Evaluation of Water Quality Pollution Indices for Groundwater Resources of New Damietta, Egypt

Abstract

Ground water is the most important source of domestic and irrigation purpose in both rural and urban regions. The present study is carried out to find the ground water quality by heavy metal concentration from three sites. Nine heavy metals were selected (Cd, Pb, Cr, As, Cu, Hg, Se, Zn and Ni). It was showed that concentration values were 0.0016-0.0016, 0.003-0.00, 0.006-0.00, 0.00-0.004 and 0.002 mg/L, respectively. To assess ground water quality which contaminated by heavy metals, four indices were selected as follow: heavy metal pollution index (HPI), contamination index (Cd), metal enrichment index (MEI) and metal evaluation index (HEI). Results showed that the concentrations of heavy metals in water samples are within the permissible WHO limits in drinking water. Three metals of them (As, Hg and Se) were not detected in all sampling stations. MEI in the ground water samples show that N is the highest metal enrichment value of -0.6. HPI of water samples in three sites were 20.57 which was lower than 100 the critical value for drinking water. C shows that the values vary between -5.1 to -0.3 which indicate low contamination. HEI shows that the values in spring season vary from 0.001 to 0.66 and indicate low heavy metal pollution. Results show that ground water of the present study is acceptable for drinking.

Keywords: Ground water; Water quality; Pollution indices

Introduction

Today heavy metals contamination of the groundwater is one of the serious environmental problems. Some of the heavy metals considered as micronutrients can cause adverse effects to human health when their contents exceed the permissible limit in drinking water [1]. Thus, heavy metals assessment in groundwater used for drinking purpose is very significance from the human health viewpoint. Heavy metals are usually present in trace amounts in natural water but many of them are toxic even at very low concentration though many of the metals are essential components of the biological system. Metals such as As, Pb, Cd, Ni, Hg, Cr, Co, Zn and Se are highly toxic even in minor quantity. Increasing amount of heavy metals in aquatic resources is currently an area of greater concern especially since a large number of industries discharge their metal containing wastes into fresh water without any acceptable treatment [2]. The waste water without any treatment may cause adverse effect on the health of human, domestic animals, wildlife and environment. Contaminated ground water has deteriorated the drinking water and impacts on soil systems and crop productivity. Contaminated water when used for irrigation purpose affects soil quality and crop health of the agricultural system. The textile effluent had consisting high concentration of trace heavy metals and through its accumulation in different trophic levels of ecosystem ultimately cause the health hazards among livestock and human beings [3]. So, it is very much essential to assess the quality of wastewater before discharging it and to develop an economical method for the prevention and control of ground water pollution. Ground water contaminated by textile eﬄuents, has impact on agriculture irrigation, drinking utilities, soil and agricultural systems [4]. For evaluation of water quality contamination, several methods such as the contamination index (Cd), metal enrichment index (MEI), the heavy metal pollution index (HPI) and the heavy metal evaluation index (HEI) were developed. These indices help assessing the present level of pollution in water resources and combine all the water pollution parameters into some easy approach [5]. The main objective of the study is to examine heavy metal concentration in groundwater of New Damietta and to suggest the suitable indices to evaluate groundwater quality.

Materials and Methods

Study area

DNM Textile Company was incorporated in 2011 in city of Damietta, Egypt with 100% Turkish capital. DNM is a vertically integrated denim fabric production plant constructed at the Public Free Zone on an outdoor area of 150.000 square meters with an indoor area of 130.000 square meters fitted with the state-of-the-art technological machinery. DNM produces 50 tons of yarn on daily basis. With the total annual production capacity of 25 million meters, the annual production capacity of the plant aimed after completion of the 2nd phase in the forthcoming term shall be 50 million meters (Figure 1).

Sample analysis

Ground water and soil samples were collected from three locations at DNM textile company (Damietta). Sampling locations (Spinning, Weaving and Dyeing) were selected as an indicator of textile industry.
Digestion and analysis

Water samples were acidified in the field with concentrated 
HNO₃ (5 ml/l of water sample to reduce the pH of the sample, pH > 
2.0) for the total metal estimation. Total metal content in soil 
was determined by digesting 0.5 g of soil/sediment sample from each 
site with a mixture of Conc HNO₃ and HClO₄ (10 ml + 2 ml). The 
digested samples were filtered through Whatman filter No. 42 and 
finally volumes were made 10 ml with 0.1 N HNO₃ and analyzed 
for heavy metals using Atomic Absorption Spectrophotometer 
(Model ECIL-4129).

