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HEAVY METALS CONTAMINATION OF SHALLOW GROUND WATER IN DIRECT CONTACT WITH FAILED SEPTIC TANKS

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ABSTRACT

Improper use of septic systems has shown to contribute in ground water contamination by heavy metals, toxic chemicals, and organic chemicals typically found in septic tank cleaning products. Therefore, it suggested evaluating the implication of heavy metals on shallow ground water contamination with direct contact of failed septic tanks. In conducting this research, a laboratory physical vadose model with a vertical flow direction was designed and packed with Silt-Clay soil, which was modified by replacing (20% by weight) of fine sand to satisfy the desired hydraulic conductivity to collect water samples, using a new packing technique other than the ordinary compaction procedure. The model was then fully saturated, well-drained, and run using raw filtered septic water. The model was run for three months and water samples were collected on daily basis at 12.5cms from top of model representing 6.25m underground (model scale was 1:50). Collected samples were analyzed weekly for any pollution occurrence in ground water quality with reference to heavy metals including Fe, Pb, Cu, Cd, Zn, Cr, Al, and Mn. Analytical results used to identify trends of contamination and predict future trends. Results revealed that Fe and Mn were much higher than the permissible limits of world health organization (WHO, 2008) then Al and Cd. Cr fluctuated around the permissible level, Zn precipitated and disappeared within the soil while both of Pb and Cu were safe and at very low level. This study helps the local government in establishing precaution strategies for ground water management to protect public health.

***KEYWORDS**:* Ground Water , Septic Tank, Heavy Metals, Physical Vadose Model (PVM)

1. INTRODUCTION

Ground water was and still an alternative source for people to rely on for their needs, but being the water underground does not mean it is safe, but contrarily, it is vulnerable, like surface water, to human activities and once contaminated; it is costly and difficult to clean (USEPA, 1993). Therefore, efforts have continuously made to ensure its quality specifically when use for drinking purposes. The most serious threat to human health and the environment is the contamination of ground water (Holland, 1992) and the most frequently reported cause of ground water contamination related to water-borne diseases out breaks by bacteria and viruses are the unsewered septic systems (Yates, 1985). Ground water contamination is likely to occur in areas of non-regulated (improperly constructed and poorly maintained) septic tanks and improper waste disposal, which in areas of shallow ground water and high permeable aquifers, lead to a high risk of contamination by heavy metals, toxic and organic chemicals typically found in septic tank cleaning products. Heavy metals in water refers to the heavy, dense (more than 5g/cm^3), metallic elements that occur in trace levels. Many of trace elements such as Pb, Cd, and Hg are very toxic to aquatic life and human health when present in surface and underground water above background concentrations, and they cannot be destroyed or degraded (tend to accumulate) and hence referred to as trace metals (Abdul Jameel et al., 2012). Pure water is rarely to find in nature and normally contains mineral constituents at some amount (Caylak, E. and Tokar, M., 2012), but the presence of some heavy metals like manganese (Mn), aluminum (Al), copper (Cu), iron. (Fe), cadmium (Cd), zinc (Zn), chromium (Cr), lead (Pb) in the water at excessive level of concentration may result in negative public health implications. However, some of them are required micronutrients like copper and selenium and some are essential components of enzymes where they attract substrate molecules and facilitate their conversion to specific end products (Mayake et al., 2004). Therefore this study was conducted to investigate the effect of failed and non-regulated septic tank systems (followed in Duhok city as an area of investigation) on the quality of regional shallow ground water with regard to selected heavy metals. The outcomes of this study would help the local authorities in establishing precaution strategies of managing the ground water and protecting the public health.

