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Research Article

Studies on the Effect of Natural Treatment on Sewage Water, El-Salhiya - Qena City, Egypt

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Abstract Natural treatment of sewage wastewater has an environmental and economic means. It is applied by infiltrating wastewater through the vadose zone (unsaturated zone) of an aquifer. This method of treatment proved its effectiveness in removing or reducing most of harmful substances through physic-chemical and biological analysis. The obtained results validated that most of toxic substances were removed by percent of 99.1%, 97.6%, 94.7%, 98.6%, 100%, 99.9% and 100% for TSS, BOD, COD, NH_3, PO_4, total coliform and fecal coliform bacteria, respectively. The study suggests that, the possible removal mechanisms in the vadose zone were primarily filtrations, adsorption and biodegradation, which are the most commonly referenced. These processes are low cost, low or no energy consumption, and low mechanical technology as well as helps in environmental cleanup.

Keywords *Natural treatment; groundwater; sewage wastewater; hydro chemistry*

1. Introduction

1.1. Background

Due to increasing development in desert areas outside the densely populated Nile Valley and Delta has led to the need for exploring alternative renewable water resources (Abdalla, 2012; Abdelkareem et al., 2012; Abdelkareem and El-Baz, 2015). Renewable water resources available in Egypt represent a total of approximately 57 billion cubic meters (BCM)/year. Approximately 97 percent comes from the Nile, with the remainder from precipitation; which is mainly confined to the northern coast. On the other hand, Water demand increasing by 72 BCM/year, over 80 percent of which is used for agriculture. The present per capita water share is below 1,000 m^3/year and it might reach 600 m^3/year in the year 2025, which would indicate water scarcity (water scarcity level starts at 1,000 m^3/year) (Abdel Kader and Abdel Rassoul, 2010). Sewage effluent comprises 99.9% water and 0.1 % organic and inorganic solids in suspended and soluble forms. Raw sewage water contains many microorganisms (bacteria, viruses, and parasitic protozoa), which may be pathogenic, and parasitic worms (Lim et al., 2010).

Sanitation and wastewater treatment services in Egypt are less developed than water supply services. In 2012, Egypt had 372 municipal wastewater treatment plants treating an average of 10.1 million cubic meters per day. The capacity of Egypt's wastewater treatment plants was more than 11 million cubic meters per day, serving more than 18 million people (Abdallah, 2014). Egypt produces 5.5–6.5 BCM per year as sewage water. Of that amount, about 2.97 BCM per year is treated, but only 0.7 BCM per year is used for agriculture (0.26 BCM is undergoing secondary treatment and 0.44 BCM undergoing primary treatment), mainly in direct reuse in desert areas or indirect reuse through mixing with agricultural drainage water (Abdel-Shafy and Abdel-Sabour, 2006). The main wastewater treatment technologies used in Egypt are trickling filter, conventional activated sludge, oxidation ditches, stabilization ponds, constructed wetlands, rotating biological contactor (RBC), sequencing batch reactors (SBR), up-flow anaerobic sludge blanket, and modified septic tank (Abdallah, 2014).

1.2. Previous Work

Natural treatment of contaminated water were studied by many authors such as Shamrukh and Abdalla (2010, 2011 and 2016) studied the effects of riverbank filtration RBF as a natural treatment process to improve water supply quality along Nile towns in Upper Egypt. The study showed that the effectiveness of RBF for removing the pathogens and suspended solids in the abstracted water. Akber et al., (2008) examined the feasibility of long-term irrigation with municipal tertiary treated wastewater using pilot-scale soil aquifer treatment system SAT in Kuwait. The removal efficiencies of biological oxygen demand (BOD), organic carbon (OC) and ammonia were about 100, 90 and 90% respectively. In addition, bacteria were also removed with 50-100% efficiency depending on its type. Gungor and Unlu (2005) studied the nitrite and nitrate removal efficiencies of soil aquifer treatment columns, bench-scale soil column experiments were performed to examine the effects of soil type and infiltration conditions on the removal efficiencies of wastewater nitrites and nitrates during the biological ripening phase of soil aquifer treatment (SAT) columns. The study showed that infiltration rate and the length of wetting period were important parameters affecting nitrogen removal efficiency of SAT columns. Cherif et al., (2013) studied the aquifer recharge by treated wastewaters Korba case study, Tunisia. The study describes the evolution of groundwater quality after recharge with treated wastewaters, three significant parameters controlled throughout the studied area: salinity, nitrates concentrations and total coliforms. The study showed that an improvement of the salinity groundwater levels but no net change in the distribution of nitrate and bacteria else than displacement of the polluted area.

1.3. Objective of the Current Study

The main purpose of this study is to assess and quantify the effects of natural treatment processes on groundwater quality in surface aquifer using the possible aquifer physical, chemical and microbiological indicators in El-Saliya area (Qena), Egypt, where the Quaternary aquifer is recharging mainly from vertical infiltration of sewage wastewater.

2. Study Area

The study area located in the southern part of Upper Egypt between Latitude: 26^{o}13´54´´N and longitudes 32^{o}51´17´´E east of the River Nile (Figure 1). The major source of fresh water in the study area is the River Nile which diverted through Asfun and El-Kalabia irrigation canals and the Quaternary groundwater aquifer. The study area was selected for the present study because of the following: It includes El-Salhiya sewage water plant which was constructed in Qena city (25°9′24″N 32°46′34″E), Egypt in 1985. The capacity of this plant is 25000 m^3/day. Usually, it receives a huge amount of sewage water more than 45000 m^3/day. There is a farm belongs to this plant that has an area of 500 acres with wooden trees. Also, the Quaternary aquifer in the study area exhibits the best conditions in favor of surface recharge where it is unconfined under the reclaimed new areas. As well as most of groundwater wells in the study area are used to irrigate the reclaimed land. In many parts of the study area, the aquifer is recharged by effluent treated or untreated sewage water from sewage bonds, some of this wastewater used to irrigate wooden forests in the area (Figure 2). All of the above mentioned reasons help to study the effect of natural treatment on wastewater in the study area.

