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Performance Evaluation of Suez Bay Industrial Wastewater Treatment Plant Case Study: Ataqa Region, Egypt

Lubna A. Ibrahim[1,2,3*], ElSayed ElBastamy ElSayed[2]

[1]*Drainage Research Institute, National Water Research Center, Egypt.*
[2] *Central Laboratory for Environmental Quality Monitoring, National Water Research Center, Egypt.*
[3] *Water Management Research Institute, National Water Research Center, Egypt.*

ABSTRACT

The main objective of this research work was to evaluate the performance evaluation (removal efficiency) of the Suez Bay industrial wastewater treatment plant (SBIWTP) at the Ataqa region with respect to the removal of chemical and microbial pollutants to meet the prerequisite of Egyptian suggestions Law number 4 of 1994. Effluent water and sewage sludge from SBIWTP are suggested for agricultural usage. Therefore, the effluent waters have been evaluated for irrigation purposes relying on FAO regulations as well as the risk of heavy and trace elements was estimated in sewage sludge on the environment. Eighteen samples were gathered from influent and effluent waters during the 9 months of 2018. Samples were analyzed in terms of chemical, physical, and microbial parameters. Sewage sludge from SBIWTP was analyzed in accordance with the extraction method proposed by the Community Bureau of Reference (BCR). The most significant findings in this study, the influent wastewater discharged to the plant was highly contaminated with color, TSS, turbidity, NH_3, COD, BOD, oil & grease, phenol, nitrate and phosphate levels. The efficiency of removal was estimated during 9 months to be 75%, 87%, 67%, 93%, 89%, 92%, 14%, 66%, 76%, and 74%, respectively. Relying on Egyptian Law, SBIWTP confirmed good performance for all contaminated parameters except for color. Concerning to FAO guidelines, it noticed that the effluent water can be used with slight to moderate restriction for eating non-cooked medium tolerant plants in coarse soils with good permeability. The trace and heavy elements in sewage sludge demonstrated safe to low risk on the environment. Further examinations ought to be carried out especially to study the reuse of Suez Bay industrial wastewater treatment plant (SBIWTP) effluent and sludge.

Keywords: *Conventional Activated Sludge (CAS) Process; Secondary treatment; Performance evaluation; Ataqa; Suez Bay*

Corresponding author: Lubna A. Ibrahim
e-mail ✉ lubna736@hotmail.com
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1. INTRODUCTION

There is no more genuine indication of human advancement and culture than great sanitation. A good drain mirrors the civilization as plenty as a beautiful statue (Sastry *et al*., 1995). The stimulus for industrial wastewater treatment is to remove or reduce contaminants within the water that force threats human and environment if released into water bodies without legitimate or valid treatment. Safeguarding natural resources (like rivers, lakes, seas, etc.) is an imperative part of industrial wastewater treatment solutions. The industrial wastewater treatment plant in Ataqa (Northwest Gulf of Suez) has a vital mission for the removal of pollutants that are discharged as effluent in the Suez Bay. In the present study, the authors examined the performance of the Suez Bay industrial wastewater treatment plant (SBIWTP) through estimation of the efficiency of removal for each parameter and by comparing water quality parameters of influent (inlet) with effluent (outlet).

Suez Bay industrial wastewater treatment plant (SBIWTP) in the Ataqa region comprises two processes, which are primary and secondary wastewater treatment. The two processes include neutralization, coagulation & flocculation, sedimentation, Conventional Activated Sludge (CAS), and disinfection (chlorination). Most wastewater treatment plants have a basic treatment, which achieves the physical removal of floatable and settleable solids and the secondary treatment that guarantees the biological removal of dissolved solids (Brucculeri *et al.*, 2005; Dima *et al.*, 2006; Huertas *et al.*, 2008; Vaiopoulou *et al.*, 2007; Matamoros *et al.*, 2009). Oxygen transfer plays a vital role within the aerobic treatment of wastewater; the energy necessary for ideal oxygen transfer in the activated sludge approach is about 70% of absolutely the working expense of the wastewater treatment plant. Consequently, mixing could be a basic factor to be considered when planning and running an aerobic reactor (Hsiun and Wu, 1995). The activated sludge process is that the most comprehensively utilized biological approach for residential and industrial wastewater treatment. The activated sludge process changes dissolved organic pollutants into biomass, carbon dioxide, and water. Activated sludge applications are found among the literature for the treatment of chemical industrial wastewater by Nemerow and Dasgupta (1991), Jobbágy *et al*. (2000), Meng *et al*. (2004), Jiamping *et al*. (2005), and Xianling *et al*. (2005).

A byproduct of the biological wastewater treatment process of SBIWTP is the insoluble solid residue remaining after treatment named sewage sludge. The safe disposal of sewage sludge at some stage in the technique of residential and industrial wastewater treatment has turned out to be one of the significant concerns of increased production. At SBIWTP, the volume of sludge from both primary and final sedimentation tanks is reduced in the sludge thickener. The thickened sludge is dewatered at the drying beds and produced sludge cakes are transported and dumped to a designated site. The present investigation recommends the utilization of sewage sludge for land application to enhance the physicochemical and organic properties of soils, which thusly helps in better growth of plants (Aggelides and Londra, 2000). The land application was thought of as a more efficient technique for sewage sludge disposal than landfill and incineration (Zhang *et al*., 2017). However, the presence of trace and heavy elements in sewage sludge confined the utilization of sewage sludge for land application. The risk of trace and heavy elements on the environment was reliant on their concentrations, chemical speciation (forms), and soil characteristics. The authors in that investigation assessed the risk of trace and heavy elements in sewage sludge on the environment.

2. OBJECTIVES OF THE STUDY

The significance of this investigation is that no previous study on this plant was published until 2019. The performance evaluation of SBIWTP was needed to assess the efficiency of the plant in lowering the pollutants level to meet with the Egyptian environmental standards law No. 4 of 1994 in regards to criteria and determinations for specific substances while released into the marine environment. The purpose of this investigation was to assess the performance of Ataqa (Northwest Gulf of Suez) industrial wastewater treatment plant as one of the big treatment plants in Northwest Gulf of Suez, which discharges into Gulf of Suez and to display the first outcomes concerning the removal efficiencies identified with temperature, pH, color, total dissolved solids (TDS), suspended solids (SS), turbidity, ammonia, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), oil & grease, phenol, nitrate, phosphate, aluminum, barium, iron, manganese, nickel, zinc, and *fecal coliform* from January to September 2018. Performance estimation has been accomplished out by comparing the significance variables at the inlet and outlet of the investigated plant, the removal efficiency was calculated for each parameter and determined the regression equation between influent and efficacy for correlated variables. Effluent water was evaluated for irrigation purposes relying on FAO (Ayers & Westcot, 1985) regulations. The environmental risk of trace and heavy elements in sewage sludge gathered from SBIWTP was determined.