2. MATERIALS AND METHODS

2.1 Preliminary Tests

Prior to model design, a good representing soil sample from a four-meter excavated site was collected and necessary preliminary tests have performed to specify soil properties , which play important role in contaminants biodegradation process and their transport through the geological materials to be represented in the designed experimental model. Preliminary tests included in-situ bulk γ_{bulk} and dry γ_{dry} density for undisturbed soil using standard sand-cone replacement method (ASTM D1556), hydrometer analysis by standard test (ASTM D422) method, atterberg limits by (ASTM D4318) method, optimum dry density with optimum water content according to standard proctor compaction method (ASTM D-698), falling-head permeability test (method not standardized), and specific gravity test according to standard test (ASTM D854) method. Preliminary test resulted in 20.14kN/m^3 and17.18kN/m^3 for in-situ soil bulk density and in-situ soil dry density respectively. Soil specimen was classified as Low plasticity silt-Clay soil (CL) according to the Unified Soil Classification System (USCS) for laboratory classification of fine-grained soil. Liquid limit, Plastic limit, Plasticity Index (P.I = L.L – P.L) were 34.5%, 22.3%, and 12.2% respectively. Optimum water content of soil was 18.5% and the corresponding maximum dry density was 1725 kg/m^3. The average permeability coefficient factor (k) of three tested soil was 0.044 x 10^{-5} cm/sec which, was within the permeability range of silt-Clay to clay soil (10^{-8} - 10^{-5} mm/sec), and specific gravity was 2.71 (specific gravity for clay and silt clay ranges from 2.68 to 2.80) (Das, 2013). To conduct this study, it was proposed to design an experimental model to be packed with silt-Clay soil and run with septic water (to represent septic tanks as exclusive source contaminants). As septic water contains suspended materials and dissolved impurities, which may clog the soil pores, and in order to ensure collecting water samples, the hydraulic conductivity of packed material was increased by replacing 20% (by weight) of its weight with fine sand with specific gravity of 2.63 and its particles passes the sieve #30 and remains on the sieve #40. Hence, sand/clay ratio of 20/80 percent (by weight) was adopted. The porosity for silt-Clay soil was 0.354 and for dry sand was 0.346, which both were within the soil property limits (Zhang, 2011). The average actual hydraulic conductivity of packed material after texture modification was k_{act} =1.79 x 10^{-4} cm/sec (Measured through model draining process).

2.2 Design of Physical Model

A large-scaled laboratory physical experimental model was designed and constructed with a frame made of 3-inch steel of equal legs L section and net internal dimensions of 210cm height x 122cm width x 9.7cm depth. The model body was supported with four of (10mm x 180mm) galvanized hex bolts. Model walls were made of 6mm thickness of Perspex Acrylic sheets, which were roughened from inside to minimize the effect of smooth boundaries. The roughened walls were lined to designate packing material volume for desired density satisfaction. Eight sampling ports of 2x2x9.5cms were made out of perforated Acrylic material, dressed by seamless knitted filter, and installed at levels 12.5, 37.5, 62.5, 87.5, 112.5, 137.5, 162.5, and 187.5cms and labeled as Port A, Port B, Port C, Port D, Port E, Port F, Port G and Port H respectively. The interested port for this study was the port A located at 12.5cms from top of the model, which represented ground water level at 6.25m. Piezometers were installed at sampling port levels to monitor model internal pressure and hydraulic gradient. A tank of 122cm length x 6cm thick x 6cm depth with five openings of 4x6cm for width and length has designed and fabricated as a storage chamber of septic tanks on top of the model. Filling the storage chamber with septic water guaranteed the hydraulic contact with the model soil through the five openings. **Figure (1)** represents a sketch of non-scaled experimental model and **Figure (2)** represents a 1:50 scaled physical experimental model.

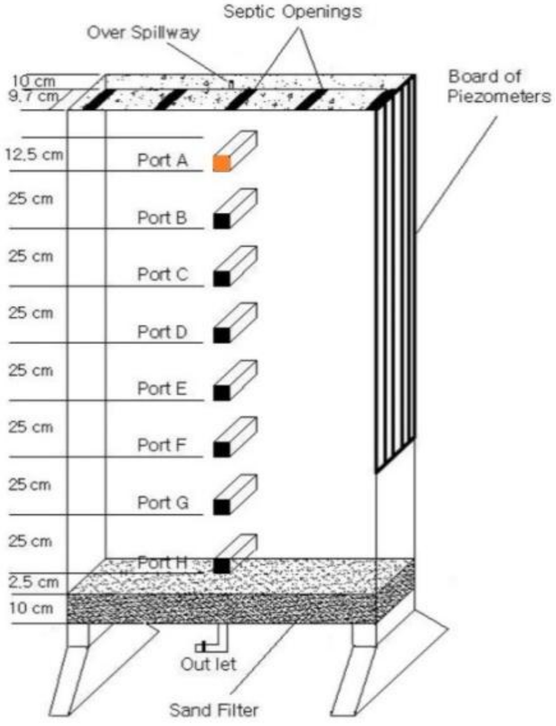

Fig.(1):- Sketch of Experimental Model

Fig. (2):- Physical Experimental Model

2.3 Design of Drain Filter

To improve flow conditions and prevent fine graded materials from permeation out of the model, a drain filter was designed. In designing drain filters and envelopes, (Bertram, 1940) and (BC Ministry of Agriculture, 2000) have established the validity of two criteria.

1. $\frac{\text{D15 (filter)}}{\text{D15 (base)}} \geq 4 \text{ to } 5$ ……………. Eq. (1)

2. $\frac{\text{D15 (filter)}}{\text{D85 (base)}} < 4 \text{ to } 5$ ……………. Eq. (2)

D_{15} is grain size for which 15 percent of the material, by weight, is finer, and D_{85} is grain size for which 85 percent of material (by weight), is finer. After satisfaction of all conditions and criteria, a drain filter was designed and provided as a layer of 100 millimeter to the bottom of model. For more details on deigning the drain filter, refer to (Kochary, S., 2017).