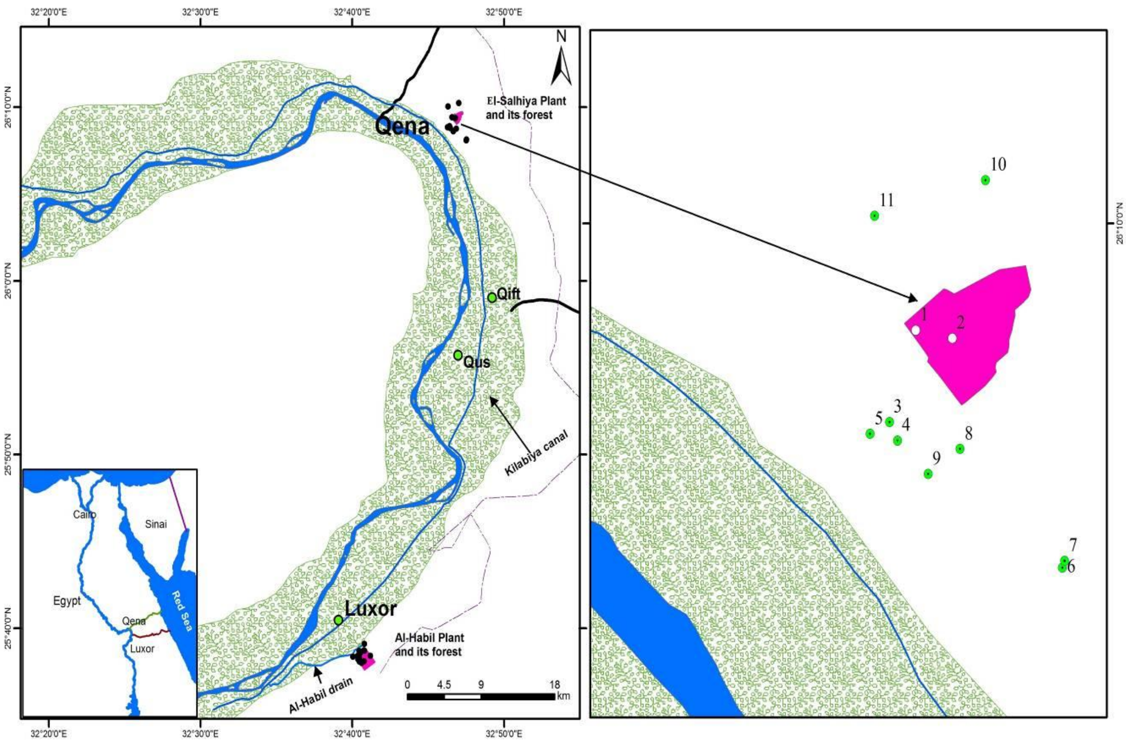

Figure 1: *Location map of the study area showing sampling points location in El-Salhyia area*

Figure 2: *Field photograph shows sewage water ponds and irrigation of wooden forests at El-Salhyia sewage plant*

2.1. Topography and Climate

The study area is characterized by variation in elevation; in Qena area, the highest elevation is in the east, and decreases toward the west (cultivated area). The elevation is ranging between 45 and 116 m above sea level. Qena is located on the alluvial plains which are represented by the cultivated younger plain occupying the central part of the Nile Valley and the older reclaimed plain at the valley fringes. The study area is located in the arid zone characterized by very dry and hot weather condition. The annual rainfall is very rare and precipitation scarcely occurs as flash floods during winter. The average temperature ranges from 23°C in winter to 44°C in summer. The relative humidity ranges between 53% in winter and 29% in summer.

2.2. Geological Setting

The area has been studied by a variety of authors such as Said (1962, 1981, 1983, 1990), Ahmed (1983), Askalany (1988), Issawi and McCauley (1992), El Balasy (1994), Abadi (1995). The sedimentary sequence in the Qena area (from top to base) as shown in the geologic map (Figure 3) could be summarized as follows:

The Quaternary deposits in the study area are comprised the following deposits:

The Holocene unit: It is represented by the silty clay layer of the Nile floodplain as well as the wadi deposits. The silty clay layer has a thickness ranging from 1 to 14 m and forms the fertile soil of the cultivated lands.
Late Pleistocene: This unit is represented by the Pre-Nile deposits composed of sand and gravel with a thickness of 30 m and extends below the silty clay layer and forms the main Quaternary aquifer in the study area.
Plio-Pleistocene: This unit is represented by the Proto-Nile and Pre Nile deposits composed of clay, sands and gravels locally capped by travertine beds. The exposed thickness of this unit is about 60 m.
Pliocene: This unit is represented by the Paleo-Nile deposits dominated by clay facies represented by clay with sand interbeds. This unit overlies the eroded surface of the Eocene carbonate.
Eocene: The Eocene unit in the study area is composed of the karstified chalky and dolomitic limestone and marl with flint bands and nodules. The exposed thickness of this unit is more than 200 m and acts as a fissured carbonate aquifer.
Paleocene-Late Cretaceous: It is dominated by shale facies with thin interbeds of chalk and phosphate which acts as an aquiclude separating the Eocene fissured carbonate aquifer from the Nubian aquifer underneath.
Upper Cretaceous-paleozoic: This unit is represented by sandstone with shale intercalations. This unit unconformably overlies the basement complex and forms the most common and extended water bearing formation of the Nubian aquifer.

