evaluate performance efficiency of Al-Rustamiyah wastewater treatment plant (3rd expansion) in terms of effluent quality at Baghdad city using cluster analysis. The plant designed to serve 1500000 individual and it is operating on biological treatment method (Activated Sludge Process) with an average wastewater inflow of 300MLD. Wastewater data were collected yearly from 2006 to 2011 by Mayoralty of Baghdad from the influent and effluent in Al-Rustamiyah wastewater treatment plant for major water quality parameters, such as biological oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS) and pH over a period of six years. Water samples were analyzed in the central laboratory of Al-Rustamiyah wastewater treatment plant. Performance efficiency of the plant has been estimated for each year. Multivariate statistical technique of the data has been attempted by applying cluster analysis using Statistical Package for Social Sciences. The result reveals that the overall performance of the existing was satisfactory. Cluster analysis shows that years (2007, 2008, 2009 and 2011) indicate a good level of treatment compared to that of 2006 and 2010. Final effluent quality (in term of mean value of six years) does not meet the stringent regulations proposed by the Iraqi National Standards set by the Regulation 25 of 1967.The BOD_5/COD ratio of the influent was calculated as 0.46 in total wastewaters.

Keywords: Al-Rustamiyah WWTP, Cluster analysis, Statistical analysis.

المستخلص:

تهدف هذه الدراسة الى تقييم كفاءة محطة الرستمية (التوسيع الثالث) لمعالجة مياه الصرف الصحي في مدينة بغداد بأستخدام التحليل العنقودي. صممت المحطة لتخدم 1500000 نسمة من السكان كما تعمل على الطريقة البيولوجية (طريقة الحمأة المنشطة) مع معدل جريان 300 مليون لتر/ يوم. تم جمع البيانات سنويا من 2006 ولغاية 2011 من أمانة بغداد/ دائرة مجاري بغداد للماء الخام والماء المعالج في محطة الرستمية للمتغيرات الأساسية لنوعية المياه وهي المطلب الحيوي للأوكسجين، المطلب الكيمياوي للأوكسجين، المواد الصلبة العالقة وpH على مدى ست سنوات. التحاليل المختبرية للعينات تمت في مختبر محطة الرستمية لمعالجة مياه الصرف وحسبت كفاءة المحطة في كل سنة. تم أستخدم التحليل المتعدد المتغيرات عن طريق تطبيق التحليل العنقودي بأستخدام برنامج (SPSS). أظهرت النتائج بأن المحطة تعمل بكفاءة مقبولة. وأظهر التحليل العنقودي بأن السنين (2007، 2008، 2009 و2011) تشير الى وجود مستوى جيد من المعالجة اذا ماقورنت بالسنين (2006 و2010). ان جودة المياه للماء المعالج (متوسط القيم لستة سنوات متتالية) لا تلائم الظوابط الصارمة التي أقترحتها المعايير الوطنية العراقية التي وظعتها المادة 25 من عام 1967. كما تضمنت الدراسة حساب نسبة BOD_5/COD للماء الخام وكانت 0.46 في مياه الصرف الأجمالي.

Introduction

Wastewater is mainly water supply of the community after being fouled by a variety of uses. Raw wastewater generally contains high levels of organic material, numerous pathogenic microorganisms, as well as nutrients and toxic compounds. Thus, it is considered as environmental and health hazards and, consequently, must immediately be conveyed away from its generation sources and treated appropriately before final disposal to protect public health [1]. The primary

objective of wastewater management is the protection of the environment in a way commensurate with public health and socio-economic concerns [2].