3. MATERIALS AND METHODS

Site of study

Suez Bay industrial wastewater treatment plant (SBIWTP) in the Ataqa region is situated in the Northwest Gulf of Suez. Northwest Gulf of Suez area is inside the northeast corner of the Arab Republic of Egypt and within the administrative boundary of Suez. The commercial enterprise is the primary action in the examination zone, with 137 processing plants utilizing 34,194 laborers. The vast majority of its processing plants are commanded by the private segment, speculation, and multinational organizations. Ataqa is the most critical region of the north-west Gulf of Suez in the quality and significance of industry, while Al-Janayn locale is the least as far as the relative significance of the business. Various industrial sectors and structures in the Ataqa region include the accompanying enterprises; building materials industry & Chinese porcelain, chemical industry, food industries, textile industry and garment, oil refining industry, engineering industry, paper products industry, printing & publishing, wood industry & its products, manufacturing industries (jewelers), and extractive industries.

Description of the SBIWTP treatment plant: Table 1 demonstrates the quantity of industrial wastewater and domestic sewage obtained from SBIWTP. The maximum capacity of the treatment plant is 55800 m^3/day. This plant is split into four parallel trains, each train has a capacity of 13950 m^3/d and may be operated independently of each other. SBIWTP comprises two steps for treatment, which are: primary wastewater treatment typically including neutralization, coagulation & flocculation, and sedimentation of wastewater to remove 1/2 of solids suspended in the wastewater; the conventional activated sludge (CAS) system is proposed as the secondary treatment process. Figure 1 shows the SBIWTP treatment plant obtained from SBIWTP.

Table 1: Capacity of Suez Bay industrial wastewater treatment plant (SBIWTP).

Item	Industrial wastewater	Domestic sewage
Average daily	46500 (m^3/d)	5400 (m^3/d)
Maximum daily	55800 (m^3/d)	7020 (m^3/d)
Peak hourly	3875 (m^3/hr)	450 (m^3/hr)

Sludge treatment facility: Drying bed method was utilized for treatment in SBIWTP. The volume of sludge from both primary and final sedimentation tanks is reduced in the sludge thickener. The thickened sludges are deterred at the drying beds and the sludge cakes produced are transported and dumped to a designed site.

Wastewater sampling

Industrial wastewater and treated water samples were assembled from the inlet and outlet of the plant wherein, a total of 18 samples was assembled during the period from January to September 2018. The samples were collected in polyethylene containers for physicochemical analysis and in brown glass for oil & grease analysis. For heavy and trace elements, the samples filtered through a 0.45 μ membrane filter were acidified with nitric acid to pH <2. Sanitization was made by sodium thiosulfate (0.1 ml of 3% $Na_2S_2O_3$ solution in a 120-ml bottle). They were transported in a water cooler at 4°C to CLEQM within the allowable time.

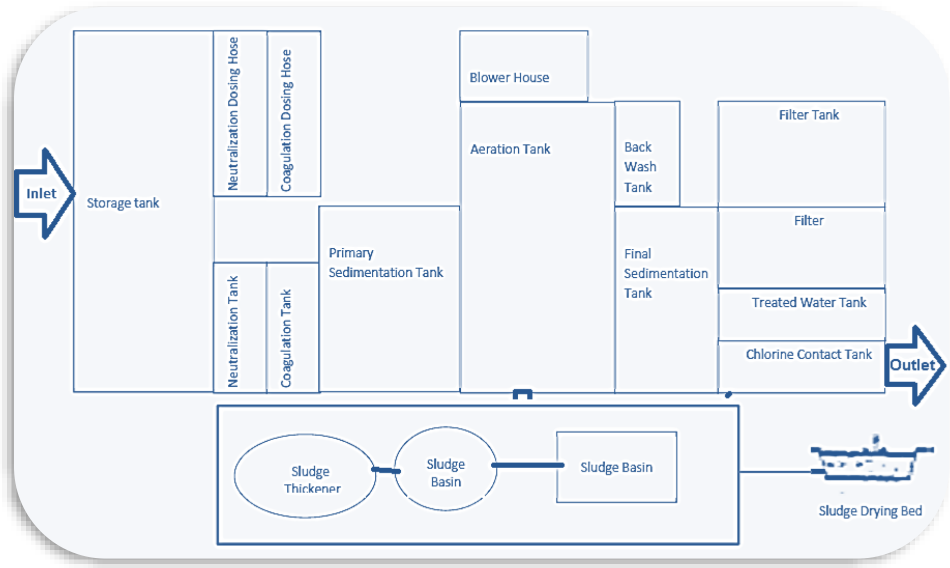

Figure 1: Schematic Diagram of Suez Bay industrial wastewater treatment plant (SBIWTP), Egypt.

Sludge sampling and pretreatment

The material used for the tests was sewage sludge, which was collected into polyethylene containers in 2018, during the period from January to September 2018, from the SBIWTP wastewater treatment plant. The collected sludge samples were dried at room temperature and thereafter stored at 4°C in a refrigerator. The dried sludge samples were gone through a 2-mm sieve for eliminating impurities (stones, plastics, grass, and root). Then, the samples were powdered to fine sizes utilizing mortar and pestle and altogether blended to accomplish homogeneity. The sludge samples were stored in plastic containers at room temperature until they were further examined.