2.4 Model Packing Process

The designed model was packed with 377.5kgs of sand/clay mixture of 20/80 percent ratio (by weight) and average dry density of 17.12kN/m^3. In packing the model, a new approach was adopted other than the ordinary (standard, modified, and static) compaction methods. The new packing procedure may be summarized in filling the model with tap water to 20-30cms depth (25cms is preferred), spread a known amount of packing material into the water uniformly over all model cross section and push down very gently until it reaches the designated line (i.e. achieve desired volume which satisfies the desired soil density). The process is to repeat until packing process complete. For more details, refer to (Kochary, S., 2017).

2.5 Model Draining Process

The packed model was drained (washed) from dissolved material contents using lab-stored tap water at steady state flow condition manner (flow in = flow out). Through draining process, the electrical conductivity (EC) of inlet and outlet water was taken daily until reached a negligible level of difference (EC in ≈ EC out). After four weeks of draining the model, EC in and EC out were 0.53 and 0.62ms/cm respectively and the resulted difference was considered negligible and hence draining process was stopped.

2.6 Model Running Process

Very recent septic water of a septic tank was collected, filtered, packed in 1.5-liter plastic bottles. Bottles were stored at 4 °c in the dark. To satisfy and maintain the steady-state flow condition for the model, a bottle of septic water was added to the model daily, and within four hours, a set of 8x180 ml samples from eight sampling ports were collected and refrigerated at 4°c without adding any preservatives for later analysis.

2.7 Methods of Analysis and Instruments Used:

On weekly basis, the collected water samples were analyzed for heavy metals including: Iron (Fe), Manganese (Mn), Zinc (Zn), Cadmium (Cd), Copper (Cu), Chromium (Cr) using flame atomic absorption spectrophotometer FAAS, and Aluminum (Al) with Lead (Pb) using flame furnace atomic absorption spectrometry FF-AAS according to standard methods procedures (APHA, 1996).

3. RESULTS AND DUSCUSSION

All heavy metals analytical results for **Port A** in the PVM model (that represents ground water level in the actual vadose zone of 6.25 meters below the surface) overall model running processes are listed in **Table 1**. Results are in mg/l (ppm) and µg/l (ppb) concentration.

Table (1): -Collective of heavy metals data overall model running process

Time (days)	Iron (ppm)	Lead (ppb)	Copper (ppm)	Cadmium (ppb)	Zinc (ppm)	Chromium (ppb)	Aluminum (ppm)	Manganese (ppm)
0	0.05	3.60	0.01	0.00	0.57	0.00	0.06	0.04
7	2.45	4.01	0.05	4.30	23.89	0.00	0.16	3.61
14	1.66	3.75	0.02	4.30	8.37	13.40	0.31	2.38
21	4.27	3.99	0.03	9.10	7.87	56.60	0.17	0.92
28	5.49	3.96	0.04	3.40	11.01	71.00	0.16	1.56
35	4.58	3.41	0.03	0.00	4.08	88.20	0.16	0.87
42	4.77	3.24	0.03	1.80	2.72	4.00	0.14	0.67
49	8.73	3.75	0.03	5.10	2.78	29.80	0.09	0.60
56	5.51	3.60	0.04	7.50	6.07	63.90	0.26	0.71
63	4.42	4.99	0.33	7.30	0.71	48.70	0.22	0.84
70	2.78	3.87	0.51	35.60	0.59	14.10	0.34	0.57
77	2.07	3.60	0.33	9.40	0.48	51.40	0.44	0.69
84	3.54	3.55	0.53	9.40	0.68	17.10	1.36	1.02
91	6.25	3.38	0.32	13.50	0.64	43.00	2.07	0.89

Table (2) :-Iraqi National Drinking Water Standards and WHO guidelines

No	Parameter	Unit	Iraqi Standards	WHO Standards
1	Manganese (Mn)	mg/L	0.1 [1]	0.05 [5, 6]
2	Aluminum (Al)	mg/L	0. 2 [1]	0.1 [5, 6]
3	Cadmium (Cd)	mg/L	0.003 [2]	0.003 [5, 6]
4	Chromium (Cr)	mg/L	0.05 [1]	0.05 [4]
5	Lead (Pb)	mg/L	0.01 [1, 2]	0.01 [5, 6]
6	Iron (Fe)	mg/L	0.3 [1, 2]	0.100 [5, 6]
7	Zinc (Zn)	mg/L	3 [1, 2]	3 [3]
8	Copper (Cu)	mg/L	1 [1, 2]	2 [5, 6]

Iraqi Standards for (2001) [1], Iraqi Quality Standards (2009) [2], WHO drinking standards (1993)[3], WHO drinking
standards (1995)[4], WHO drinking water standards, 3rd edition (2008)[5], WHO drinking water standards, 4th edition (2011)[6].