Baghdad is consists of two main parts, namely, Al-Rusafa and Alkarkh, the first attempt to establish a sewage network for the city of Baghdad was in 1942, while implementation work of the first network began already in 1955 [3]. Then, the sewage network has expanded to serve 80% of the populations [4]

The sewerage network of Al-Rusafa worked on the basis of the separate system, but a combined system has been adopted since 1980 in most of Alkarkh part. In general, the wastewater quantities generated within the urban and rural areas of the mayoralty of Baghdad are 1,426,013 and 2,354 m^3/d respectively [4]. Al-Rustamiyah wastewater treatment plant is considered the wastewater collected through the sewerage network of Al-Rusafa part. The secondary treated wastewater effluent (biological) for Al-Rustamiyah wastewater treatment plant was designed to produce an average of final effluent quality of biological oxygen demand (BOD) and total suspended solids (TSS) as 20 and 30 mg/L, respectively to meet the Iraqi National Standards set by the Regulation 25 of 1967.

There are three main wastewater treatment plants were built within Baghdad city, namely Alkarkh WWTP, southern Al-Rustumiya WWTP (0, 1, 2) and northern Al-Rustumiya WWTP (3^{rd} expansion). Al-Rustumiya Wastewater Treatment Plant (3^{rd} expansion) has begun to operate in 1984. The Plant works with an activated sludge system which biologically treats compounds of carbon in raw wastewaters. Al-Rustamiyah wastewater treatment plant (3^{rd} expansion) serve 1500000 population and the treatment facility is a conventional activated sludge system with an average wastewater inflow of 300MLD [5]. The sewerage system is designed to accommodate the domestic effluent. The treated wastewater in the plant is then being discharged to Diyala River. A full outline of the plant units is shown in Fig.1.

