DOMESTIC WASTEWATER EFFECT ON THE POLLUTION OF THE GROUNDWATER IN RURAL AREAS IN EGYPT

Alnos Easa [*] and Ashraf Abou-Rayan [*]

Associate Professors, High Institute of Technology, Benha University,
Benha 13512, Egypt
[*] Currently at Northern Border University, Saudi Arabia
E-mails: alyeasa@yahoo.com, aabourayan@yahoo.com

ABSTRACT

One of the results of random system of buildings in the third world is the problem of water pollution. Underground septic tanks are used to collect domestic wastewater. Groundwater pollution is a consequence of wastewater discharging into permeable underground septic tanks. In this study, groundwater (from a well used for irrigation and drinking) samples were taken at the pumping level. A series of chemical analysis was carried out for water samples at different periods of time. Harmful effects of wastewater on the chemical compositions of groundwater were detected. In addition to that, toxicity and chemistry of heavy metals are increased in groundwater.

Keywords: Wastewater, Groundwater, Pollution, Chemical compositions, Heavy metals, Toxicity chemical compositions

1. INTRODUCTION

Throughout history, the quality of drinking and irrigation water has been a factor of determining human welfare. Fecal pollution of drinking water has frequently caused waterborne diseases that have decimated the population of whole cities. Today, there are still occasional epidemics of bacterial and viral diseases caused by infections agents carried in drinking water. Currently, waterborne toxic chemicals pose the greatest thereat to the safety of water supplies. There are many possible sources of chemicals contamination. These include wastes from industrial chemical production, metal plating operations, domestic wastewater and pesticide runoff from agricultural lands [1,2,3,4]. It is clear that water pollution is a public concern. Therefore, an understanding of water pollution and its control depends upon a basic knowledge of aquatic environmental chemistry [3,4,5].

The traditional method of collecting and discharging wastewater using septic tanks lead to wastewater leakage, which severely affect soil and groundwater properties [4,5]. Wastewater-contaminated soil and groundwater is located and noticed in many residential and industrial districts in many countries throughout the third world. It is known that wastewater, depending on its source, contains dissolved salts, organic matter, oil, grease, detergents, many types of metals, toxicity and heavy metals,…etc. [6,7,8].

Many irrigation, agriculture and geotechnical engineers reported the changes of groundwater properties, geotechnical properties of soil and agriculture crops to the worst. They mentioned that, the increase of un-useful plants, ground pollution and geotechnical problems of many underground constructions were mainly associated with wastewater seepage into the subgrade soil [8]. Therefore, the attention was paid to investigate the effect of domestic wastewater seepage on the physical and chemical properties of groundwater and engineering properties of underlying soil [9,10,11,12].

Trace elements such as lead, mercury, cadmium, zinc, cobalt and chromium originating from various sources may finally reach surface soil. These metals are concentrated in the plant tissues and then transferred across the food chains into human beings. It had been discovered that cadmium, found in wastes of zinc melting industry, was thrown into rivers where it transferees into the soil and groundwater then into the agriculture crops. All of these have raised the environmental pollution which had bad impact on the agriculture crops leading to increased rate of infertility among young newly-wed couples [13,14,15,16,17].

In the present study, natural domestic wastewater-contaminated groundwater samples were extracted at the pumping level of groundwater. X-ray and Chemical conventional tests were carried out to measure pollutants concentration of groundwater. Also, infrared spectrophotometer (IR) and atomic absorption spectrophotometer (AAS) equipments were used. These tests were performed at various periods of time.

2. SITE DESCRIPTION

The investigated area contains dwelling buildings of 6 stories, located in the Tahta City, Egypt. These buildings were constructed in 1990 on agricultural land. Figure 1 shows the general layout. According to soil investigation and foundation report [12], it was found that:

a- Soil layers generally consist of clayey silt and silty clay to 7.5m depth from ground surface. These layers are followed by sandy layers, as shown in Figure 2.

b- The sand soil from 7.5m to 11.0m depth was classified as fine to medium sand (sand1) and that from 11.0m to the boring end was classified as medium to coarse sand (sand2). Sieve analysis of sand is indicated in Figure 3 and the properties are tabulated in Table 1.

c- Groundwater level was located at 4.5m deep from ground surface.