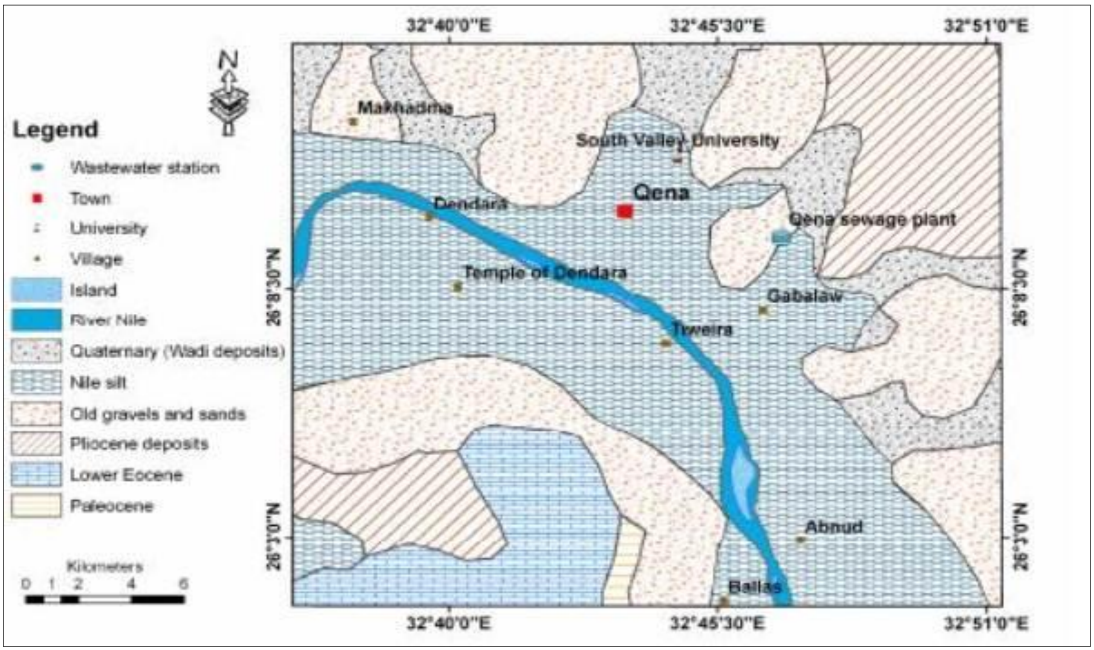

Figure 3: *Geologic map of the study area showing the exposed stratigraphic units (TEGPC and CONOCO 1987)*

2.3. Hydrogeology

The groundwater system in the study area belongs to the regional Quaternary aquifer that extends along the Nile Valley.

2.3.1. *The Quaternary aquifer*

This aquifer can be categorized into two hydrogeological units: the upper Holocene aquitard and the lower Pleistocene aquifer. The Holocene aquitard which composed of clay, silty-clay and clayey-silt deposits and graded sand and gravel intercalated with clayey lenses (Figure 4). The Holocene aquitard is including the phreatic groundwater that constitutes the base of the cultivated lands with thickness varies from 12.5 m to 26 m in the western bank of the River Nile (Kamel, 2004). This unit receives the surface water seepage from irrigation activities. The horizontal and vertical permeability ranges from 0.40 to 1.00 m/day while the vertical hydraulic conductivity is low and increases with depth (Abd El-Moneim, 1988). The Pleistocene aquifer is formed from graded sand and gravel intercalated with clayey lenses. The aquifer in the Nile Valley is extensive and highly productive and distinguished into semi-confined conditions under the cultivated areas and unconfined conditions under the new reclaimed areas at the desert fringes on both sides of the Nile Valley. The aquifer thickness decreases from 300 m at the northern boundary to a few meters in the south western boundary of the study area (Sayed, 2004). The hydraulic conductivity (K) ranges from 60 to 100 m/day and transmissivity ranges from 2000 to 6000 m^2/day (Attia, 1985; Abd El Bassier, 1997). The infiltration tests, according to (Barber and Carr, 1981; Abdel Moneim, 1988) were applied to estimate the infiltration rate of the top layer, the results indicated that the average infiltration rate is 2.5 m/day, this indicating that there is a good hydraulic connection between the upper and lower layer.