Iron is essential element in human nutrition with minimum daily requirement of 10 to 50 mg/day (FAO/WHO1988). It present at significant amounts in soils and rocks at insoluble forms. However, naturally occurring reactions in ground formations can raise more soluble forms of iron in water passing through such formations resulting in appreciable amounts of iron in ground waters. Micro biodegradation of organic matters added by septic effluent can change the chemistry of the aquifer, and cause increased amounts of manganese and iron to dissolve into the ground water from soil and rocks. There is no harmful effect of consuming waters with significant amounts of iron as, in nature, its degree of toxicity may be lessened by its interaction with other constituents of water. In this study, results revealed that iron concentration was much higher than 100 ppb (0.1 ppm), the maximum permissible limit of world health organization (WHO, 2008). When considering the outliers, the maximum level of 5.51 ppm for iron was detected after 28 days of model runing. However, this concentration started declines (precipitate within the soil) and reaches the maximum permissible level in 95 days according to the poly2 relation in **Figure 3.**

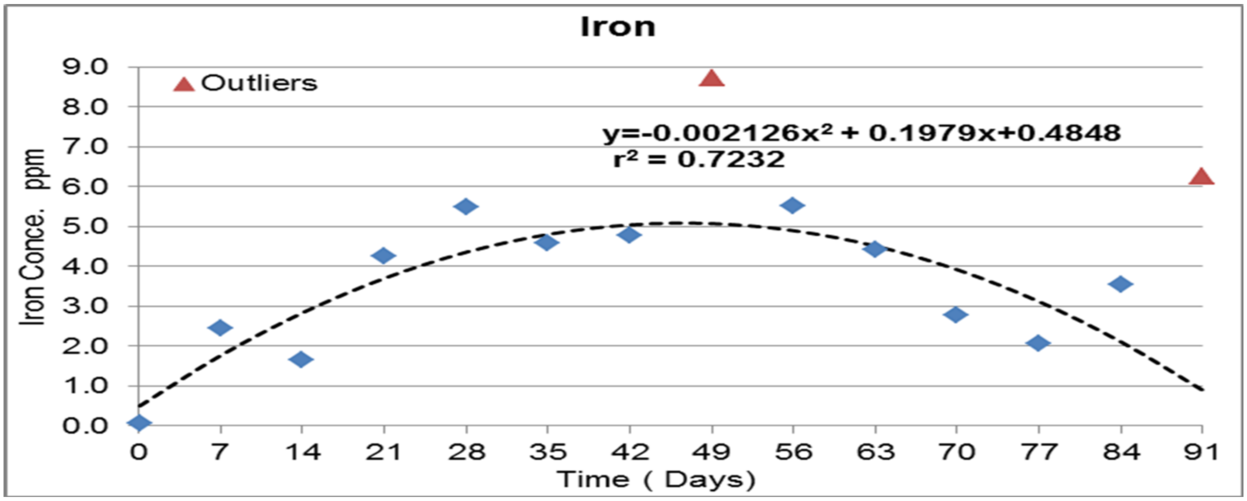

Fig. (3):- Iron Concentration over all running process in ppm.

Lead is one of the most commonly determined heavy metals. It is a cumulative general metabolic poison (Adepoju-Bello and Alabi, 2005), and associated with several health hazards like anemia (Moore,1998) and reproductive effects (Kumar and Puri, 2012). In addition, Lead and Mercury may cause autoimmunity (when immune system of a body attacks its own cells). At higher concentrations, Lead and Mercury can cause irriversable brain damage (Momodu and Anyakora, 2010). Results of this study revealed that Lead is accumalating within the soil and the maximum concentration of 3.99 ppb was detected three weeks after running the model, which was much lower than the maximum permissible level of 10 ppb (0.01 ppm) of (WHO,2008). This indicates that Lead releases from septic water (or septic tanks) does not affect the quality of ground water as it accumalates in the soil. **Figure 4**.