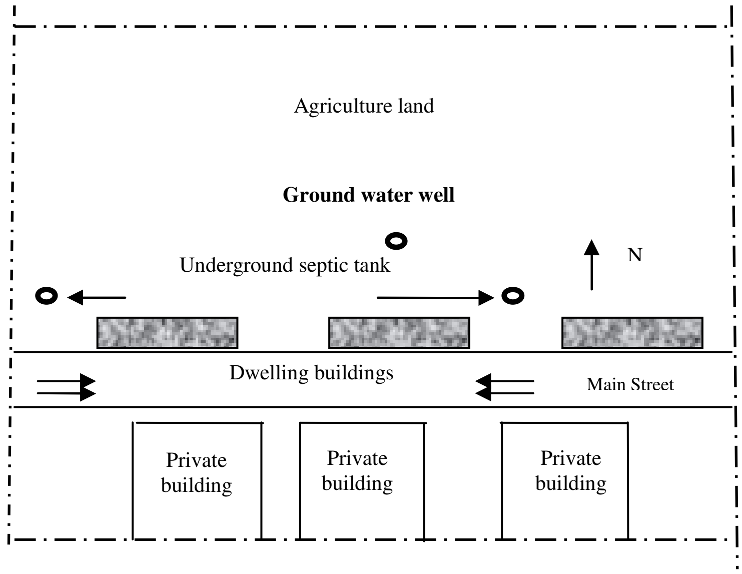

Figure 1 General layout of dwelling buildings and the adopted well point

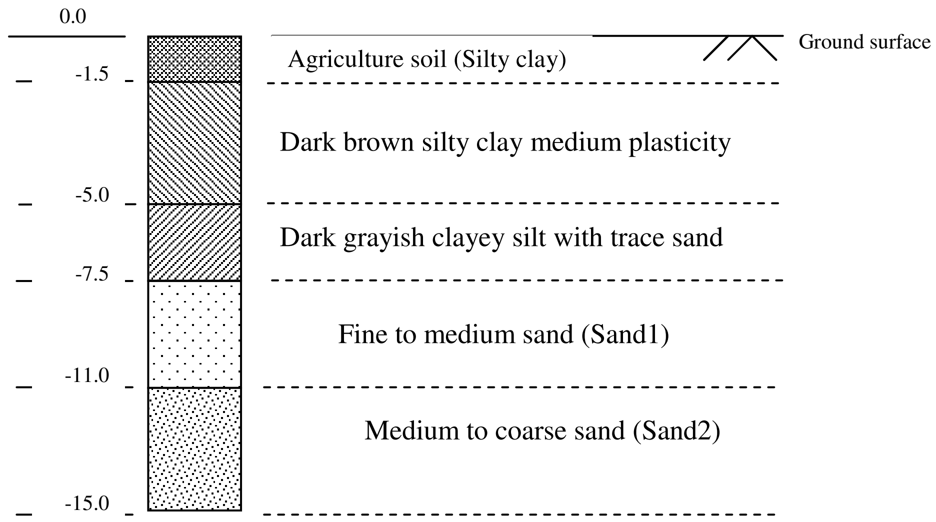

Figure 2 Boring log of building site and agriculture land

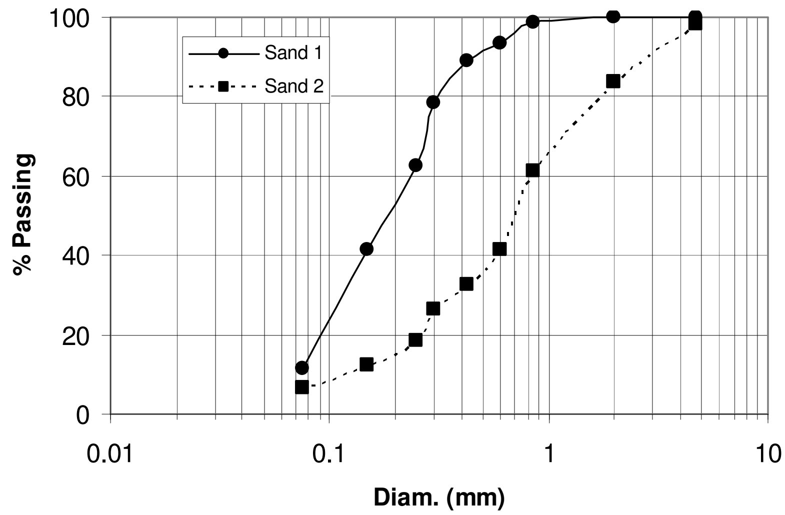

Figure 3 Sieve analysis of sand soil

Table 1 Engineering properties of sand soil

Property	Value	
	Sand1	Sand2
Uniformly coefficient (C_u)	1.9	7.0
Curvature coefficient (C_c)	0.98	1.33
Friction angle (Φ)	34°	38°
Coefficient of permeability (k)	$1.4x10^{-3}$ cm/sec.	$5.2x10^{-2}$ cm/sec.

Circular underground-permeable septic tanks (3m in diameter and 10m in depth) have been used to collect the domestic wastewater, Fig. 4. These tanks were constructed by brick and masonry wall of 25cm (8m away from buildings/ every two buildings, as shown in Figure 1). Thirty samples of wastewater (sample every four months) were taken at 1.0-1.5m deep from wastewater level inside the septic tank. Based on the criteria mentioned in Lykins [6], physical and chemical analyses of wastewater were carried out. Tables 2 and 3 summarize the results of physical properties and chemical constituents of the domestic wastewater, respectively.