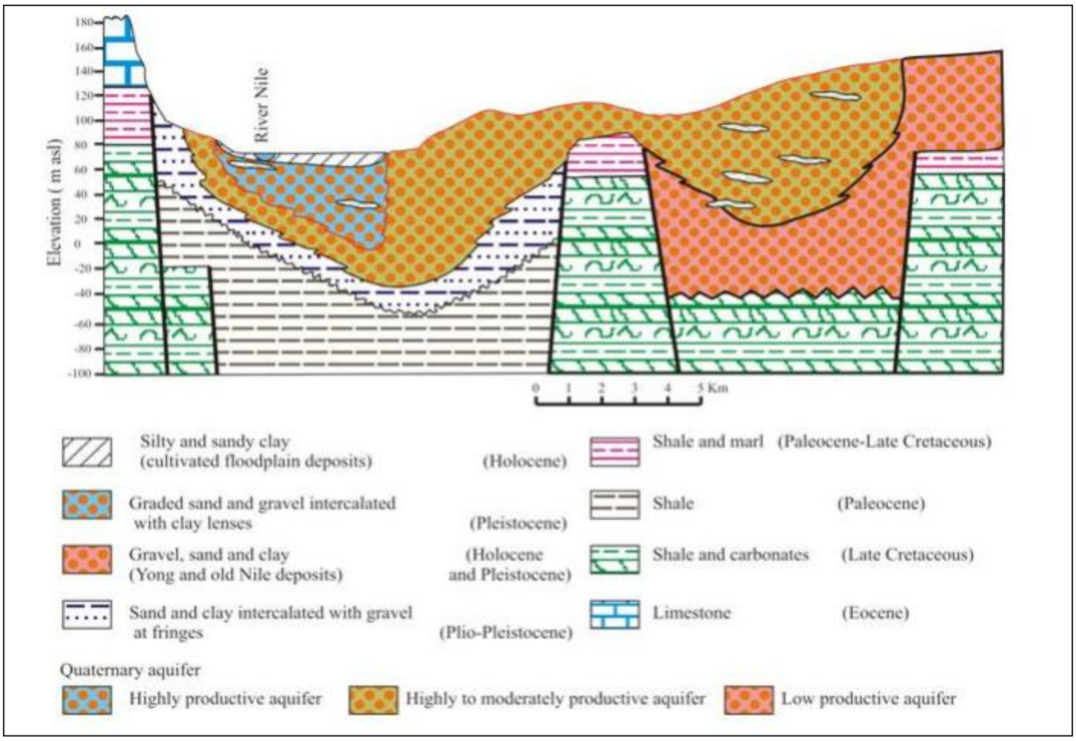

***Figure 4:** Hydrogeologic cross section at Qena area (RIGW, 1994)*

In the study area the Quaternary aquifer is mainly recharged by the irrigation water and seepage from irrigation canal through the Holocene aquitard, secondary source of groundwater recharge is the under flow from rainfall during winter months each few years (Brikowski and Faid, 2006; Ahmed, 2003). In addition, seepage from irrigation of the new reclaimed areas at the desert fringes in the study area (Figure 5). The sewage wastewater in the study area of the El-Salhyia sewage water plant, are considered as another recharge source, where raw and treated sewage water are discharged directly on the ground forming some ponds that are used in irrigating woody forests in El-Salhyia areas. Discharge component from the aquifer is through groundwater pumping for irrigation and drinking purposes and natural discharge towards the River Nile (Ahmed, 2003). The depth to groundwater in the Quaternary aquifer as measured from some available wells varies from 30 m to about 120 m. The Plio-Pleistocene aquifer this aquifer represents the secondary aquifer in the study area and exposed at the outer fringes of the Nile aquifer system adjacent to the floodplain. It is composed of clay sand, and gravel (Kamel, 2004; Ismail et al., 2005). The Plio-Pleistocene aquifer has more thickness near the Quaternary aquifer and decreases towards the Eocene limestone boundary on both sides of the Nile valley. At the valley fringes, the groundwater in this aquifer is under phreatic conditions. This aquifer is of low productivity.

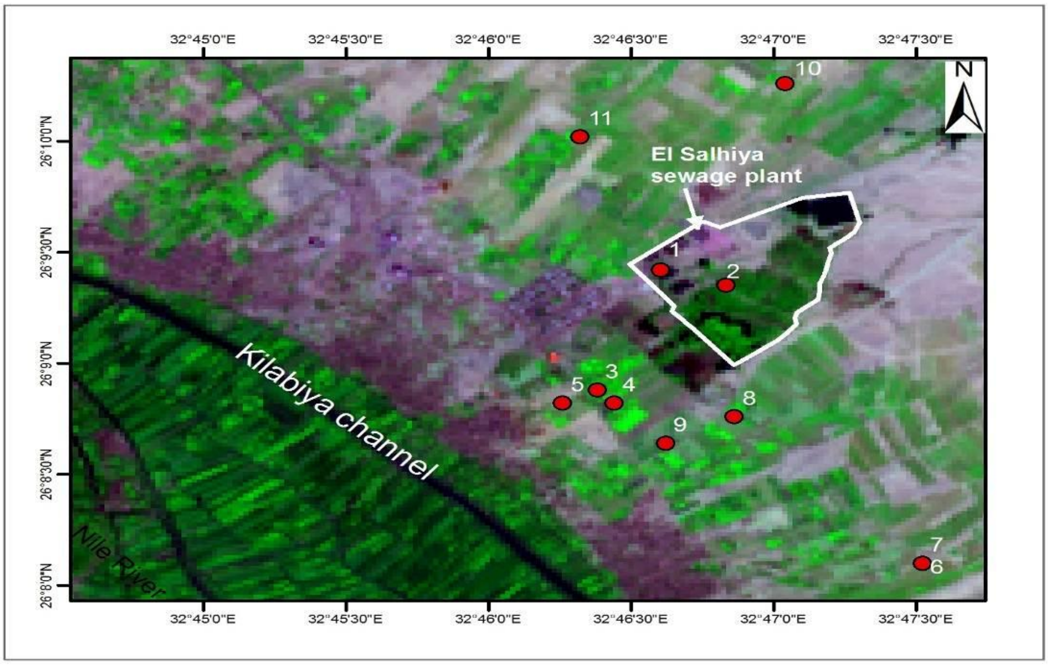

Figure 5: *Land sat image of Qena study area showing the new reclaimed areas at El-Salhyia sewage plant*