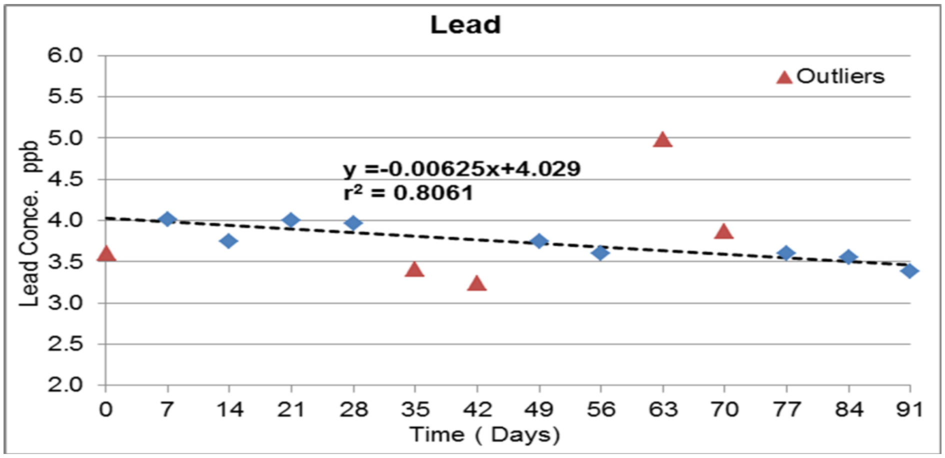

Fig. (4):- Lead Concentration over all running process in ppb.

Copper is essential substance to human life, but chronic exposure to contaminant drinking water with copper can result in the development of anemia, liver and kidney damage (Madsen, et al., 1990; Bent and Bohm, 1995). In addition; too much copper in drinking water may cause vomiting, diarrhea, and nausea while lack of copper intake causes anemia, growth inhibition, and blood circulation problems (Jennings et al., 1996). Results for this study revealed that septic water does not effect the quality of ground water as its maximum concentration was 0.33 ppm which, was much lower than the maximum permissible level of 2000 ppb (2ppm) for (WHO, 2008). For long time period, the maximum permisible level of Copper would be reached in about 906 days (2.5 years) according to the relation in **Figure 5**.

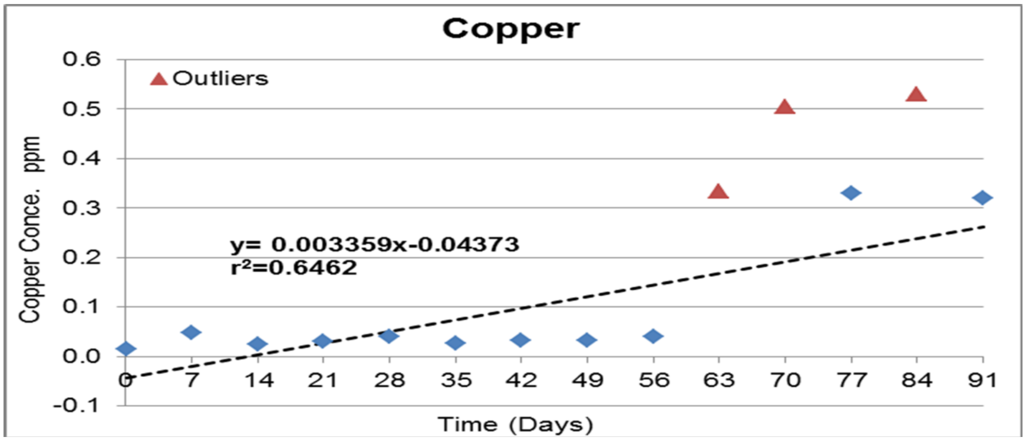

Fig. (5):- Copper Concentration over all running process in ppm.

Cadmium poisoning has been associated with kidney's diseases (renal failure) while chronic exposure to contaminant drinking water with cadmium can result in the development of chronic anemia (Jennings et al. 1996; Stowe et al. 1972; Sakata et al. 1988). United States Environmental Protection Agency (USEPA) has classifeied cadmium as a possible human carcinogen by inhalation. The concentration of cadmium in natural surface water and ground water is usually less than one microgram per liter while in drinking water, it should not exceed three microgram per liter (WHO, 2008). Cadmium analytical results for this study revealed that septic water has an instant effect on the quality of ground water as its concentration at starting time of model running was 4.3 ppb and it reached 13.5 ppb after 91 days of model running, and its accumalation rate follows the relation in **Figure 6**.