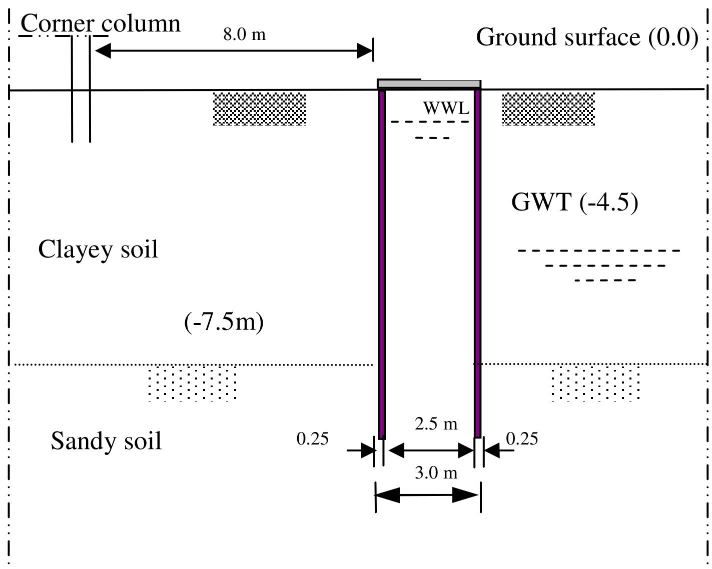

Figure 4 Sectional elevation of permeable septic tank

Table 2: Physical properties of wastewater (1997-2009)

Property	Quantity		
	Maximum	Minimum	Average
Color	Dark–Very dark gray		
Temperature, °C	25	19	22
pH	7.8	5.6	6.7
Total Suspended Solids (TSS), mg/liter	1480	1048	1264
Volatile Suspended Solids (VSS), mg/ liter	1022	946	984
Biological Oxygen Demand (BOD), mg/ liter	469	405	437

Table 3: Chemical constituents of wastewater (1997-2009)

Constituents	Values (mg/L)		
	Maximum	**Minimum**	**Average**
Sulphurous (S)	6.5	2.7	4.6
Chlorides (Cl^-)	362	294	328
Nitrates (NO_3)	210	180	195
Alkaline (ALK)	483	307	395
Copper (Cu^{2+})	0.2	0.16	0.18
Cyanide (CN^-)	0.055	0.035	0.045
Sulfides (SO_4^{2-})	262	232	247
Ammonia (NH_3)	73	69	71
Phosphate (PO_4)	46.7	41.9	44.3
Iron (Fe^{2+})	3.28	3.02	3.15
Zinc (Zn^{2+})	0.13	0.11	0.12
Chromium (Cr^{2+})	0.026	0.022	0.024

As consequences using permeable septic tanks, it was noticed that buildings, plants, agriculture crops, land, and ground irrigation water were facing many problems such as:

a- Flooded wastewater in the surrounding areas of septic tanks, agriculture lands and buildings, is the cause of death for agriculture crops with an increase of un-useful plants (Figure 5).

b- The change of groundwater color and odor to bad conditions.

c- Falling of wall finishing, cracks and wastewater percolation were detected in brick wall and columns especially in ground story**.** Damage of floors of ground levels associated with settlement or swelling of soil under the floor layers.

Figure 5 Flooded wastewater in the surrounding areas of septic tank and agriculture land

These problems were attributed to the discharging of domestic wastewater into groundwater and to seepage into ground soil, [12]. Therefore, it is the extremely important to study the effect of domestic wastewater seepage on the pollution of underground water.

3. INVESTIGATION OF GROUNDWATER POLLUTION

The consensus of most researchers is that the groundwater pollution depends upon the discharging period of wastewater and soil permeability [15,16]. For the purpose of this study, well point was constructed within the agriculture land and was used to obtain groundwater for irrigation with distance 16.0m from the septic tank center, as shown in Figure 1. To study the effect of domestic wastewater discharging on groundwater properties, samples were obtained from 15.0m deep below the ground surface at various periods of time (1997, 2000, 2003, 2006, and 2009).

In-situ and laboratory visual inspection showed that dark color and bad odor of groundwater increase gradually with the increase of wastewater discharging period. Chemical analyses were carried out (at the laboratories of Central Metallurgical Research and Development Institute, CMRDI) to determine the pollutants concentration of groundwater as dissolved solids, heavy metals…etc. Infrared spectrophotometer (IR) and atomic absorption spectrophotometer (AAS) were used identify pollutants concentration and chemical elements of the groundwater samples based on Vogal [18] and Carroll [19] approach.