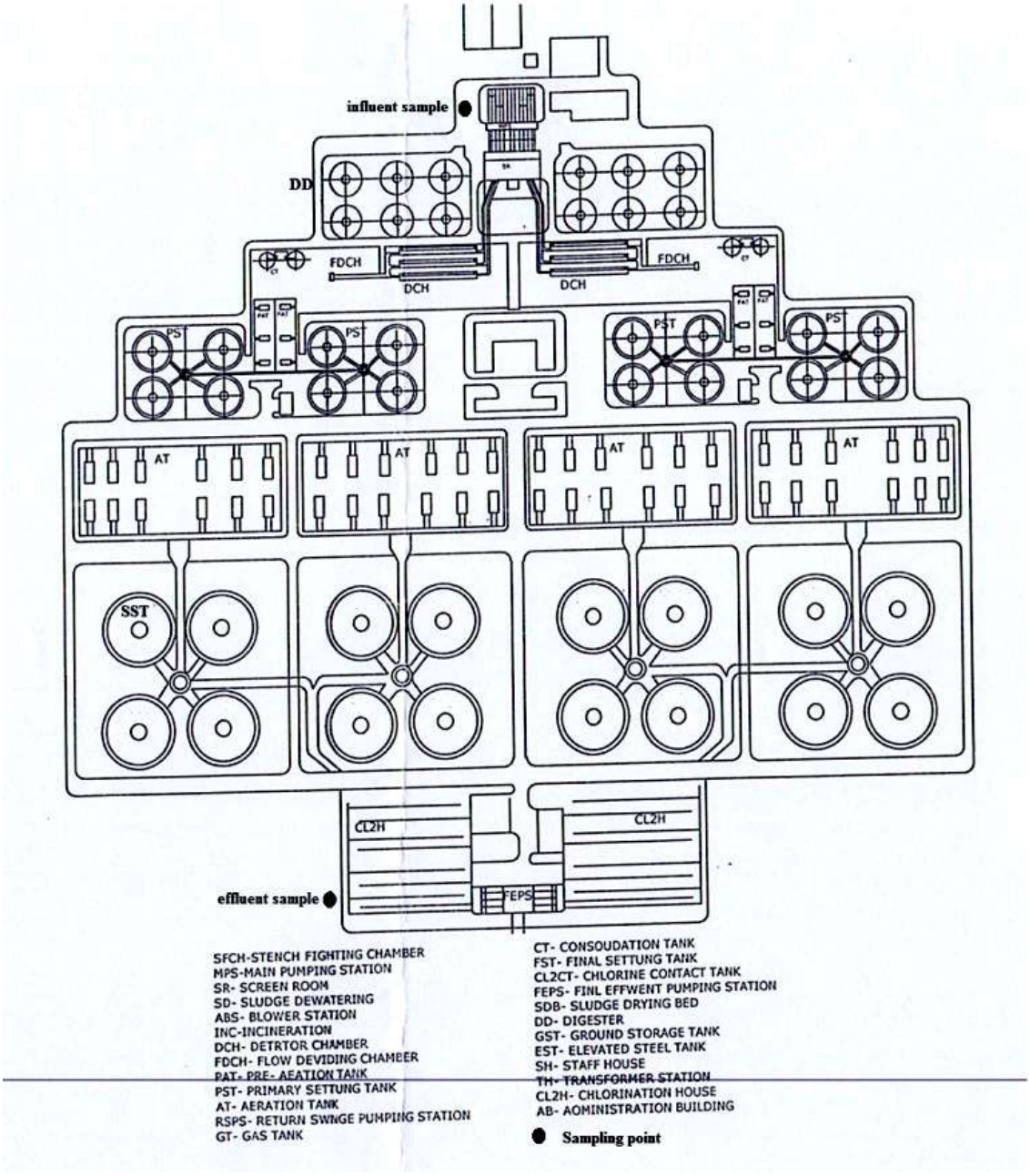

Fig.1 Schematic Diagram of Al-Rustumiya Wastewater Treatment Plant, Baghdad

The application of multivariate statistical techniques, such as cluster analysis (CA), helps in the interpretation of complex data matrices to better understand the ecological status of the studied systems [6].

The data sets collected yearly from the Mayoralty of Baghdad during 2006 to 2011 from the influent and effluent of Al-Rustamiyah wastewater treatment plant are discussed in this study and temporal evaluation of the performance efficiency in term of quality effluent of Al-Rustamiyah wastewater treatment plant at Baghdad city also detected by using cluster analysis.

Materials and Methods:

Major water quality parameters were selected for this study; biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS) and pH over a period of six years. In the present study, data have been collected yearly by the Mayoralty of Baghdad (2006 -2011) from the influent and effluent in Al-Rustamiyah WWTP. All the analyses were done by the technician

LAB of the Al-Rustamiyah WWTP in which, composite samples of influent and effluent of the plant were adopted on daily basis. The sampling locations are illustrated in Fig. 1.
The analyzed COD, BOD_5, TSS and pH parameters were conducted by technicians following the standard methods for the examination of wastewater [7]. The analyses were carried out by the staff of the central laboratory of Al-Rustamiyah WWTP and results were rendered available upon the author's request.

Statistical analysis:

Means, maximum values, minimum values and standard deviations of parameters selected in this study during six years were calculated using SPSS17. A multivariate statistical technique of the data has been attempted by applying cluster analysis using SPSS .Cluster analysis is efficient ways of displaying complex relationships among many years [8, 9]. The term cluster analysis encompasses a number of different algorithms and methods for grouping objects of similar kind into respective categories. In other words cluster analysis is a group of multivariate techniques whose primary purpose is to assemble objects based on the characteristics they possess. Cluster analysis classifies objects so that each object can be similar to the others in the cluster with respect to a predetermined selection criterion. Hierarchical agglomerative clustering is the most common approach, which provides intuitive similarity relationships between any one sample and the entire data set, and is typically illustrated by a dendrogram (tree diagram). Euclidean distance method was used for determining distance. This is probably the most commonly chosen type of distance. It simply is the geometric distance in the multidimensional space and is computed as:

$$\text{Distance}(X,Y) = \left\{ \sum i(Xi - Yi)^2 \right\}^{1/2} \ldots\ldots 1$$

In this study cluster analysis was done using SPSS package. Generally, it is good practice to transform the dimensions so they have similar scales [10, 11].

Removal efficiency:

The effectiveness of removal of TSS, BOD and COD was calculated using the following formula [12]:

% Removal efficiency of $P = (P\text{inf} - P\text{eff}) / P\text{inf} \times 100 \ldots\ldots 2$

Where, *P* is the selected parameter, *Pinf* is the mean influent and *Peff* is the mean effluent.