3. Methodology

Eleven samples were collected from El-Salhyia sewage water treatment plant and surrounding groundwater in the study area. Physico-chemical water quality measurements and microbial parameters were analyzed. pH and electrical conductivity (EC) of the water samples were measured immediately at the sampling sites. The samples were analyzed for Total Suspended Solid (TSS), Total Dissolved Solids (TDS), nitrates, ammonia, phosphates, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and total, fecal coliform bacteria according to Egyptian standards and the procedures of the American Public Health Association (APHA, 1998). pH and Electrical Conductivity (EC): of the water samples were measured by using checker meter (Model Horiba water checker U-10). Soluble anions: of the water samples were determined by using High Performance Liquid Chromatography HPLC (Model Shimadzu -SCL- 10ASB) and (TDS) of the water, samples were determined by gravimetry method (A-9) according to standard methods for examination of water and wastewater. Microbial measurements for pathogens were carried out at the laboratories of Ministry of Health in Egypt. The results of groundwater samples were compared with those of the outflow sewage water sample for El-Salhyia sewage water treatment plant, and the usefulness of the natural treatment processes are evaluated based on this comparison.

4. Results and Discussion

4.1. Physico-chemical characteristics of El-Salhiya sewage water treatment plant

The various physico-chemical characteristics of El-Salhiya sewage water treatment plant in Qena are listed in Table 1. The result showed that, pH values of sewage water samples range from 6.8 to 7.3 for inflow and outflow wastewater respectively, the TSS concentrations range from 124 mg/l for inflow wastewater to 97 mg/l in effluent sewage water which might be due to gravity settling of suspended particulates in settling tank during the secondary treatment process (WSP, 2008).

Table 1: *Physico-chemical characteristics of El-Salhiya sewage water treatment plant*

Location	Sample number	pH	TSS	TDS	BOD	COD	NO_3^-	NH_3	PO_4^{3-}	SO_4^{2-}
		(-)	(mg/L)							
Inflow wastewater	1	6.8	124	437	130	152	21.5	16.5	2.3	41.0
Outflow wastewater	2	7.3	97	453	99	123	22.0	16.3	2.9	22.8

The TDS values range from 437 mg/l for inflow wastewater to 453 mg/l in effluent sewage water. BOD concentration was reduced from 130 mg/l in inflow wastewater to 99 mg/l in effluent sewage water; COD was reduced from 152 mg/l in inflow wastewater to 123 mg/l in effluent sewage water which are treated by biological treatment (activated sludge), aerobic sludge consisting of active bacteria, which consume and remove aerobically biodegradable organic substances**,** this natural treatment is represented by the following equation (Fujii, 2009); Organic pollutants → mCO_2 + nH_2O + Bacteria cell. Nitrate concentration is slightly increased from 21.5 mg/l in inflow wastewater to 22.0 mg/l in effluent sewage water, reflecting the nitrification process. The transformation of ammonia to nitrate via an intermediate step of nitrite is called nitrification. The transformation of nitrate to gaseous nitrogen is referred as denitrification (Tilley et al., 2014), while ammonia is slightly reduced from 16.5 mg/l in inflow wastewater to 16.3 mg/l in effluent sewage water. Phosphates concentration increased from 2.3 mg/l in inflow wastewater to 2.9 mg/l in effluent sewage water. Biological elimination of phosphorus in conventional wastewater treatment system occurs through the uptake of phosphorus by some bacterial cells. However, only little phosphorus can be removed through this way, as the phosphorus mass fraction in volatile sludge is only about 2.5% (Haandel and Lubbe, 2007). For sulfate, the results showed that the concentration in inflow sewage water sample is 41 mg/L but it decreased to 22.8 mg/L in outflow sample, this may be due to sulfur oxidation bacteria (Thiobacillus Thiooxidans) in secondary treatment process (Biological treatment) oxidize reducing sulfur compounds such as thiosulfuric ($S_2O_3^{2-}$) and sulfide (S^{2-}), sulfite (SO_3^{2-}) into sulfuric acid ion (SO_4^{2-}) by utilizing oxygen in air (Fujii, 2009).

4.2. Microbiological analysis of El-Salhiya sewage water plant

The results of total and fecal indicator organisms for El-Salhiya sewage plant are shown in (Table 2). The results showed that the count of total coliform bacteria in inflow sewage water sample in El-Salhiya sewage plant is >1.810.000 cell/100 ml, while in outflow sample was less than 1.810.000 cell/100 ml. The results showed that the count of fecal coliform bacteria in inflow sewage water sample in El-Salhiya sewage plant is 100.000 cell/100ml while it decreased to 80.000 cell/100 ml in outflow sample, the decrease in fecal count in outflow wastewater may be due to sedimentation processes which eliminate large numbers of pathogens, while aeration promotes antagonistic reactions between different microorganisms, causing their elimination (Leong, 1983). The station is unable to filter the impurities because it receives a huge amount of sewage water.

4.3. Groundwater characteristics around El-Salhiya sewage water

The main physico-chemical characteristics of groundwater samples around El-Salhiya sewage water plant were determined. Discussion on some of the important water quality parameters follows.

Hydrogen ion concentration (pH) Interpolation of pH values using GIS (Figure 6) shows the distribution of pH values for groundwater samples around El-Salhiya sewage plant. The map showed that the groundwater, in most wells have slightly alkaline conditions (7.4 to 8.2), this alkaline condition might be due to the high concentration of base compounds such as bicarbonates.