4. RESULTS

4.1 pH

The pH value of ground water samples were measured using pH-meter. Figure 6 shows the measured pH value of groundwater as a function of investigation year (IY). According to the obtained results, it is evident that:

a- pH value decreases gradually with the increase of wastewater discharging period. The pH value of the groundwater at the investigation year 2009 (IY=2009) decreases by about 15% less than that of IY=1997. This indicates that, the ground water acidity is increased.

b- The decrease of pH values of groundwater associates with the increase of acidic chemical compositions, dissolved components and complex of detergents as mentioned by Lykins [6] and Abdel-Nasser [7].

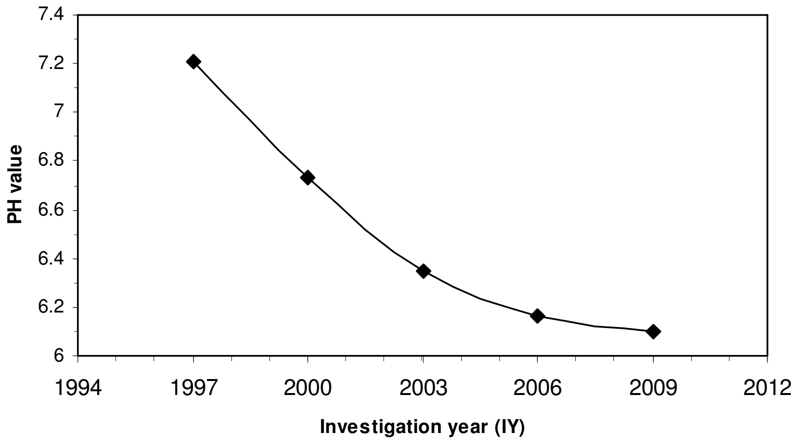

Figure 6 Effect of wastewater discharging on pH of groundwater

4.2 Total Dissolved Solids (TDS)

The concentration of total dissolved solids (TDS) in groundwater at various investigation years is shown in Figure 7. It is clear that:

a- Total dissolved solids (TDS) concentration increase gradually. The increase of TDS is about 100% at IY=2009 for contaminated groundwater more than that for groundwater at IY=1997.

b- The increase of TDS concentration in groundwater is a consequence of the highly concentration of total suspended solids (TSS) and volatile suspended solids (VSS) in domestic wastewater, Table 2. This result agrees with that mentioned by Orr [4].

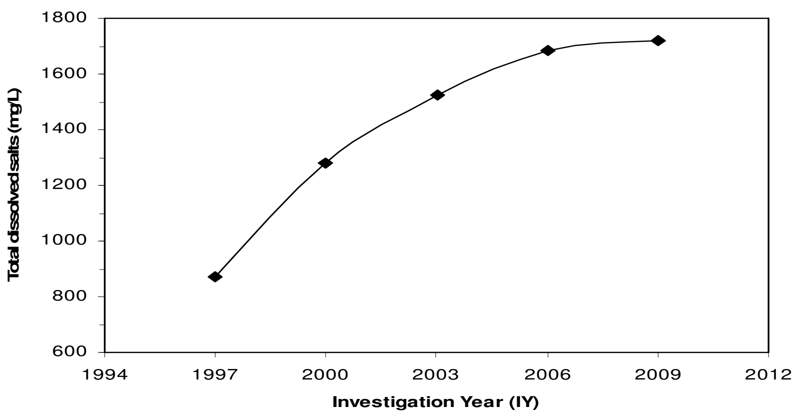

Figure 7 Effect of wastewater discharging on total dissolved solids of groundwater

4.3 Sulphates and Chlorides

Sulphates (SO_4^{2-}) and Chlorides (Cl^-) concentrations of groundwater at various investigation years (IY) are shown in Figure 8. Referring to the concentration values:

a- Sulphates (SO_4^{2-}) and chlorides (Cl^-) concentrations are highly increased**.** The increase of SO_4^{2-} and Cl^- concentrations are about 460% and 560%, respectively, at IY=2009.
b- The increase of Sulphates (SO_4^{2-}) and Chlorides (Cl^-) concentrations in groundwater is getting along with the presence of Sulphates (SO_4^{2-}) and Chlorides (Cl^-) in domestic wastewater, Table 3. This result agrees with those by Orr [4] and the above pH values.