Results and discussion

The evaluation of performance efficiency of the plant was undertaken in terms of effluent quality. The variations in the raw wastewater characteristics with time are illustrated graphically in Fig. 2. The results of the physicochemical parameters of the final effluent are presented in Fig. 3.To characterize the quality of waste water averages, standard deviations as well as maximum and minimum values were calculated for the selected parameters from the data, descriptive statistics for the water quality data of the plant are given in Table 1.

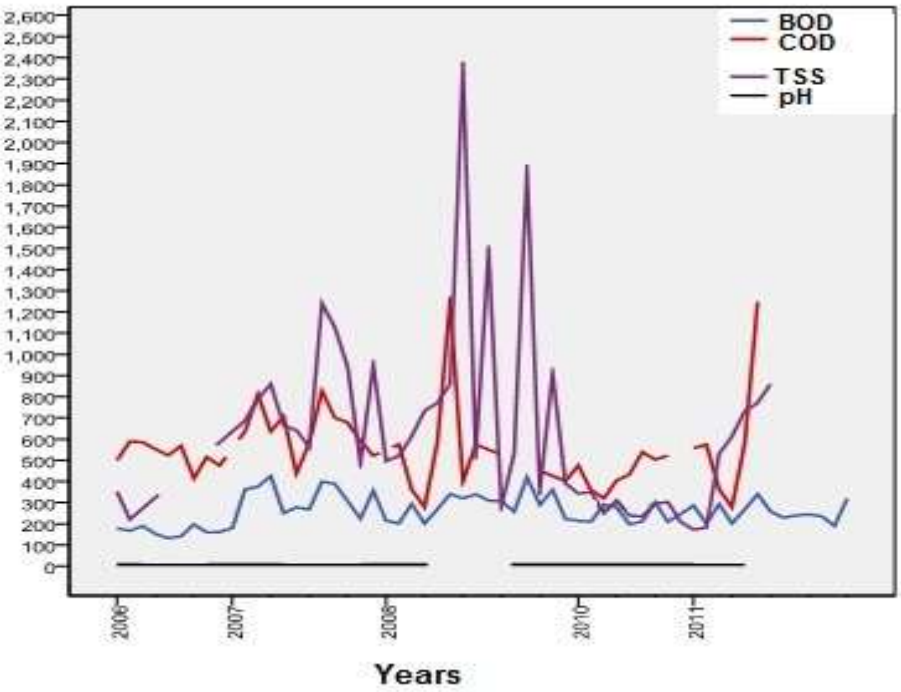

Fig. 2 Variations in the raw wastewater (influent) characteristics over six years
*All values in mg/L except pH

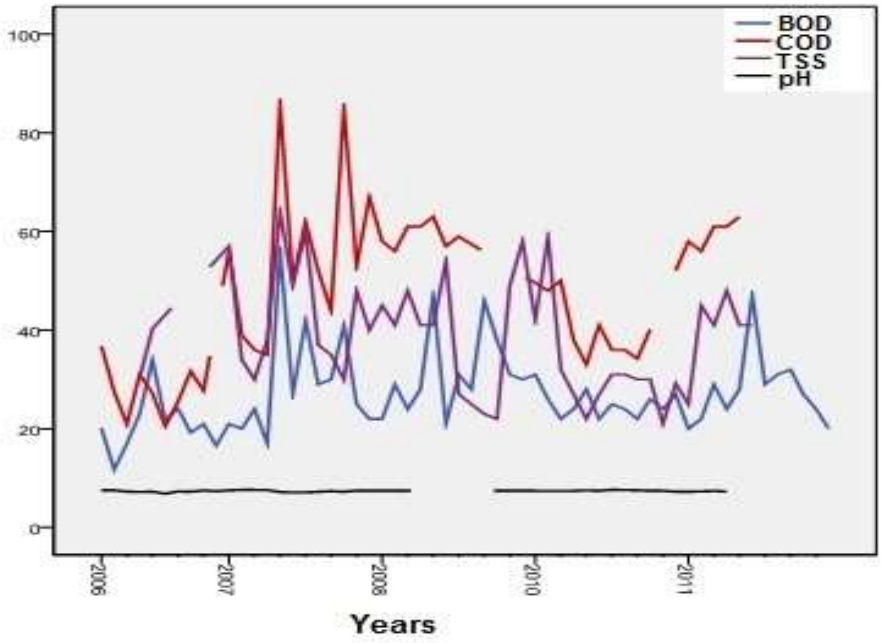

Fig. 3 Yearly variations in the wastewater characteristics of final effluent in Al-Rustamiyah Wastewater Treatment plant