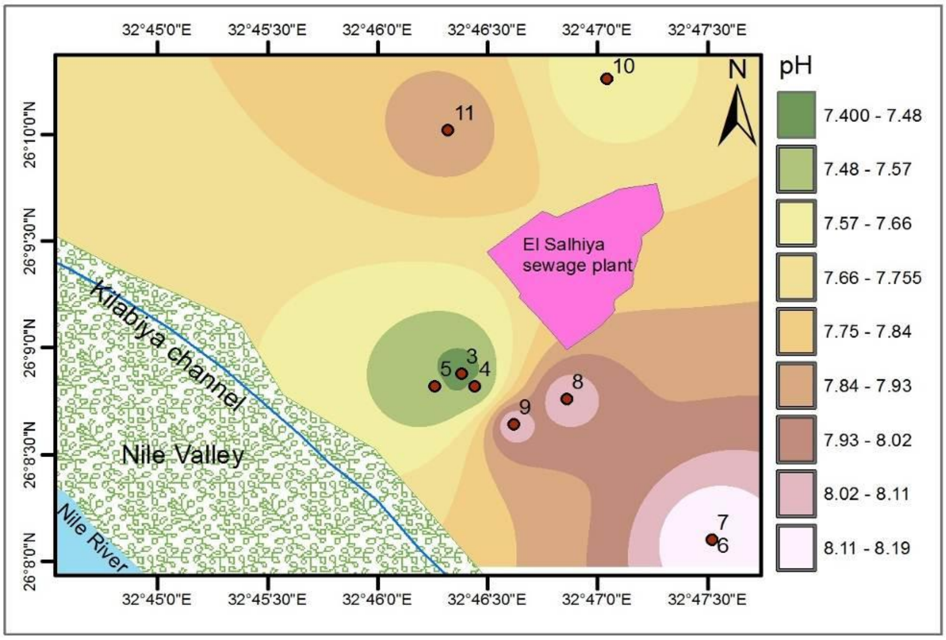

Figure 6: *GIS map shows pH distributions in groundwater samples around El-Salhiya plant*

Total Dissolved Solids (TDS) TDS values for groundwater samples around El-Salhiya sewage plant ranged from 715 mg/L to 3160 mg/L. Interpolation of TDS values (Figure 7) shows that TDS values increase towards desert and reclaimed lands, this might be due to the leaching processes of fertilizer and natural minerals already present in the desert soil (as gypsum $CaSO_4$, $2H_2O$ and halite NaCl). No significant change in the TDS was observed between the outflow sewage water of El-Salhiya plant and the groundwater around it.

Total Suspended Solid (TSS) The results showed that the TSS values of groundwater samples around El-Salhiya sewage plant are less than the values of outflow water sample in El-Salhiya sewage plant. Figure 8 shows the comparison of TSS values between effluent sewage water of El-Salhiya plant and groundwater samples around it. The Figure indicates that infiltrating effluent sewage water, which recharges the groundwater has been filtrated during their passage through the top soil layer. Therefore the TSS are removed by physical mechanism (filtration) at or near the soil surface (in first few meters), where the TSS has been reduced by about 99.1%. These results proof the natural filtration effectiveness, these are in agreement with the previous work carried out at other sites (Idelovitch et al., 2003; Akber et al., 2003).

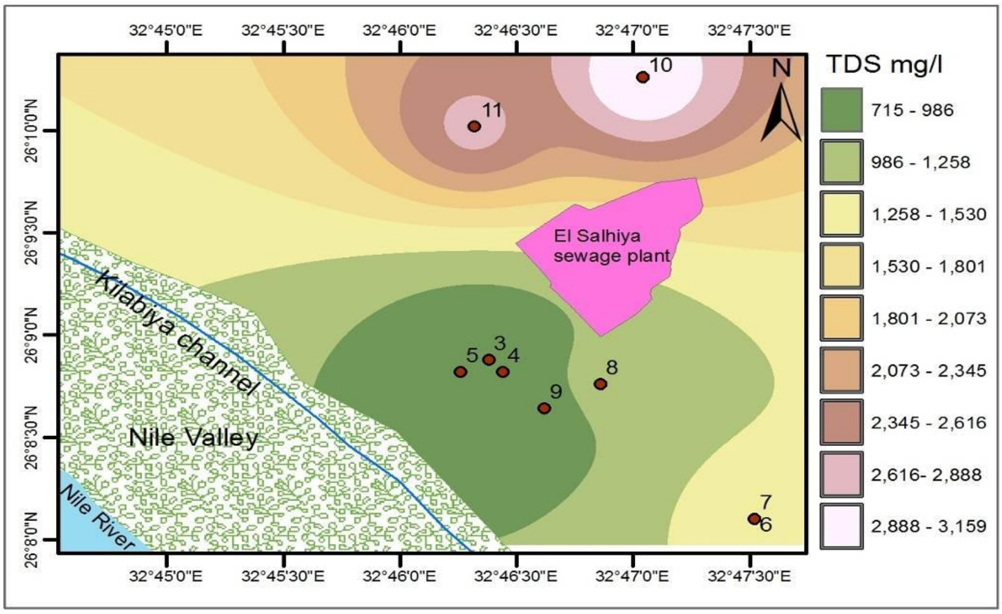

Figure 7: *GIS map shows TDS distributions in groundwater samples around El-Salhiya plant*