Laboratory analyses of water samples

Water quality was evaluated by standard techniques for testing freshwater and wastewater (APHA, 2005). pH was measured at 25 °C utilizing Info Lab meter. Carbonate (CO_3^{2-}) and bicarbonates (HCO_3^-) ions were titrimetrically assessed against 0.2N H_2SO_4, using phenolphthalein and methyl orange indicators, respectively. True color was assessed for water samples filtered through the 0.45-µm membrane filter by the visual assessment of samples using well-known colored solutions of platinum-cobalt concentrations. Ammonia was detected by the Kjeldahl method utilizing Gerhardt Vapodest 20S programmable distillation system. Turbidimeter Thermo Orion AQ 4500 was utilized to measure the turbidity of water samples using calibration solutions of 0.1, 15, and 100 NTU. Total dissolved solids (TDS) were determined by weighing the solid residue acquired by evaporating a measured volume of filtered water sample to dryness at 103-105 °C. Suspended solids (SS) were determined by filtering a known volume of water through a 0.45-µm filter paper and noticing an increase in the weight of filter paper after dryness at 103-105°C. Major anions; chloride (Cl^-), sulfate (SO_4^{2-}) and nitrate (NO_3^-) were predestined utilizing Ion Chromatography (IC). Major cations; (calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}), and sodium (Na^+)) and heavy & trace metals (Al, Ba, Mn, Fe, Ni, and Zn) were predestined in water by utilizing Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) Dual View.

Biological Oxygen Demand (BOD) was measured using BOD fast respirometry system model TS606/2 at 20°C incubation in a thermostatic incubator chamber model WTW for 5 days. The Chemical Oxygen Demand (COD) was calorimetrically estimated using a strong chemical oxidant (potassium dichromate) in acid medium. The blended solution was heated to oxidize organic carbon into carbon dioxide and water. It measures the amount of dichromate consumed in the breakdown of organic matter using COD Reactor (block heater operates at 150±2°C) and Spectrophotometer Huch-DR-201. Oil & grease (O & G) was estimated utilizing Soxhlet extraction (APHA, 2005). This technique is based on the acidification of the sample to pH<2 with hydrochloric acid, at that point separates the oils from the liquid by filtration and serially extracted with dichloromethane in a separation funnel. The solvent is evaporated from the extract. Phenol was evaluated by the chloroform extraction calorimetric technique at 460 nm (APHA, 2005) utilizing chloroform for extraction. This methodology relies on the formation of a colored antipyrine dye from the reaction of phenols with 4-aminoantipyrine at pH 7.9±0.1 and potassium ferricyanide.

Efficiency of treatment

The removal efficiency was calculated from the initial (Ci) and final (Cf) concentrations of the studied parameters according to the accompanying equation (Ewida and Ibrahim, 2014; Ibrahim *et al*., 2017; Ibrahim *et al*., 2019).

$$\text{Re}\mathit{moval\ efficiency}\ \ (\%) = [\frac{(Ci - Cf)}{Ci}] \times 100$$

Laboratory analyses for sewage sludge samples

Organic matter was assessed by Walkley and Black technique (1934). Nitrogen was assessed by the Alkaline-Permanganate technique (Subbiah and Asija, 1956). Phosphorus was assessed utilizing the Bray and Kurtz method (1945). The total concentration of trace and heavy elements were determined in sewage sludge in line with Charles and Okoro (2011). 0.5 g of the powdered sample, 5 ml of HNO_3 (60% m/m), and 5 ml of $HClO_4$ (60%m/m) were used for digestion at 150 °C in an oven for 12 h. The final digest was evaporated to dryness, then deionized water was added, the solution was transferred into a 100-ml calibrated flask and reached the volume with deionized water.

Sequential extractions for trace and heavy elements from sewage sludge: Six fractions for the studied trace and heavy elements in the sewage sludge were obtained by sequential extraction (Tessier *et al*., 1979; Bourque *et al*., 1994) using the accompanying protocol.

1. F-I: Water-soluble fraction in which the elements are effectively removed by deionized water (pH=7).
2. F-II: Exchangeable fraction could be replaced by competing cations (Tessier *et al*., 1979), which was extracted in a high electrolyte solution (pH=7).
3. F-III: Carbonate fraction represents elements associated with the carbonate species and was extracted in a sodium acetate at pH=5.
4. F-IV: Iron and manganese oxide fraction described by lower stability under the reductive condition. F-IV was extracted with $NH_2OH.HCl$ at 300 °C (Tessier *et al*., 1979).
5. F-V: Organic matter fraction in which elements bound to organic compounds would be relocated into the surrounding environment by reacting with oxidants. F-V was extracted with hydrogen peroxide and nitric acid at 30 °C (Bourque *et al*., 1994).
6. F-VI: Residual fraction displays metals impeded inside the crystal structure of recalcitrant minerals. F-VI was extracted with HNO_3, HCl, and HF acids (Tessier *et al*., 1979; Bermond, 1994; Bourque *et al*., 1994).

Statistical analysis

Experimental outcomes were exposed to the analysis of variance (ANOVA), Duncan test was performed for the comparison of means at 0.05 level of significance. All statistical procedures were computed utilizing statistical package IBM SAS ver. 20 (SAS Institute, Cary, NC, USA).

4. RESULTS AND DISCUSSIONS

Influent and effluent water characteristics

SBIWTP is significant for the removal of organic substances and nutrients, as well as for the overall effluent quality. Table 2 summarizes the mean values for the data collected from January to September of 2018. The annual average influent and effluent for temperature, pH, color, TDS, TSS, turbidity, ammonia, COD, BOD_5, nitrate, phosphate, oil & grease, phenol,

Table 2: Descriptive statistics for influent and effluent concentrations, plant removal efficiency (%), P-value, and Egyptian Law No. 4 of 1994 for 21 water quality parameters measured at Ataqa treatment plant (n=9).