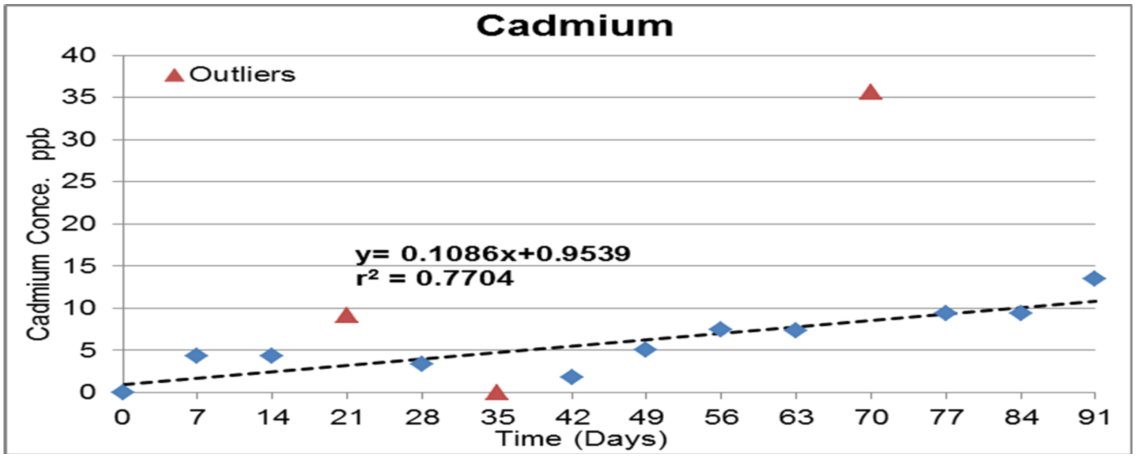

Fig. (6):- Cadmium Concentration over all running process in ppb.

Zinc element presents in most rocks, certain minerals, and some carbonate sediments. It releases to the environment naturally, but its anthropogenic discharge (primarily from mining, metallurgic operations, and waste disposal) is much greater than its natural sources. Zinc ion is one of the most mobile heavy metals ions since it present as soluble compounds at neutral and acidic pH (pH ≤ 7) (Simeonov and Sargsyan, 2008), and at higher pH values, zinc is capable of forming carbonate and hydroxide complexes with variety of organic and inorganic groups such as anions, amino acids, and organic acids, which controls the solubility of zinc (Budavari et al.,1989). Zinc leaches from distribution pipes and household plumbing resulting in high concentration in drinking water with compare to raw water. Maximum permissible level of zinc ion Zn^{+2} is 10µg/l in surface water and 50µg/l in ground water. Concentration of Zinc in drinking water should not exceed 5mg/l (WHO, 2008) . Results for this study revealed that zinc concentration was 8.37 mg/l for week 2 of model running (which was above the permissible level) and started declining following the poly2 relation of **Figure 7** until it reaches 0.64 mg/l at week 13 which is much lower than permissible level.

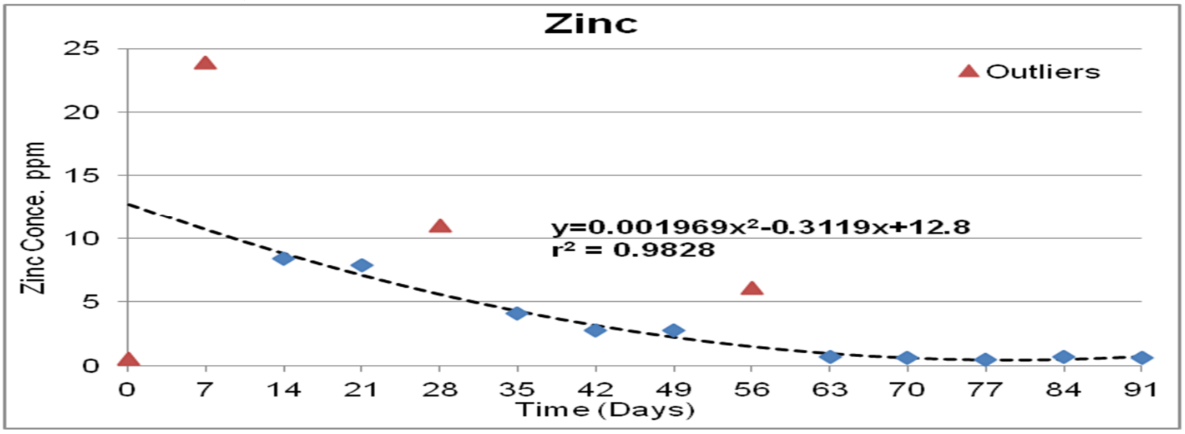

Fig.(7):- Zinc Concentration over all running process in ppm.

Chromium is a naturally occurring heavy metal found in three common stable valence states: Cr (0) element metal, Cr (III) trivalent, and Cr (VI) hexavalent. Cr (III) is an essential dietary micronutrient in low doses while Cr (VI) is carcinogenic. Cr (VI) considers 1,000 times more toxic than Cr (III) (USEPA, 1998). Long-term inhalation of Cr (VI) compounds induces DNA damage and gene mutation and increases the risk of lung cancer. WHO guideline is 50 microgram per liter (50 ppb) (AWWA, 2013) while USEPA has set 100 microgram per liter (100 ppb) as a maximum concentration level (MCL) for total chromium in drinking water including Cr (VI) and Cr (III) as both forms convert to each other in human body and in water depending on environmental conditions. Results for this study revealed that chromium concentration was 13.4 ppb for week 2 of model running (lower than the permissible level of WHO guideline) and started accumulating until it reached 88.2 ppb at week 5 (which still was within the maximum concentration level of USEPA) and then started declining following the poly2 relation of **Figure 8** until it reaches 20.32 ppb at week 13, which is much lower than permissible level. This suggests that septic water does not affect the quality of ground water with respect to chromium.