*All values in mg/L except pH

Table1:Descriptive statistics for the water quality data of Al-Rustamiyah Wastewater Treatment plant

Parameters	Years	Influent					Effluent				
		Min	Max	Mean	St.Dv	N	Min	Max	Mean	St.Dv	N
BOD_5	6	132.4	426	260.9	73.08	1015	11.7	56	27	8.2	981
COD	6	279	1248	559.2	204.9	738	20.5	86	47.4	16.06	621
TSS	6	173	2355	650.9	443.8	864	21	64	38.3	11.42	753
pH	5	6.23	7.56	7.04	0.32	1248	6.82	7.64	7.36	0.17	1233

The composition of wastewater effluent varies from facility to facility according to level of treatment, type of households, businesses, industries, and public facilities discharging into the system [12] and this could be an important contributory factor to the observed differences in pH. The pH level of a water system determines its usefulness for a variety of purposes. Very high pH has been reported [13] to be toxic to aquatic life and alter the solubility of other chemical pollutants as well as some essential elements in water systems, thereby causing adverse effects on the ecosystem and those who depend on it. The European Union tolerance limit for pH in water for the support of fisheries and aquatic life is also set at 6–9 pH units [14].

Generally, pH values of the influent and the effluent were slightly alkaline (Mean value) ranging from 6.23 to 7.56 and from 6.82 to 7.64, with a mean value 7.04, 7.36 respectively during the period of the study (Table 1). The increase in effluent pH compared to influent pH is attributed to the decrease in dissolved CO_2 concentration through a reduction in the concentration of organic matter due to oxidation during the pre-aeration tank unit existing in the Al-Rustamiyah Wastewater Treatment plant [15].

TSS is a very important variable in wastewater discharge control. Apart from being source of aesthetic nuisance along river bank, TSS causes havoc in irrigation systems where in form of algae can block pipes, sprinklers, emitters and narrow water channels. TSS can also adsorb heavy metals unto their surfaces and thereby facilitating formation of heavy metal complexes [16]. By this an effluent high in TSS can become an easy vehicle for the introduction of heavy metals to the environment.

Means of TSS concentration of raw influent were 650.9 while means of TSS of treated effluent were found to sharply decline to 38.3. Although TSS concentration of raw influent had a great variations (between 173 and 2355), a small variation was observed in TSS concentration of treated effluent (between 21 and 64) during the six years (Table 1) which implies that the performance of Al-Rustamiyah WWTP is independent on the influent characteristics. The treatment plant discharges its effluent into Diyala River. High TSS can cause reduction in sunlight intensity in water bodies and reduce primary productivity especially on green algae. This is can disturb the aquatic food chain. Less light can also affect temperature in the aquatic environment impacting negatively on primary and secondary productivity of aquatic life and temperature stratification of the system. TSS can also be a source of organic decay that can release nauseating odors [16].

The removal efficiency for the TSS during the period of data collection from 2006 to 2011 is given in Table 2. Al-Rustamiyah WWTP achieved good removal efficiency of TSS ranged from 87.76% to 95.84% during six years as shown in Fig 4.

Biological oxygen demand (BOD) and Chemical oxygen demand (COD) are two of the most important biochemical parameters commonly used to examine waste water quality since they reflect the organic load in wastewater [17, 18].

COD is a measure of the amount of oxygen required by a strong oxidant (e.g., H_2SO_4) to break down both organic and inorganic matters in a water system [19]. Elevated levels of COD in water systems lead to drastic oxygen depletion which adversely affects the aquatic biota [20].