	Influent			Effluent			Removal efficiency (%)	P-value	Egyptian Law No. 4 of 1994 for protection of the marine environment
	Minimum	Maximum	Mean ± SD	Minimum	Maximum	Mean ± SD			
Temperature	32.50	36.80	34.7^{A}±1.37	19.60	24.50	21.7^{B}±1.34	37.4±3.5	0.0002	Not to exceed 10 °C over the prevailing rate
pH*	7.12	7.50	7.35^{B}±0.19	7.52	8.12	7.93^{A}±0.19	-20.1±34.5	0.049	6 - 9
Color*	24.00	97.00	40.8^{A}±24.18	5.00	15.00	9^{B}±2.92	75.2±8.2	0.001	Free of coloring
TDS	1436.00	2541.00	1860.66^{A}±510	1294.00	2711.00	1836.44^{A}±53	0.7±11.4	0.923	2000
TSS	27.00	289.00	185.33^{A}±85	4.00	42.00	24.55^{B}±15	87.4±4.4	0.0005	60
Turbidity*	3.60	94.00	51.53^{A}±35	1.47	36.00	18.16^{B}±12.85	67.0±6.5	0.016	50
Ammonia NH_3	8.86	50.20	35.50^{A}±13.21	0.06	2.61	1.88^{B}±0.74	93.2±5.34	0.0001	3.0
COD	215.00	560.00	326.5^{A}±116.06	25.00	55.00	13.11^{B}±8.27	89.1±7.3	0.0002	100
BOD	120.00	320.00	170.17^{A}±65	4.00	28.00	10.22^{B}±6.63	92.9±5.6	0.0001	60
Oil & Grease	0.01	59.20	21.39^{A}±20	0.03	26.70	6.60^{A}±9.20	14.4±14.4	0.061	15
Phenol	0.05	1.37	0.29^{A}±0.46	<0.01	0.084	0.030^{A}±0.027	65.9±34.5	0.120	1
Nitrate	26.5	51.00	42.39^{A}±9.25	3.20	20.00	10.75^{B}±5.74	76.0±10.8	0.0001	40
Phosphate	<0.2	14	9.85^{A}±4.8	<0.2	3.34	1.34^{B}±0.88	74.8±30.2	0.006	5
Aluminum	0.07	0.399	0.192^{A}±0.125	0.006	0.061	0.022^{B}±0.019	83.8±19.8	0.001	3
Barium	0.01	0.045	0.036^{A}±0.011	0.004	0.053	0.019^{B}±0.017	46.2±41.2	0.018	2
Iron	0.177	2.33	0.71^{A}±0.76	0.01	0.536	0.124^{B}±0.17	79.6±18.2	0.04	1.5
Manganese	0.082	0.172	0.135^{A}±0.033	<0.002	0.166	0.049^{B}±0.05	59.5±46.5	0.001	1.0
Nickel	0.003	0.056	0.018^{A}±0.016	<0.0001	0.019	0.008^{A}±0.007	35.6±37.1	0.115	0.1
zinc	0.002	0.121	0.038^{A}±0.038	<0.0001	0.121	0.008^{B}±0.007	59.6±34.2	0.043	5
*Fecal Coliform**	20	220	77^{A}±79	1	20	9^{B}±8	85.5±11.2	0.021	5000

* pH is unitless, the unit of color is Pt.Co, turbidity is NTU, *fecal coliform* is CFU/100ml, and the units of other parameters in Table 2 are mg/L. Data represented as mean ± SD of 9 samples. Different single letters (A and B) in the same raw are significantly different (p<0.05). Negative values of the removal efficiency represent the formation of treatment byproducts or increase the concentration after-treatment process.

aluminum, barium, iron, manganese, nickel, zinc, and *fecal coliform* concentrations and their removal efficiencies are presented. Standard deviations of the parameters are also given. The higher value of the standard deviation of physicochemical and microbial properties of influent waters is indicative to the source of industrial wastewater which is varied every month, while for effluent, it can be ascribed to the percent of error in the performance (efficiency) of the treatment process. Comparing the measured constituent of influent with Law No. 4 (1994) indicated contamination with color, TSS, turbidity, NH_3, COD, BOD, oil & grease, phenol, nitrate as well as high levels of phosphate (Table 2).

As shown in Table 2, statistically comparing 20 water quality parameters of influent with effluent demonstrated that Oil & Grease, phenol, and nickel did not show any significant variation ($p>0.05$), while the remains of water quality parameters (temperature, pH, color, TDS, TSS, turbidity, NH_3, BOD, COD, nitrate, phosphate, aluminum, barium, manganese, iron, zinc, and *fecal coliform*) showed significant quality variation ($p<0.05$).

The results presented in Table 2 indicated that the treatment plant operated efficiently, especially in terms of inorganic and organic parameters' removal with respect to the fulfilling discharge standard (Law No.4, 1994). The removal efficiency for all months was found comparable for ammonia & BOD_5, which was about 93% and for manganese and zinc were about 59%. While for color, TSS, nitrate, phosphate, COD, aluminum, iron, and *fecal coliform* it varied from 74% to 89%, but for turbidity and phenol, it ranged from 66% to 68%, and for temperature, barium, nickel, and oil & grease it was 35%-50%.

Figure 2 is the plots of the average influent and effluent concentrations for the parameters (color, TSS, turbidity, ammonia, COD, BOD_5, oil & grease, phenol, nitrate, and phosphate) containing a concentration higher than prescribed in Law No. 4 (1994) as a function of time in the months of 2018. Based on the outcomes, the plant did not encounter any heavy or trace metal problems during the investigated period.

The temperature of the water is a critical parameter in light of its impact on chemical reactions and rates of reaction, aquatic life, and furthermore the suitability of the water for beneficial uses. Increased temperature, for instance, can cause an adjustment within the species of fish that can exist in the receiving water body. In the present study, the influent temperature significantly decreased by about 37%. Both influent and effluent water was at the range of Egyptian Law (1994).

The pH values ranged from 7.12 to 7.75 and 7.52 to 8.12 with the average values of 7.35±0.19 and 7.93±0.19 for influent and effluent water, respectively (Table 1). Both influent and effluent water had a pH within the standard limit and showed significant variation ($p<0.05$). The pH of effluent increased by about 20% than that of influent, which can be attributed to the influent that was affected by the disposal of mainly acidic sewage and industrial effluents as well as to oil refineries effluents. The conversion of most of the organic compounds into methane & CO_2 and the higher microbial activity might be the reason for the increase in the pH of effluent water. The percentage of increase of pH are functioned of their influent pH values as outlined in the accompanying equation (1):

$$\text{Increase of pH (\%)} = 19.08\ \text{pH (influent)} - 148.2; \quad R^2 = 0.62 \qquad (1)$$

The color removal efficiency was 75.2%±8.2% regarding a concentration of 9±2.92 Pt.Co. Both influent and effluent water had color strength higher than the permissible limit and showed significant variations. The deficiency of complete color removal can be credited to a deficiency of completely removing the total dissolved organics, iron, and manganese concentrations. There is no acceptable regression equation for influent color with efficiency (%).

The average TDS concentration in the influent wastewater was 1860.66±510 mg/L. Among the collected samples, three samples were higher than the standard limit of 2000 mg/L. The average reduction in TDS was limited to 0.7 % indicating a high deficiency in the plant's processes. The deficiency was mainly related to the chemical (alum) used in the coagulation step. In spite of that TDS, values comply with the permissible limits described in Law 4 (1994). There is no acceptable regression equation for influent TDS with efficiency (%).