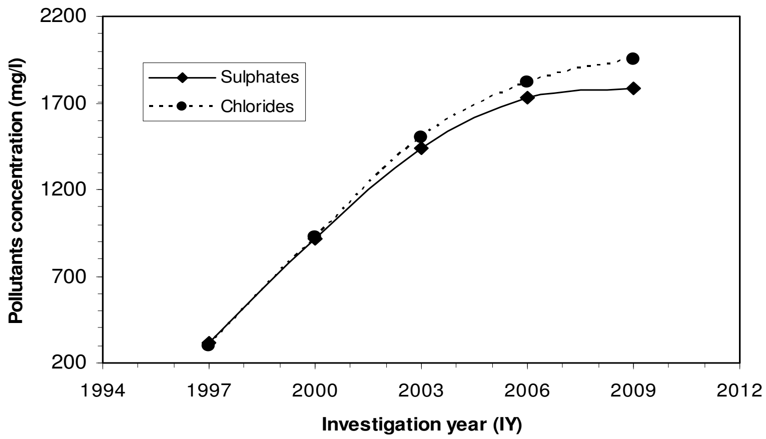

Figure 8 Effect of wastewater discharging on sulphates and chloride of groundwater

4.4 Pollutant Elements

The measured concentration of Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Sodium (Na^+), Iron (Fe^{2+}) Aluminum (Al^{3+}), Fluoride (F^-), Mercury (Hg^{2+}), Cadmium (Cd^{2+}), Lead (Pb^{2+}), Manganese (Mn^{2+}), Chromium (Cr^{3+}), Arsenic (As^{3+}), Cyanide (CN^-), Selenium (Se^{2-}), Copper (Cu^{2+}), Nitrite (NO_2^-), Zinc (Zn^{2+}), Nitrate (NO_3^-), Cobalt (Co^{2+}) and Nickel (Ni^{2+}) of groundwater at various investigation years (IY) are represented in Figures 9-15. The obtained results represent the effect of domestic wastewater discharging into groundwater and soil. As the increase of wastewater discharging period, it is evident that:

a- The concentration values of Magnesium (Mg^{2+}) are highly decreased, while, Calcium (Ca^{2+}) and Sodium (Na^{2+}) concentrations are gradually increased, Figure 9. For instance, at IY=2009, Mg^{2+} concentration decreases by about 80% less than that of IY=1997. While, the concentration of Ca^{2+} and Na^{2+} at IY=2009 increases by about 58% and 120% respectively, more than that of IY=1997.
b- The decrease of magnesium cations (Mg^{2+}) may be attributed to the presence of acids of SO_4^{2-} or Cl^- in wastewater. Where, the chemical process between Mg^{2+} and SO_4^{2-} or Cl^- produce chemical solids as $MgSO_4$ or $Mg(CO_3)$…etc. The solids are sediment and become a part of the soil.

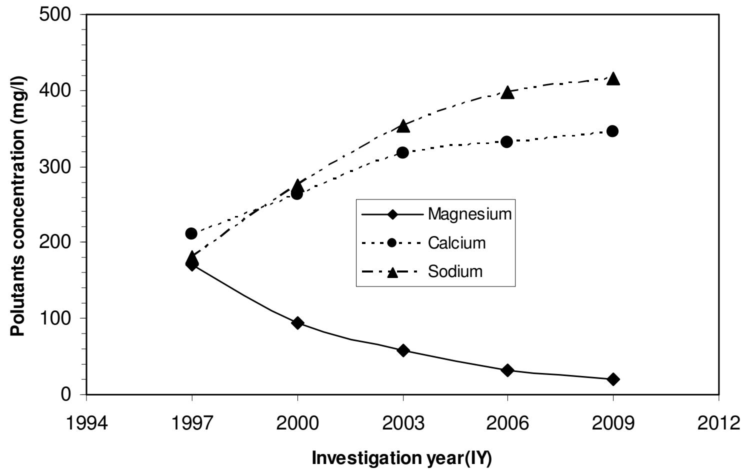

Figure 9 Effect of wastewater discharging on Mg^{2+}, Ca^{2+} and Na^{2+} of groundwater

c- The concentration of Fe^{2+}, Al^{3+} and F^- is highly increased, Figure 10. For example, at IY=2009, the concentration of Fe^{2+}, Al^{3+} and F^- increase by about 150%, 130% and 380%, respectively, more than that of IY=1997.

d- The concentration values of heavy metals Hg^{2+}, Cd^{2+} and Pb^{2+} are highly increased, Figure 11. For instance, at IY=2009, Hg^{2+} and Pb^{2+} concentrations increase by about 470% and 135% respectively, more than that at IY=1997. On the other hand, at IY=2009 the concentration of Cd^{2+} was 0.017 mg/liter compared with zero value at IY=1997.