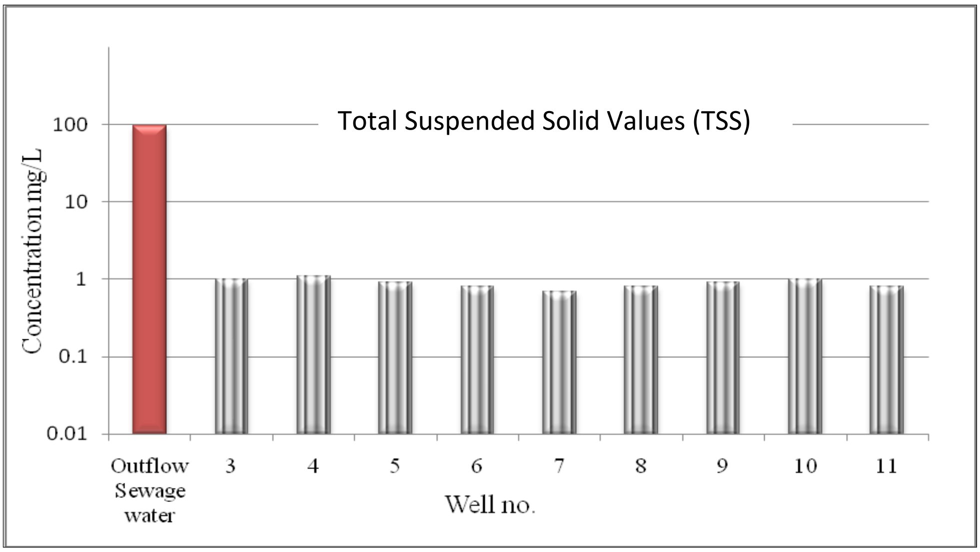

Figure 8: *Comparison of TSS values between outflow sewage water and groundwater around El-Salhiya plant*

Biochemical Oxygen Demand (BOD) The results showed that the BOD values of groundwater samples around El-Salhiya sewage plant are less than the values of outflow water sample in El-Salhiya sewage plant. Figure 9 shows the comparison of BOD values between effluent sewage water samples of El-Salhiya plant and groundwater samples around it. The figure indicates that infiltrating of sewage water effluent into the groundwater, has been naturally treated by soil aquifer. BOD content is removed by two major processes: biodegradation by aerobic and anaerobic bacteria, and adsorption by the soil particles through the vadose (unsaturated) zone. Generally microbial metabolism and degradation processes require electron donators and acceptors, organic matter of unfiltered sewage water and of solid phase working as electron donors (Shamrukh and Abdalla, 2010). BOD has been reduced by about 97.6%, reflecting the major role of natural treatment and its effectiveness, these are in agreement with the previous work carried out at other sites (Idelovitch et al., 2003; Akber et al., 2008).

Chemical Oxygen Demand (COD) Figure 9 shows the comparison of COD values between effluent sewage water samples of El-Salhiya plant and groundwater samples around it. The figure indicates that infiltrating the sewage water into the groundwater reduces the values of COD, this proof that sewage water has been naturally treated by soil aquifer. As in BOD the COD is removed by two major processes: biodegradation by aerobic and anaerobic bacteria, and adsorption by the soil particles through the vadose (unsaturated) zone. COD has been reduced by about 94.7%, reflecting the role of the natural treatment processes. These are in agreement with the previous work carried out at other sites (Sato et al., 2005; Akber et al., 2008).

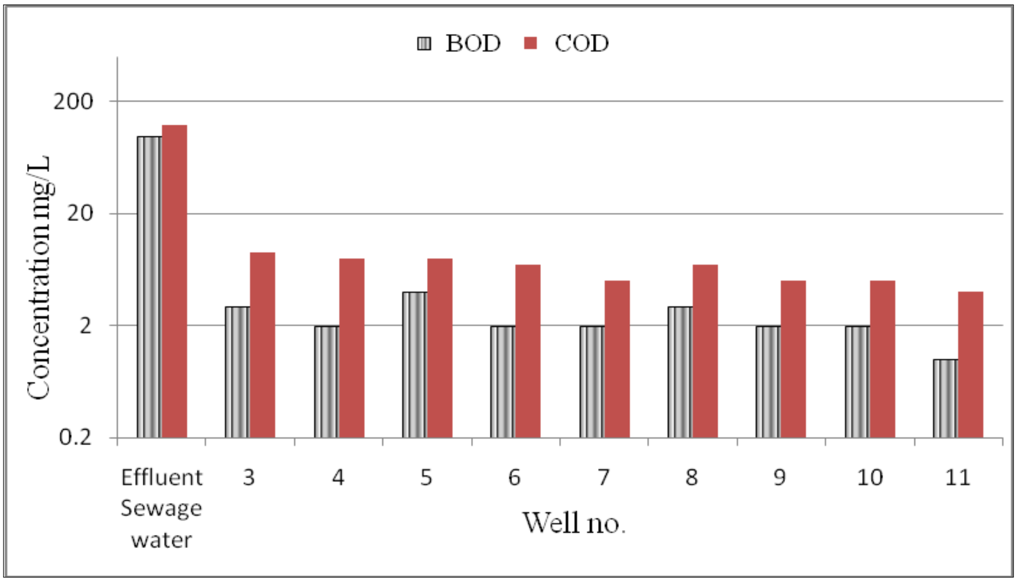

Figure 9: *Comparison of BOD and COD values between effluent sewage water and groundwater around El-Salhiya plant*

Nitrate (NO_3^-) The comparison of nitrate values between effluent sewage water samples of El-Salhiya plant and groundwater samples around it (Figure 10) shows that infiltrating sewage water, which recharges the groundwater, has been naturally treated by soil aquifer. About 44 % of the groundwater samples have lower levels of NO_3 than effluent sewage water due to denitrification process by aerobic and anaerobic bacteria (Idelovitch et al., 2003; Akber et al., 2008). While 56 % of the groundwater samples have NO_3 higher than effluent sewage water due to attributable to nitrification of NH_3, and use of nitrogen fertilizers in new cultivated area around the sewage treatment station (Divya and Belagali, 2012).