In the influent, the Chemical Oxygen Demand (COD) ranged from 279 to 1248 mg/l with a mean value of 559.2 mg/l. While the residual COD in final effluent ranged from a minimum value of 20.5 mg/l to a maximum value of 86 mg/l, with a mean value of 47.4 mg/l (Table 1).

The corresponding Biological Oxygen Demand (BOD) in raw water ranged from 132.4 to 426 mg/l, with a mean value of 260.9 mg/l. The BOD concentration in the treated effluent ranged from 11.7 to 56 mg/l, with a mean value of 27 mg/l (Table 1).

Table 2: Removal efficiency for the major water quality parameters

year	parameters	Mean influent	Mean effluent	Removal efficiency (%)
2006	BOD	166.3	20.85	87.46
	COD	525.21	27.65	94.47
	TSS	286.8	35.3	87.76
2007	BOD	321.3	29.5	90.08
	COD	648.09	55.41	91.57
	TSS	787.1	43.5	94.47
2008	BOD	301.07	31.2	89.63
	COD	574.85	59.28	89.68
	TSS	909.8	39.7	95.63
2009	BOD	283.3	24.2	91.45
	COD	531.2	52.4	90.13
	TSS	826.2	34.3	95.84
2010	BOD	243.09	24.54	89.9
	COD	430	39.52	90.8
	TSS	273.83	30.35	88.91
2011	BOD	252.41	27.75	89
	COD	609.8	59.8	90.19
	TSS	701.6	43.2	93.84

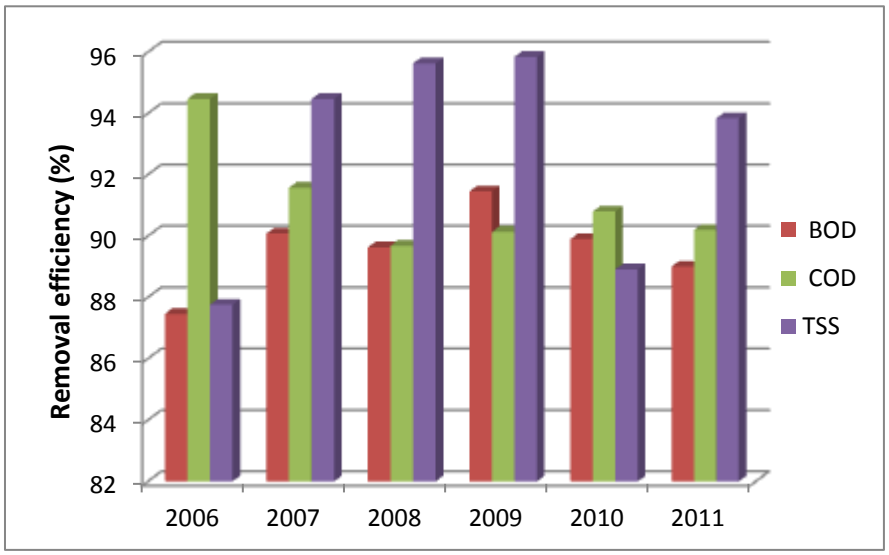

Fig. 4 Removal efficiency of the selected parameters of effluent in Al-Rustamiyah Wastewater Treatment plant

Efficiency of BOD removal was 87.46, 90, 89.63, 91.45, 89.9 and 89% while efficiency of COD removal was 94.47, 91.57, 89.68, 90.13, 90.8 and 90.19% in 2006, 2007, 2008, 2009, 2010 and 2011 respectively (Fig. 4).

The BOD/COD ratio has been reported as indicator for biodegradation capacity [12]. If BOD/COD ratio is more than 0.5, biodegradation will readily take place, if between 0.2 and 0.4 biodegradation will occur only in favorable thermal situation and if the ratio is below 0.2 biodegradation will not proceed [21]. It was found that domestic wastewater has typically a BOD/COD ratio between 0.4 and 0.8 [12] and as reference, a BOD/COD ratio of 0.4 is generally considered the cut-off point between biodegradable and nor biodegradable waste [17]. In the present study, BOD/COD ratio in raw influent was around 0.46, which indicate the presence of considerable amount of organic materials vulnerable to biodegradability.