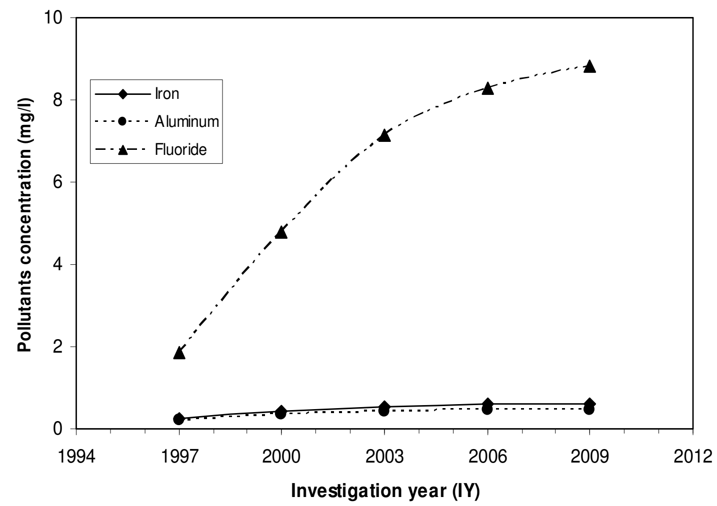

Figure 10 Effect of wastewater discharging on Fe^{2+}, Al^{3+} and F^- of groundwater

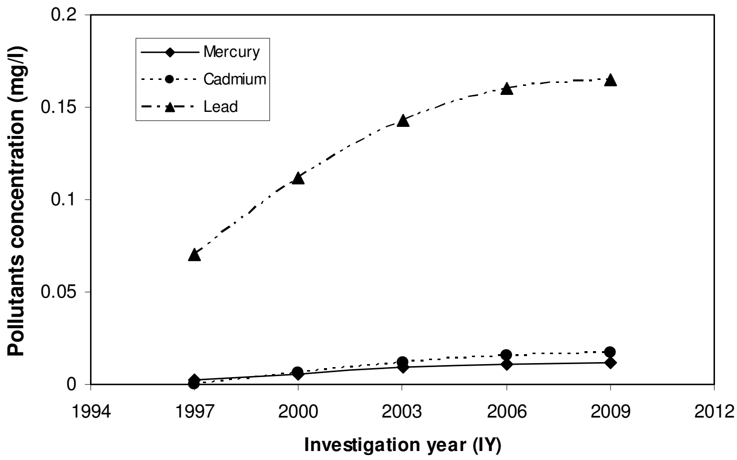

Figure 11 Effect of wastewater discharging on Hg^{2+}, Cd^{2+} and Pb^{2+} of groundwater

e- The concentration values of Mn^{2+}, Cr^{3+}, As^{3+}, CN^{-} and Se^{2-} are highly increased, Figure 12. The increase of Mn^{2+}, As^{3+} and CN^{-} concentrations is about 140%, 300% and 700%, respectively, at IY=2009 for pollutant ground water more than that of IY=1997. The concentration of Cr^{3+} and Se^{2-} was zero at IY=1997, then gradually increases to 0.375 and 0.285 mg/liter, respectively at IY=2009.

f- The concentrations of Cu^{2+}, NO_2^{-}, Zn^{2+}, NO_3^{-}, Co^{2+} and Ni^{2+} are highly increased, Figures 13-15. For instance, at IY=2009, the concentration of Cu^{2+}, NO_2^{-}, Zn^{2+} and NO_3^{-} increase by about 90%, 260%, 150% and 175%, respectively, more than that of IY=1997. On the other side, the concentration of Co^{2+} and Ni^{2+} is zero at IY=1997, then, the concentration increases gradually to 1.8 and 0.12 mg/liter, respectively at IY=2009.

From the aforementioned results, it is wide clear that the increase of heavy metal elements and other elements concentration in groundwater is attributed to: a) the discharging of wastewater into groundwater and soil, b) the presence of many injurious chemical compositions in the wastewater.

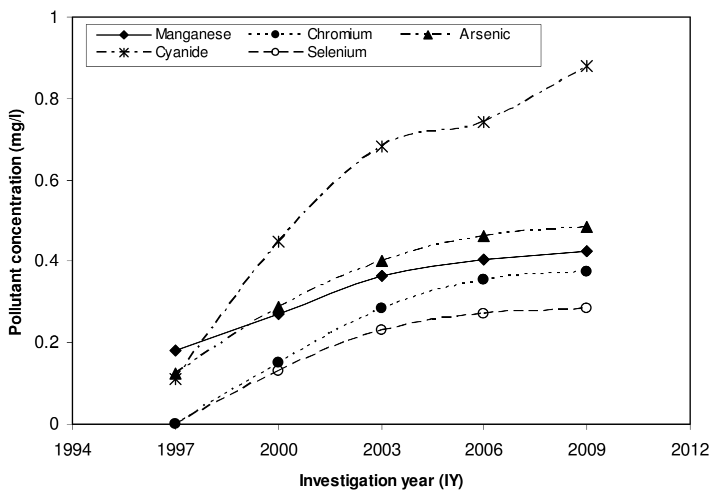

Figure 12 Effect of wastewater discharging on Mn^{2+}, Cr^{3+}, As^{3+}, CN^{-} and Se^{2-} of groundwater