All values of TSS in all samples collected from influent wastewater were higher than the standard limit of 60 mg/L. Higher TSS can decrease the quality of water by absorbing light, for this reason, it causes the consumption of oxygen level in the water sample. The plant was able to reduce the concentration of TSS from 185.33±85 mg/L in the raw wastewater to 24.55±15 mg/L in the discharged water that was in accordance with the standard limit. The average TSS reduction was 87% that higher removal efficiency is attributed to efficient grit removal and primary treatment applied.

Nutrient removal: wastewater effluents with high concentrations of nutrients (ammonia, Phosphorus, and organic nitrogen) can cause undesirable phytoplankton growth (Eutrophication) in receiving water body (Mara, 1986; Metcalf and Eddy, 1991; Horan, 1989; Hodgson, 2000). The influent wastewater contained ammonia with an average of 35.5±13.2 mg/L, which was higher than the standard limit of 3 mg/L, while the effluent water contained 1.88±0.74 mg/L, which was lower than the recommended limit. The higher ammonia concentrations are attributed to the reduction of nitrite to ammonia by bacteria (Ahmed *et al*., 2010) and the presence of petroleum compounds. A comparison between 9 influent samples versus effluent samples showed an average of 93% reduction.

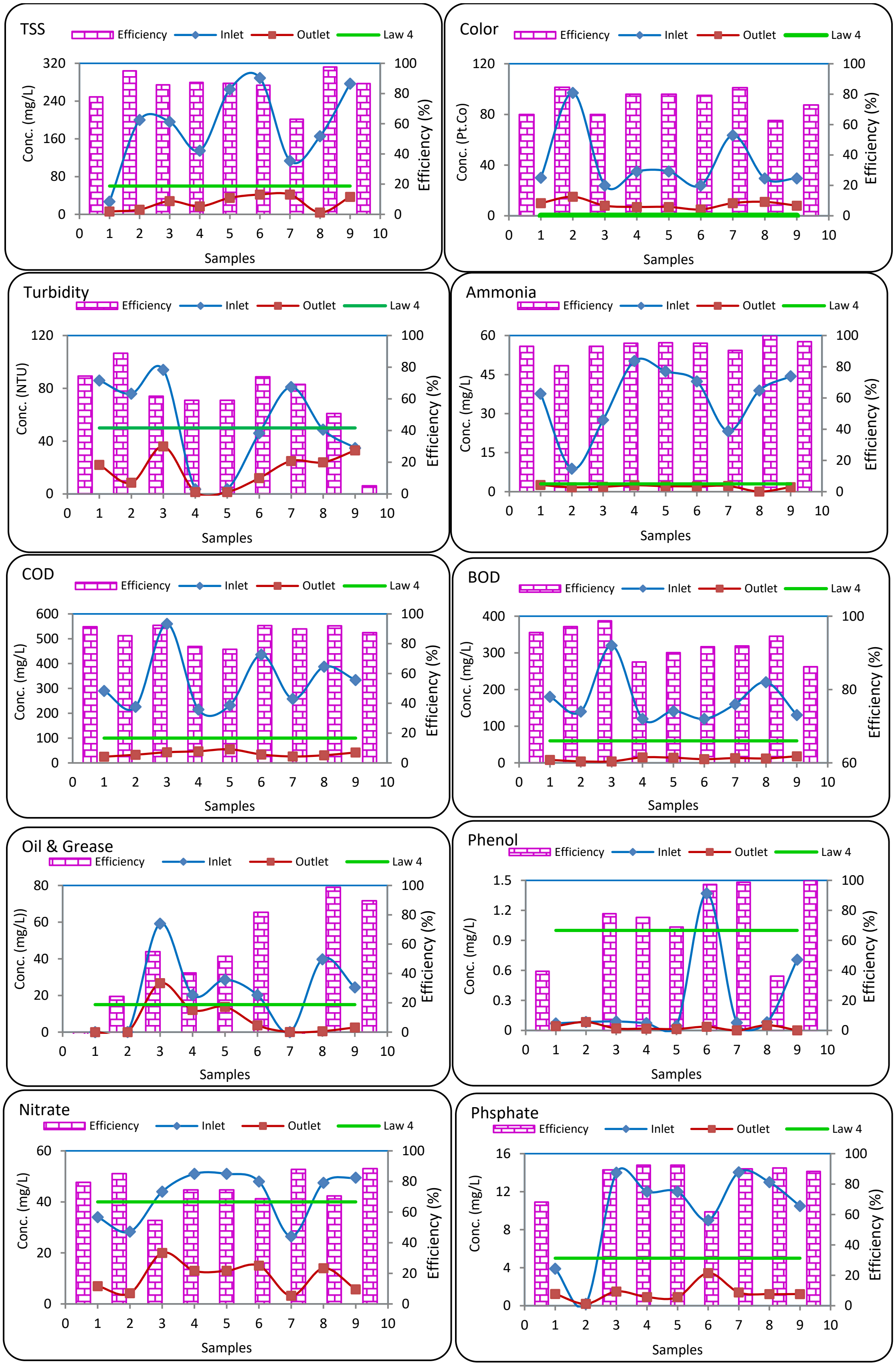

Figure 2: Plant efficiency and concentrations of TSS, color, turbidity, ammonia, BOD, COD, Oil & Grease, phenol, nitrate, and phosphate in influent and effluent water in comparison to Egyptian Law No. 4 (1994).

The higher efficiently is ascribed to the presence of enough oxygen responsible for the nitrification process. The biological removal of nitrogen is ascribed by three equations (2), (3), and (4) (Kang *et al*., 2008). Ammonification (Kang *et al*., 2008) in which organic carbon is converted to ammonium through hydrolysis and microbial activities as indicated by equation (2). Nitrification (Kang *et al*., 2008) in which ammonia converts to nitrate as indicated by equations (3) and (4), under aerobic conditions with oxygen.

$$\text{Organic nitrogen} \xrightarrow{\text{hydrolysis,bacteria}} NH_4^+ \qquad (2)$$

$$NH_4^+ + \frac{3}{2}O_2 + 2HCO_3^- \xrightarrow{\text{bacteria}} NO_2^- + 2H_2CO_3 + H_2O \qquad (3)$$

$$NO_2^- + \frac{1}{2}O_2 \xrightarrow{\text{bacteria}} NO_3^- \qquad (4)$$

The removal efficiencies for ammonia showed a regression equation with their influent values as showed in the next equation (5):

Efficiency (%) = 0.343 ammonia (influent) + 81.03; R^2 = 0.72 (5)