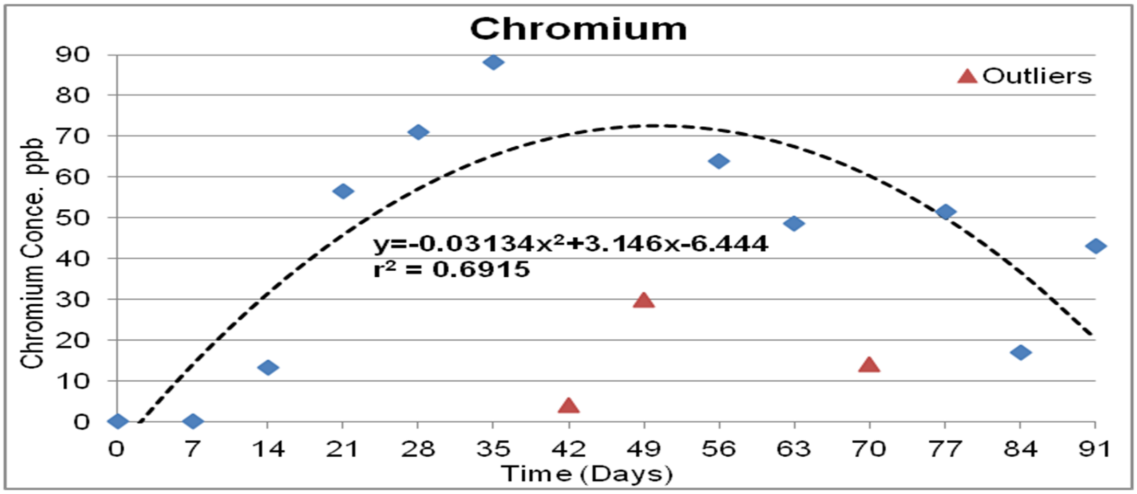

Fig. (8):- Chromium Concentration over all running process in ppb.

Aluminum is a reactive metal and rarely available at its free form. It oxidizes very rapidly to Al_2O_3, which is an extremely stable compound (WHO, 2003). The solubility of Aluminum in pure water is at minimal level when pH ranges from 5.5 to 6.0. However, the concentration of total dissolved aluminum increases at higher and lower pH values (WHO, 2003). In drinking water treatment process, Aluminum salts (alum or aluminum sulfate, and poly-aluminum chloride) are widely used as effective coagulants to remove the harmful waterborne microorganisms. Aluminum at high concentrations is a toxic agent to aquatic organisms as its ions react with phosphates, which is essential to water organisms. USEPA recommends secondary drinking water standards of 0.05 to 0.2 mg/l for aluminum however WHO has regulated guideline not to accede 0.2 mg/l. Results for this study revealed that Aluminum concentration was 0.16 mg/l at first week of model running, which was within the standards recommended by USEPA. However, its concentration started to increase until it exceeded the maximum level regulated by (WHO) in week 8 of model running. While model was running, Aluminum continued accumulating within the soil following the poly2 relation of **Figure 9** until it reaches 0.54 mg/l in week 13, which was much higher than the permissible level. This suggests that septic water has a negative effect on the quality of ground water (with respect to Aluminum) if used for drinking purposes.