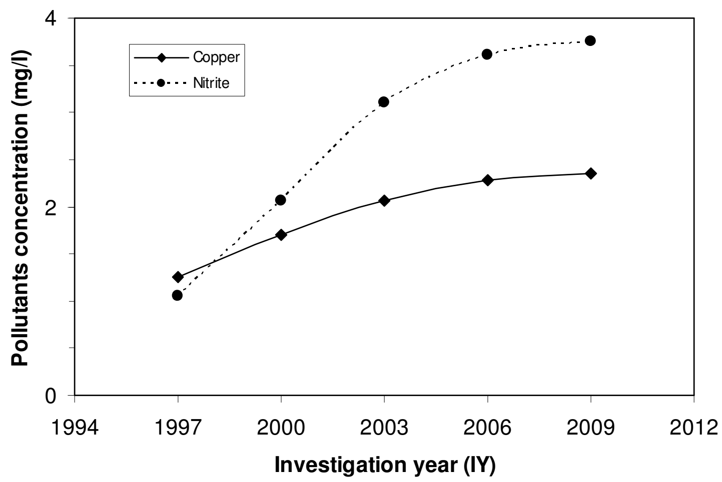

Figure 13 Effect of wastewater discharging on Cu^{2+} and NO_2^- of groundwater

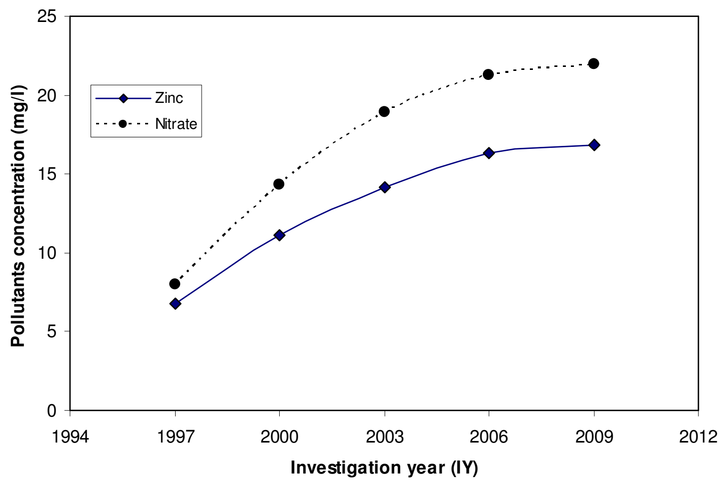

Figure 14 Effect of wastewater discharging on Zn^{2+} and NO_3^- of groundwater

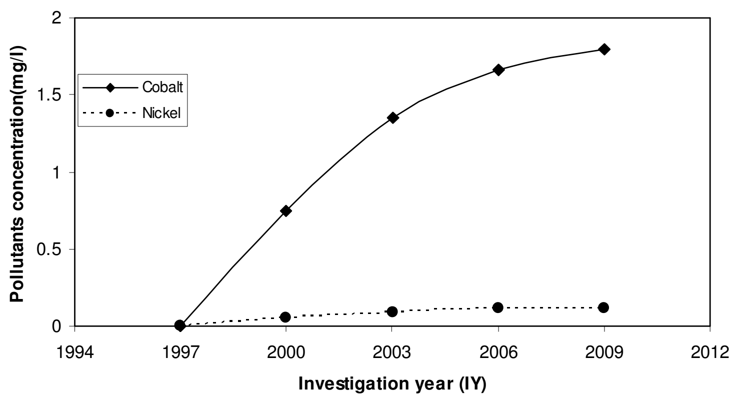

Figure 15 Effect of wastewater discharging on Co^{2+} and Ni^{2+} of groundwater

5. DISCUSSIONS

Referring to the aforementioned results, the discharging of domestic wastewater into the ground has a significant negative effect on: (a) the groundwater which is used for drinking and irrigation in rural areas in Egypt and other countries, (b) agriculture land and crops, and (c) underground construction and soil properties, and (d) the concentration of some inorganic elements as heavy metals is very high. The concentration values of inorganic elements in the studied contaminated groundwater compared with world standard and recommendation are tabulated in Table 4.