The concentration of nitrate at the treatment plant is presented in Table 1 and Figure 2. The treatment system performed a total reduction of 76 % of the influent nitrate concentration, resulting in an outlet value of 10.75 mg/L. The removal of nitrate was explained denitrification process (by equation (6)), in which nitrate reacts with organic carbon to form nitrogen gas under anoxic conditions.

$$NO_3^- + \text{organic carbon} \xrightarrow{\text{bacteria}} N_2(g) + CO_2(g) + H_2O + OH^- \qquad (6)$$

The major sources of phosphorus are detergents and human waste (Lindquist *et al*., 2003). The inlet held a concentration of 9.85±4.8 mg phosphate/L, which was reduced to 1.34±0.88 mg/l at the point of the outlet (Table 2 and Figure 2). Phosphorus is removed through the oxidation of organic matter releases energy and enables the binding of phosphate to bacterial cells (Kang *et al*., 2008). These resulted in the reduction of dissolved phosphorus in the water and disposal of stored phosphorus with the waste sludge.

High BOD_5 and COD are mainly attributed to the rise in the content of total petroleum hydrocarbons and mercaptans compounds content in the industrial wastewater, presence of iron & steel, pulp & paper, petrochemical & refiners, beside the chemical plants in that area. Furthermore, the presence of a high amount of organic compounds in the effluents enhances the growth of microorganisms in wastewater. For BOD_5, the plant was able to lessen the concentration of BOD_5 from 170.1 mg/L in the raw wastewater to 10.2 mg/L in the discharged wastewater. For COD, the plant can lessen COD from 326.5±116.1 mg/L to 13.1±8.3 mg/L. For BOD and COD, the average removal efficiency was 92.9% and 89.1%, respectively. The reduction in BOD_5 and COD was achievable due to long retention time at the aeration tank, adequate air provided to wastewater in the aeration tank and the ability of microorganisms to convert organic wastes to stabilized low-energy compounds (Woodruff and Moore, 1988). The average values of the BOD_5/COD ratio for untreated industrial wastewater were ranged from 0.28 to 0.62 from January to September 2018 influent wastewaters with an average of 0.54. The variations in the ratio during the studied months indicate that the source of industrial wastewater is varied. The BOD_5/COD ratio reveals the treatability of wastewater. If the proportion of BOD_5/COD is above 0.5, the wastewater is viewed as exceedingly biodegradable. If the proportion is below about 0.3, either the waste may have some harmful components or acclimated microorganisms might be required in its stabilization. Accordingly, the biodegradability of industrial wastewater at the Ataqa plant has been varied from easily biodegradable to non-biodegradable and toxic. There is no acceptable regression equation for BOD influent with efficiency (%). While for COD, the efficiencies of removal (%) are a function of influent COD concentrations as displayed within the accompanying equation (7). The lower R^2 found for the efficiency of COD inferred that some different variables may control the treatment process.

Efficiency (%) = 0.036 COD (influent) + 75.34 R^2= 0.47 (7)

The high oil & grease concentrations within the influent wastewater can be credited to the increasing utilization of oil & grease in high-demanded oil processed foods and oil refining enterprises. Oil & grease of effluent water show non-significantly reduction regarding influent wastewater. The inlet held a concentration of 21.39 mg oil & grease/L which was reduced to 6.6 mg/L at the point of the outlet. As seen in Table 2, 14% of the initial concentration was reduced. The low removal efficiency for oil & grease is due to the fundamental disadvantage of the conventional techniques that remove oil and grease utilizing skimming tanks and oil and grease traps within the treatment plant. No correlation was found between influent oil & grease and removal efficiency.

Phenol in influent wastewater demonstrated non-significant variation with phenol of effluent treated water. About 66% of phenol concentrations were removed by the Ataqa treatment plant. These outcomes exhibited that the activated sludge process is poor in the removal of the low phenol concentrations. The influent phenol is not correlated with the removal efficiency (%).

The acquired consequences of heavy or trace elements analyzed in influent and effluent water were less than the recommended limits. The reduction of aluminum, barium, iron, manganese, nickel, and zinc in effluent water can be ascribed to the increase of the water pH from 7.35±0.19 to 7.93±0.19 and consequent precipitation (settling) of these elements takes place (Ibrahim *et al*., 2017 & 2019). The elements are removed by the adsorption of dissolved elements or fine particulate elements to the biological floc in the aeration tanks with the subsequent settling out of the material in the secondary clarifiers (Oliver and Cosgrove, 1974). The highly effective correlation between barium & manganese (R^2=0.7, p<0.02) and iron & zinc (R^2=0.8, p<0.009) in the influent elements demonstrates that their compounds are utilized in different enterprises for different purposes (Stakeniene *et al*., 2011). This also suggests the possibility of basic sources of origins, which can be anthropogenic (Armah, 2010). The influent concentrations for all studied trace and heavy metals are not correlated with the removal efficiency (%).

Fecal coliform represented in Table (2) demonstrated that both the influent and effluent water of the plant were lower than the quality limit Egyptian Law number 4 of 1994. The low counts of *fecal coliform* are retained to the low ratio of domestic (10% of the plant total capacity) to industrial wastewater (90% of the plant total capacity) as shown in Table 1. *Fecal coliform* significantly reduced after primary and secondary treatment with a removal efficiency of 85.5±11.2%. The higher removal efficiencies are attributed by Ibrahim *et al.*, (2019) to combined mechanisms (coagulation/flocculation and bactericidal effect). The first mechanism is the ability of chemicals used in coagulation & flocculation to form big sized flocs in drain water due to its high content of organic matters and other contaminants. Thus, these flocs can adsorb most of the bacterial cells during the mixing step and settle them on the bottom, which is mostly removed during filtration. The second mechanism is the chlorine dose used as disinfection. The influent *fecal coliform* is not correlated with the removal efficiency (%).

Evaluation of outlet for irrigation

The temperature of the effluent sample ranged from 19.5 to 24.5 °C with a mean value of 21.8±1.4, indicating that water is suitable for irrigation and there is no thermal pollution according to FAO (Ayers & Westcot, 1985). The pH value ranged from 7.5 to 8.1 with a mean value of 7.9±0.2 that is within the adequate FAO limit (6.5-8.5) for irrigation water and does not have any significant negative impact on plants, soils, and equipment of irrigation. A bicarbonate ion for effluent waters ranges from 1.5 to 8.5 meq/L, which demonstrates that this water has a slight to moderate restriction. The bicarbonate hazard of water could be expressed as Residual Sodium Carbonate (RSC), calculated as expressed within the accompanying equation (8). RSC values for effluent samples are under zero indicating that this water is good for irrigation based on Richard's (1954) classification.