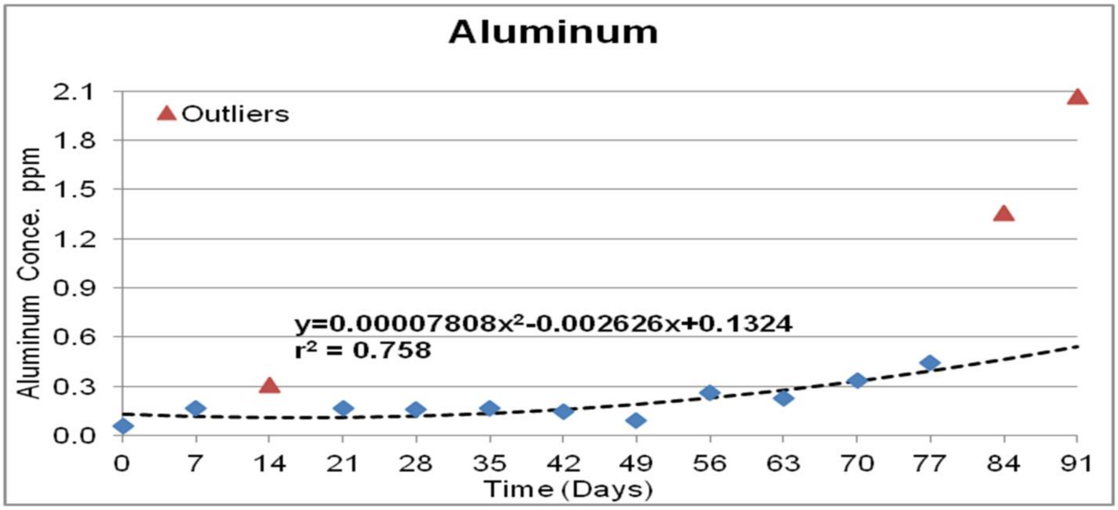

Fig. (9):- Aluminum Concentration over all running process in ppm.

Regarding the Manganese, anaerobic ground water contains elevated level of dissolved divalent form of Manganese Mn^{+2}, which predominate in most water at pH between 4 and 7 while at higher pH values, highly oxidized forms of manganese may occur (WHO, 2004). The level of manganese that leaches naturally into ground water depends on types of minerals and rocks at water table while elevated level of manganese in the water by human activities may be attributed to the leaches from landfills, agricultural chemicals, and industrial effluents. European Standards have reduced drinking water guideline for Manganese from 0.5 to 0.05 mg/l (Directive, 1998) and USEPA has set a secondary standard of 0.05 mg/l for manganese at which it affects the water quality. According to poly2 relation in **Figure 10**, Manganese concentration was 0.24 mg/l for first week of model running, which was much higher than the permissible level of both European Standards and USEPA suggesting that septic water has an immediate effect on the ground water quality. However, Manganese started accumulating within the soil over all model running process until its concentration has reached 2.5 mg/l in week # 13.

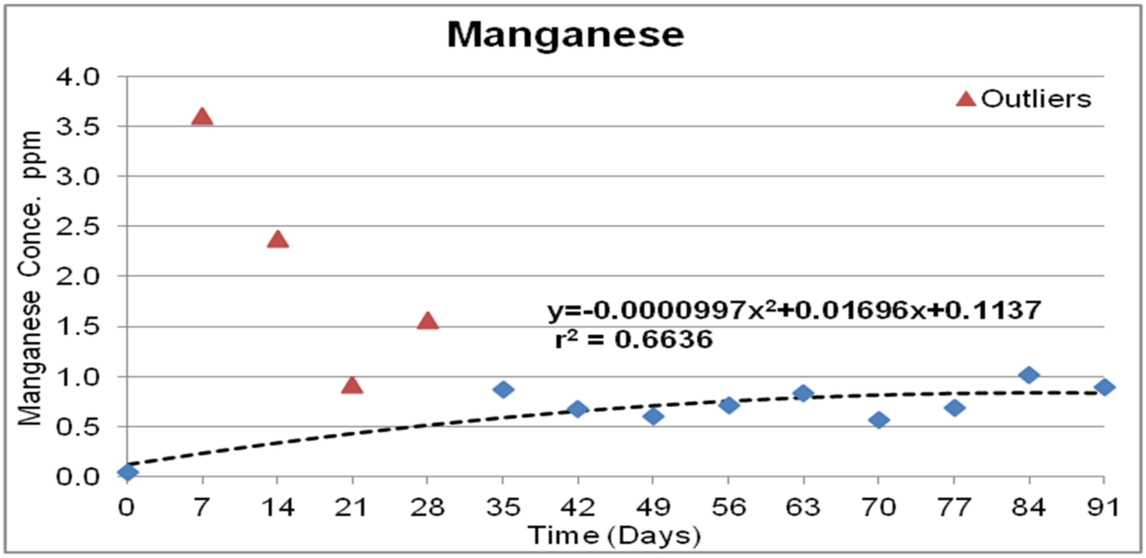

Fig. (10): -Manganese Concentration over all running process in ppm.

4. CONCLUSION

Shallow ground waters are at high risk of heavy metals discharges from black water (of septic tanks) specifically with Cadmium, Aluminum, and Manganese as they are toxic metals and have negative implications on human health. Deeper ground water (of higher distance from septic tanks) are relatively safer and more suitable for drinking purposes, with regard to heavy metals, as their concentration may be eliminated (absorbed or precipitated within the soil) before it reaches the ground water. In such a situation as of area of investigation, ground water management strategies are due which, should include the improvement of existed septic systems in order to minimize the seepage percolation and to provide enough time for the soil to reduce the hazard poses to the ground water by septic tanks. Furthermore, regulations are to be established regarding the construction, citing, density, and maintenance of septic systems to protect the public health.

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