Ammonia (NH_3) The results showed that the NH_3 values of groundwater samples around (El-Salhiya) sewage plant decreased more than the values of outflow water sample in El-Salhiya sewage plant. Figure 10 shows the comparison of NH_3 values between effluent sewage water samples of El-Salhiya plant and groundwater samples around it. It indicates that infiltrating sewage water has been naturally treated by soil aquifer. Ammonia is removed with nitrification processes in a soil aquifer system. During infiltration, most of the ammonia is oxidized into nitrate due to aerobic bioprocesses (nitrification) (Foppen, 2002; Yun-zheng and Jian-long, 2006). NH_3 has been reduced by about 98.6%; these results of natural treatment effectiveness are in agreement with the previous work carried out at other sites (Idelovitch et al., 2003; Akber et al., 2008).

Phosphates (PO_4^{3-}) Phosphate not detected in groundwater samples around El-Salhiya sewage water plant. This might be due to the natural treatment effect of the soil aquifer, where phosphate is completely removed (100%) by physical and chemical mechanisms. Chemical precipitation and adsorption on clay and silt lenses are mainly effective on the removal of PO_4^{3-} and the reduction of phosphate could also be a result of bacterial uptake (Reemtsma et al., 2000; Viswanathan et al., 1999). These results of natural treatment effectiveness are in agreement with the previous work carried out at other sites (Cha et al., 2006; Idelovitch et al., 2003; Akber et al., 2003).

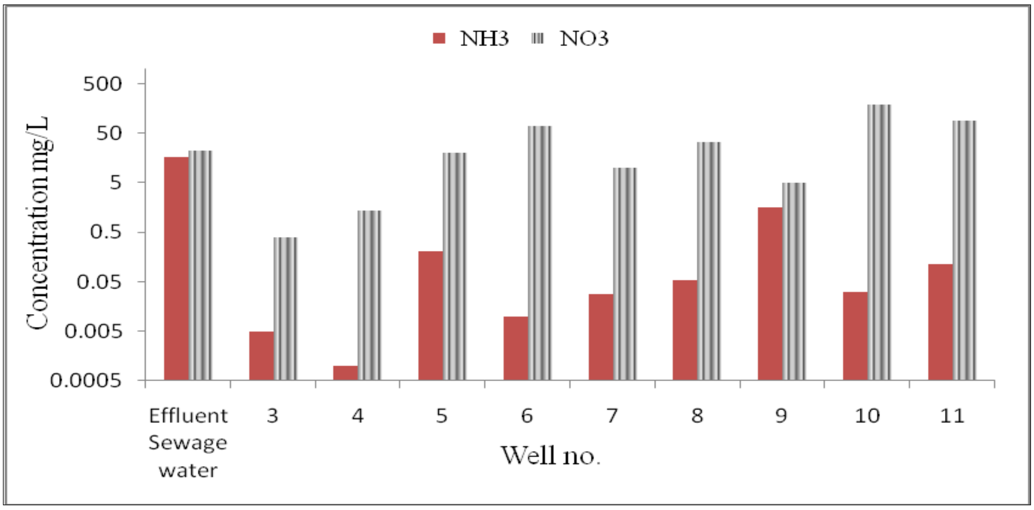

Figure 10: *Comparison of NH_3 and NO_3 concentrations between effluent sewage water and groundwater around El-Salhiya plant*

Total coliform bacteria Total coliform bacteria is not detected in wells (6, 7, 10 and 11) reflecting the removal efficiency of the soil particles (Table 2). Table 2 indicates that infiltered effluent sewage water, which recharges the groundwater, has been naturally treated by soil aquifer, where total coliform bacteria are removed by about 99.9% due to filtration processes and impact of travel time during percolation through soil matrix. This finding is in agreement with other results of Akber et al., (2008); Shamrukh and Abdalla, (2010); Viswanathan et al., (1999).

Fecal coliform bacteria The results of microbiological analysis showed that fecal coliform bacteria in groundwater samples around El-Salhiya sewage water plant was not detected (Table 2). This might indicate that infiltrating effluent sewage water has been naturally treated during wastewater effluent infiltration and percolation through the vadose zone, where fecal coliform bacteria are removed by about 100% may due to filtration processes and impact of travel time during percolation into the aquifer.

Table 2: *Comparison of total and fecal coliform bacteria between influent, effluent sewage water and groundwater around El-Salhiya plant*

Sample NO.	Total coliform (cell/100ml)	Fecal coliform (cell/100ml)
Influent sewage water (1)	>1.810.000	100.000
Effluent sewage water (2)	1.810.000	80.000
Well 3	2	Negative
Well 4	3	Negative
Well 5	2	Negative
Well 6	Negative	Negative
Well 7	Negative	Negative
Well 8	1	Negative
Well 9	1	Negative
Well 10	Negative	Negative
Well 11	Negative	Negative

5. Conclusion

The natural treatment process of sewage wastewater during infiltration and percolation into the soil aquifer through the unsaturated zones improved of sewage water in the study area. The significant observations are as follows:

1) Phosphate removal was generally very high in all groundwater samples in the study area.
2) There was a drop in the bacterial content for the groundwater samples in the study area.
3) TSS is removed by physical mechanism (filtration) at or near the soil surface.
4) Organic substances, BOD and COD were removed by biodegradation and adsorption processes.
5) Leaching from the unsaturated zone tends to increase the TDS of the infiltrated water and the nitrification process increases the nitrate content in the groundwater samples.
6) The low content of clay minerals and organics in the unsaturated zone may prevent the 100% removal of some of the bacteria and other pollutants.

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