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad in\, meq/L \qquad (8)$$

According to FAO (Pescod, 1992), the effluent water samples with EC 2.7±0.8 mS/cm are suitable for with salt-tolerant plants i.e., Maize, Flax, Groundnut peanut, Millet foxtail, Sugarcane, Sunflower, alfalfa, Rice paddy, Burnet, Clover Berseem, Clover ladino, Clover alsike, Clover red, clover white, and clover strawberry.

The TSS value of effluent waters ranges from 4 to 42 mg/L with a mean value of 24±15 mg/L. According to Harivandi (1999), the TSS level below 50 mg/L showed that this water is safe or OK for drip irrigation systems. The mean value of TDS is 1836±537 mg/L, which demonstrates this water can be utilized with slight to moderate restriction. The proportion of cations in order of the largest to lowest abundance was: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$; while that for anions was: $Cl^- > SO_4^{2-} > HCO_3^- + CO_3^{2-} > NO_3^- > PO_4^{3-}$. Calcium and magnesium in the effluent waters are under 20 meq/L demonstrated that this water can be utilized for irrigation. Potassium concentration ranged from 0.26 to 0.51 meq/L with a mean value of 0.39 ± 0.09 meq/L, which is less than the recommended value of 2 meq/L. Sodium and chloride are the major salinity parameters in the effluent water, in light of the fact that their concentrations are generally reflected in the EC values. Na and Cl in water are severe to be used for irrigation.

The average SAR (Sodium Adsorption Ratio), equation (9) was 9.32±1.39 indicating that these waters are suitable for coarse-textured or organic soil with good permeability. The potential infiltration due to SAR and EC demonstrated that these waters have no slight reduction in the yield. Figure 3 shows the Wilcox diagram (Wilcox, 1948), which is dependent on the conductance EC and sodium percentage. The distribution of the plotted points demonstrates that effluent waters are doubtful to unsuitable for irrigation.

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \quad in\, meq/L \qquad (9)$$

Effluent samples contain BOD less than the recommended limit for agricultural reuse for food crop commercial process and non-food crops (30 mg/L). The mean values for trace or heavy elements of Al, Ba, Fe, Mn, Ni, and Zn were 0.022±0.019, 0.019±0.017, 0.124±0.17, 0.050±0.056, 0.009±0.007, and 0.008±0.007 mg/L, respectively demonstrating that they are less than the recommended limit for irrigation (Ayers & Westcot,, 1985).

Irrigation water with partially treated wastewater may contain pathogens that are risky to farm staff and people in general if certain protection practices are not applied. According to WHO (2006) guidelines, a maximum range of 1000 *fecal coliform* per 100 ml is recommended for irrigation water. The effluent water containing *fecal coliform* less than 1000 CFU/ml indicates its quality or suitability for irrigation of crops likely to be eaten uncooked, sports fields, and public parks.

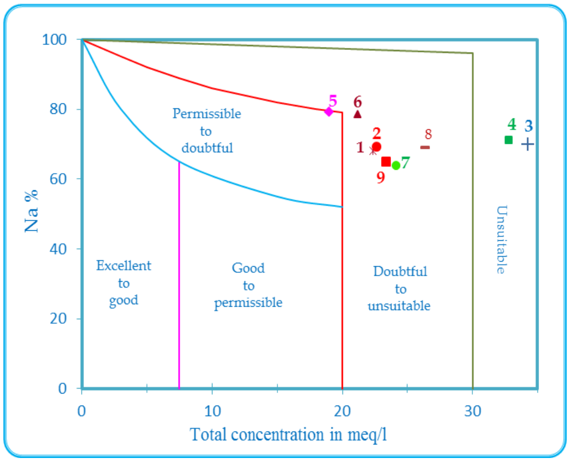

Figure 3: Wilcox diagram for outlet water samples.

In conclusion, effluent water cannot be utilized in soil without drainage and special management for salinity control as drip irrigation systems required. Plants with medium salt tolerance should be selected.

Sewage sludge characteristics and environmental risk

Sewage sludge characteristics: The results of the analysis of sewage sludge collected from SBIWTP are displayed in Table 3 that contains nutrients including organic matter (OM), nitrogen (N), and available phosphorus (P). These nutrients favor its agricultural use. Table 3 shows the nutrient contents within the dry sewage sludge. The organic matter content of the sludge samples varies within the range of 34-57% with a median average of 46%. Nitrogen content varies in the range of 1.44-4.67% with a median value of 3.12%. The high content of nitrogen could be associated with the mineralization of nitrogen through the breakdown of organic nitrogen by anaerobic digestion process that resulted in a higher nitrogen concentration. The high level of nitrogen content (3.12%) bound to the organic matter (46%) in sewage sludge indicates the significance of sewage sludge for agricultural purposes.

Mobility and risk assessment of trace and heavy elements in sewage sludge from SBIWTP: Trace and heavy elements contamination has become the essential impediment for the land utilization of sewage sludge (Liu and Sun, 2013). The accumulation of heavy and trace elements in the soil to toxic levels outcomes from the long- term land utilization of sludge from treatment plants. The risk of trace and heavy metals relies on different factors as their total content, chemical fractions (forms), and soil characteristics. In sewage sludge, heavy or trace elements are found in mobile species that migrate to the soil, and in immobile species that do not drastically affect ground and water environments. Fractionation (speciation) analysis is based on the sequential extraction performed according to BCR methodology. These procedures are beneficial in categorizing the metals into numerous operationally defined geochemical fractions such as water-soluble, exchangeable, metals associated with carbonates, iron and manganese oxides, organic matter, and residual fractions.