The overall efficiency of the Al-Rustamiyah Wastewater Treatment Plant for removing the BOD, COD and TSS was considered good. A removal of more than 89%, 90% and 94% was achieved for BOD, COD and TSS respectively.

Cluster analysis

The output result of cluster analysis has shown as a dendogram, where the distance between two years corresponds to the similarity and dissimilarity between two years (similarity between two years in term of treatment efficiency), i.e. greater will be the distance, lesser will be the similarity (Figure 5). Two main clusters can be observed: the first of them includes two tight subgroups which represent years (2007, 2008, 2009 and 2011) which are characterized by the most efficient years in term of treatment efficiency of the plant. In the second main cluster (from the left): one significantly different group can be seen and is constituted by years (2006 and 2010), which showing the worst years in term of treatment efficiency of the plant. It may be due to different factors such as operational factor, in 2006, the plant was operated by ANRA company without effective control by Mayoralty of Baghdad till 2007 or mechanical failure factor (many mechanical failures occurs in the plant with no maintenance which led to less efficiency for the treatment process). Years (2007, 2008, 2009 and 2011) indicate a good level of treatment compared to that of 2006 and 2010.

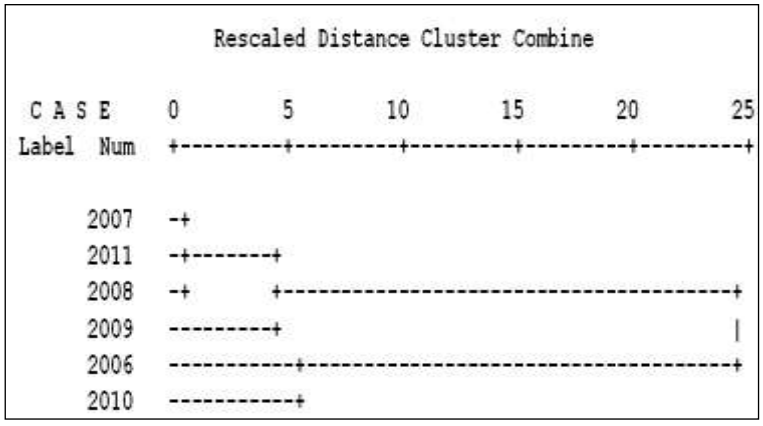

Figure 5: Dendogram showing clustering of years according to major water quality parameters of Al-Rustamiyah Wastewater Treatment Plant (The axis shown at the top indicates the relative similarity of different cluster groups. Lesser distance corresponds to greater similarity between years)

Conclusions

The primary objective of this study was to evaluate the performance efficiency of Al-Rustamiyah wastewater treatment plant at Baghdad city. This study will be the initial step for determination of general characterization of domestic wastewaters of Baghdad.

The removal efficiency of TSS was found to be more than 94%. Therefore, the wastewater treatment units confirm that the TSS removal is significant throughout the wastewater processes. . The removal efficiency of BOD was found to be more than 89% and that of COD was 90%. The overall performance of the existing was satisfactory.

The secondary treated wastewater effluent for Iraqi (WWTP) was designed to produce an average of final effluent quality of biological oxygen demand (BOD) and total suspended solids (TSS) as 20 and 30 mg/L, respectively to meet the Iraqi National Standards set by the Regulation 25 of 1967. This study indicates that Al-Rustamiyah wastewater treatment plant is capable of producing a good quality effluent with respect to BOD, COD and TSS but Final effluent quality in term of mean value of six years does not meet the stringent regulations proposed by the Iraqi National Standards set by the Regulation 25 of 1967. Temporally, cluster analysis shows that years (2007, 2008, 2009 and 2011) indicate a good level of treatment compared to that of 2006 and 2010.

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