Referring to the comparison between drinking water standard and contaminated groundwater analysis, it is evident that:

a- The studied groundwater at the first investigation year (IY=1997) was in acceptable state and most results of inorganic substances were closed to the WHO, U.S., Canadian and European Union standards for drinking water, [20,21,22]. Therefore, at that time groundwater were used safely in drinking and irrigation.

b- With the increase of discharging domestic wastewater into the groundwater and soil, the concentration of inorganic elements is extremely increased. Moreover, the toxicity and heavy metals are highly increased than that recommended and mentioned in the standards. Currently, at IY=2009, the groundwater in this area contains many injurious chemical compositions and became pollutant groundwater.

c- Heavy metals including Cadmium, Lead, Zinc, Cobalt, and Mercury…etc are increased to very dangerous concentrations. For example, heavy metals as Cadmium, Lead, Zinc, Selenium and Mercury are increased by about 240%, 1500%, 240%, 1000% and 1000%, respectively, more than that recommended by the world standards for drinking water. The increase of chlorides and sulfates concentration in groundwater more than that mentioned and recommended in the standards changing the properties of groundwater to the worst.

d- Trace of some heavy metals are relatively toxic to most plants and less to mammals as Nickel (Ni^{2+}) and Copper (Cu^{2+}). Cadmium (Cd^{2+}) and Lead (Pb^{2+}) are toxicity chemical and cause anemia, high blood pressure, kidney diseases and kidney damage, also, destroys testicular tissue to aquatic biota.

6. CONCLUSIONS AND RECOMMENDATIONS

Domestic wastewater discharging into ground water and soil has significant negative impacts on the chemical and physical properties of ground water. These impacts are the increase of the concentration of undesirable chemical elements as toxicity chemicals and heavy metals. The following conclusions with respect to the increase of wastewater discharging time can be derived depending upon the presented results:

1. The domestic wastewater spread into soil and groundwater by discharging and collecting wastewater in permeable septic tanks.

Table 4: Drinking water standard of inorganic substances compared with the obtained results of studied groundwater

Element	Drinking water standard and recommendation (mg/liter)				Groundwater (1997-2009)
	World Health Organization	U.S.	Canada	European Union	
Aluminum (Al^{3+})	0.2	0.2	--	0.2	0.21-0.48
Arsenic (As^{3+})	0.01	0.05	0.025	0.01	0.123-0.485
Cadmium (Cd^{2+})	0.003	0.005	0.005	0.005	0.0-0.017
Chromium (Cr^{3+})	0.05	0.1	0.05	0.05	0.0-0.375
Copper (Cu^{2+})	1.0	1.3	1.0	2.0	1.25-2.35
Iron (Fe^{2+})	0.3	0.3	0.3	0.2	0.25-0.62
Lead (Pb^{2+})	0.01	0.015	0.01	0.01	0.07-0.165
Manganese (Mn^{2+})	0.1	0.05	0.05	0.05	0.18-0.425
Mercury (Hg^{2+})	0.001	0.002	0.001	0.001	0.0021-0.021
Nickel (Ni^{2+})	0.02	--	--	0.02	0.0-0.12
Selenium (Se^{2-})	0.01	0.05	0.01	0.01	0.0-0.285
Cyanide (CN^{-})	0.07	0.2	0.2	0.05	0.11-0.88
Fluoride (F^{-})	1.5	4.0	1.5	1.0	1.85-8.83
Nitrate (NO_3^{-})	50	10	10	50	8-22
Nitrite (NO_2^{-})	3.0	1.0	3.2	0.5	1.05-3.75
Zinc (Zn^{2+})	3.0	5.0	5.0	--	6.75-16.85
Chloride (Cl^{-})	250	250	--	--	295-1948
Sulfate (SO_4^{2-})	250	250	500	250	318-1788

2. The domestic wastewater is considered as the main source of pollution of groundwater. It contains many toxic and injurious chemical constituents. Where it has serious effect on public health problems.
3. Groundwater changes to acidity case as the decrease of pH value; also, sulphates and chlorides concentrations are highly increased. Therefore, total dissolved solids (TDS) concentration is increased as the complex chemical processes have occurred.
4. The contaminated groundwater increases the toxicity chemistry and heavy metals as Cadmium, Chromium, Zinc, Arsenic, Iron, Lead…etc. Therefore, groundwater becomes dangerous for human, animals and plants.
5. The concentration of contaminated chemical elements is extremely higher than that recommended by the WHO. Some of heavy metals concentration increases by about 1000% more than that recommended by WHO and other standard specifications.

This study indicates the seriously dangerous effects of discharging domestic wastewater into soil and aquifers. Therefore, to face the pollution of groundwater and soil and to avoid the effect of wastewater discharging, the following is recommended:

- Prevent the use of permeable septic tanks for collecting domestic and industrial wastewater. While, the closed underground tanks are suitable and can be used.

A Firm legislation must be issued to arrange the suitable ways for collecting and discharging wastewater.

- Standard sewage networks must be constructed to collect the domestic and industrial wastewater. Moreover, the construction and maintenance of sewage networks must be done with high quality of materials and controlling to prevent any leakage of wastewater.
- The public must be informed and educated about the dangerous effect of discharging wastewater into groundwater and soil (National announcements in TV, radio, newspapers and magazines must be used).
- The effect of wastewater seepage into soil, groundwater, and surface water should be addressed on national scale.

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