Figure 4 demonstrates the relative content of a selected trace or heavy element (mass %) determined in the extracts by its total concentration. Various forms (species) of elements are present in sewage sludge, so that sequential extraction makes it possible to sate the mobility level of trace and heavy elements in sewage sludge. The sequence analysis showed the presence of trace and heavy elements in all fractions (F-I, F-II, F-III, F-IV, F-V, F-VI). For Aluminum, barium, chromium, iron, lead, manganese, nickel, and zinc, the water soluble fraction (F-I) constituted from 0.08%, 0.85%, 0.33%, 0.09%, 4.6%, 0.1%, 2.48%, and 1.33%; the exchangeable fraction (F-II) constituted 0.07%, 0.71%, 0.18%, 0.06%, 4.53%, 0.07%, 0.38%, and 0.71%; the carbonate fraction (III) fraction constituted 0,07%, 0.35%, 0.12%, 0.01%, 0.16%, 0.05%, 0.34%, and 0.18%; the oxide fraction composed of 5,72%, 13.97%, 15.59%, 6.15%, 15.45, 11.74%, 41%, and 11.58%; the organic matter composed of 15.76%, 20.29%, 21.39%, 16.02%, 20.22%, 19.23%, 35.67%, and 18.88%; and residual fraction composed of 78.31%, 63.83%, 62.40%, 77.67%, 55.03%, 68.81%, 20.31%, and 67.32%, respectively. It should be emphasized that oxide (fraction VI), organometallics (fraction V), and aluminosilicates (fraction VI) are the most prevailing species (forms) of the metals under consideration.

The chemical partitioning trends were the same for all studied elements except nickel. Data obtained by the sequential extraction procedure showed the following metal distribution pattern.

Table 3: Descriptive statistics for nutrient resources in the dried sewage sludge in SBIWTP (n=9).

	Organic matter (OM)	Nitrogen (TN)	Phosphorus (TP)
	(%)		
Minimum	34.72	1.44	0.55
Maximum	57.50	4.67	5.90
Mean± SD	45.74±6.93	3.06±1.00	1.64±1.56
Median	46.00	3.12	1.14

Aluminum, barium, chromium, iron, lead, manganese, and zinc: residual (F-VI) > organic matter fraction (F-V) > Iron and manganese oxide fraction (F-IV) > water soluble (F-I) > exchangeable (F-II) > carbonate fraction (F-III).

Nickel: Iron and manganese oxide fraction (F-IV) > organic matter fraction (F-V) > residual (F-VI) > water soluble (F-I) > exchangeable (F-II) > carbonate fraction (F-III).

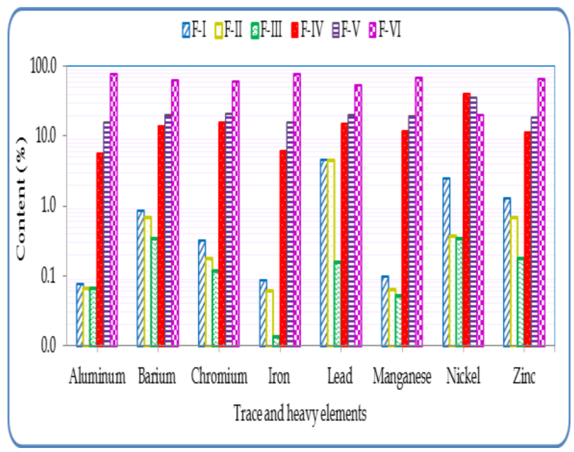

Figure 4: Speciation of trace and heavy elements in sewage sludge from industrial wastewater treatment plant in the Ataqa Region.

Risk Assessment Code (RAC) represents the fractions of water-soluble, metal exchangeable, and metal attached to carbonates (I, II, III). RAC was estimated for the heavy and trace elements, and the values were interpreted in comparison to the RAC classifications (Table 4). This category is also portrayed by Perin *et al.* (1985) to assess the environmental risk of aluminum, barium, chromium, iron, lead, manganese, nickel, and zinc in sewage sludge. According to RAC (Table 4 & Figure 5), the bioavailability of barium, lead, nickel. and zinc showed a low risk ranged from 1.9% to 9.3%, but for aluminum, chromium, iron, and manganese were considered safe to our environment, due to the available fraction less than 1%. According to the tests, it can be concluded that the dominant species of trace and heavy elements are immobile.

Table 4: Classification of risk assessment code (RAC).

RAC	No risk	Low risk	Medium risk	High risk	Very high risk
Criteria (%)	<1	1-10	11-30	31-50	>50

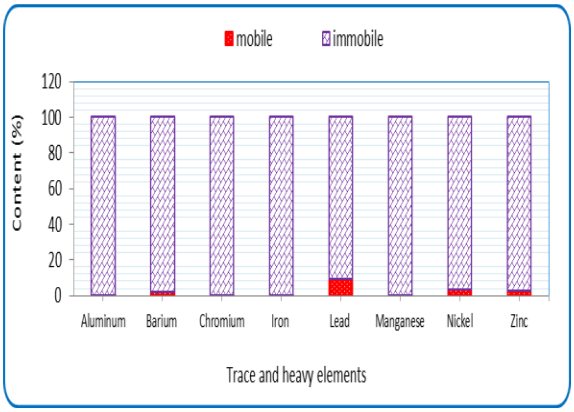

Figure 5: Analysis of the trace and heavy elements' mobility based on the metal speciation in sewage sludge from industrial wastewater treatment plant in the Ataqa Region.

5. CONCLUSION

A Secondary wastewater treatment plant with Conventional Activated Sludge (CAS) process as a biological treatment method has been considered for performance evaluation. The overall performance of the existing was satisfactory. The influent wastewater discharged to the plant was highly contaminated with color, TSS, turbidity, NH_3, COD, BOD, oil & grease, phenol, nitrate, and phosphate levels. The efficiency of removal was estimated during one year to be 75%, 87%, 67%, 93%, 89%, 92%, 14%, 66%, 76%, and 74%, respectively. Relying on the Egyptian Law, the results emphasized that the wastewater treatment plant has high removal performance and the facility met its respective effluent limitations for all contaminated parameters except for color. The regression technique is used for the prediction of pH, ammonia, and COD removal efficiencies. These regression equations indicated that the removal efficiencies are dependent on their influent concentration. Regarding FAO guidelines, it noticed that the effluent water can be used with slight to moderate restriction for eating non-cooked medium-tolerant plants in coarse soils with good permeability. On the basis of the investigations, it can be concluded that the dominant forms of heavy metals are immobile. It was demonstrated that the total content of heavy metals in sewage sludge does not provide an objective criterion to assess the environmental hazard. Therefore, after detailed analyses and examinations, effluent tertiary treatment (desalination) may be required to reach irrigation standards. Color strength requires chemical oxidation procedures for removal. Further investigations should be carried out especially to study the reuse of Suez Bay industrial wastewater treatment plant (SBIWTP) effluent and sludge.

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