Heavy Metals Assessment in Water

Metal pollution index (MI): This index indicates the total quality 
of water with respect to heavy metals and based on weighted 
arithmetic quality mean method and developed in two steps. First 
by establishing a rating scale for each selected parameter-giving 
weightage and second by selecting the pollution parameter on 
which the index is to be based. The rating system is an arbitrarily 
value between zero to one and its selection depends upon the 
importance of individual quality considerations in a comparative 
way or it can be assessed by making values inversely proportional 
to the recommended standard (Si) for the corresponding 
parameter as proposed earlier Prasad and Bose [6]. HPI is 
calculated from equation below:

\[ HPI = \sum_{i=1}^{n} W_i Q_i / \sum_{i=1}^{n} W_i \]

- \( Q_i \) = the sub-index of the parameter, \( W_i \) = the unit weightage of 
the parameter, \( n \) = the number of parameters considered, the sub-
index (Q) of the parameter is calculated by where

\[ Q_i = \sum_{i=1}^{n} (M_i - S_i / |Si - li|) \times 100 \]

- \( M_i \) = the monitored value of heavy metal of parameter, \( li \) = the ideal value of the parameter, \( S_i \) = the standard value of the 
parameter. The sign (−) indicates numerical difference of the two 
values, ignoring the algebraic sign. HPI 100 indicated that high
heavy metal pollution (critical pollution index). If the HPI values 
of water samples were greater than 100, water is not potable.
The weightage was taken as the inverse of MAC, Si the WHO [7] 
standard for drinking water and \( I_i \) the guide value for the selected 
element.

Contamination Index (\( C_i \)): In this method, the water quality 
is assessed by the calculation of the degree of contamination and 
computed separately for each sample of water analyzed, as a sum 
of the contamination factors of individual components exceeding 
the upper permissible value was taken as the maximum admissible 
concentration (MAC). Hence, the \( C_i \) summarizes the combined 
effects of several pollution parameters considered harmful to 
household water. The \( C_i \) is calculated from equation below:

\[ Cd = \sum_{i=1}^{n} C_i \]

\[ C_i = \frac{C_{ma}}{C_{io}} - 1 \]

Where \( C_i \) is contamination factor for the component, \( C_i \) is 
analytical value for the component and \( C_{ma} \) is upper permissible 
concentration of the component. The resultant Cd value which 
are grouped into three categories as follows: \( C_{da} < 1 \) (low), \( C_{da} = 1-3 \) 
(medium) and \( C_{da} > 3 \) (high) [8].

Metal Evaluation Index (HEI): Heavy metal evaluation index 
with focus on heavy metals in water samples for estimating the 
water quality. This index classify into three categories, which 
include HEI <HEI< 800 (moderate to heavy metals) and HEI> 800 
(high heavy metals). The index is calculated from the following 
equation Mohan et al. (1996):

\[ HEI = \sum_{i=1}^{n} \frac{H_i}{H_{mac}} \]

- \( H_i \) = the monitored value of the parameter.
- \( H_{mac} \) = the maximum admissible concentration of the parameter.

Metal Enrichment Index (MEI): Metal enrichment index (MEI) 
of heavy metals in the surface water samples were calculated 
using the formula:

\[ MEI = \frac{C_i - C_{io}}{C_{io}} \]

Metal Enrichment Index Where \( C_i \) is the total concentration 
of each metal i measured in the water samples; \( C_{io} \) is the heavy 
metal background established for the system studied. The WHO 
maximum permissible limits of metals in water were used as the 
background value for the metals.

Results and Discussion

Results showed that heavy metals concentrations (Cd, Pb, Cr; 
As, Cu, Hg, Se, Zn and Ni) were detected in water samples in this 
present study. The mean concentrations of heavy metals in water 
samples were: 0.0016 – 0.0016, 0.003 – 0.00, 0.006 – 0.00, 0.006 – 
0.004 and 0.002 mg/L respectively Table 1. Results showed that 
the concentrations of heavy metals in water samples are within the 
permissible WHO limits in drinking water. Three metals of them 
(As, Hg and Se) were not detected in all sampling stations. HPI of 
water samples in three sites were 20.57 which was lower than 
100 the critical value for drinking water. Abdullah [9] calculated 
the HPI and ME for Euphrates River before confluence with Tigris 
River at Qurmat-Ali. The mean value of HPI was found to be below 
the critical pollution index value of 100. Cd shows that the values 
varies from 0.001 to 0.66 and indicate low 
heavy metal pollution (Table 2). The lower values of HPI and HEI 
reported in present study of can be interpreted in terms of absence 
of the local anthropogenic sources [9]. Yari & Sobhanardakani 
[10] reported that The Cd and HEI values in Iran are found below 
the critical pollution index (100), and this indicates the water is 
not critically polluted with respect to studied heavy metals. Water
quality pollution indices for groundwater resources of Ghahav and Plain in Iran estimated as the following indices Cd, HPI and HEI in samples as -2.27, 9.01 and 1.73, respectively that indicates low contamination levels [11] (Figures 2-4). MEI in the ground water samples shows that Ni is the highest metal enrichment value of -0.6. One way ANOVA show that there is no significant among heavy metals concentrations (Table 3). f- Value among heavy metals show no obvious significant that calculated as follow f= 2.84 and p- value = 0.03. F- Value = 0.31 and p- value = 0.73. A comparison between the indices and heavy metal concentrations show strong negative correlation between Cd and Cu (-0.997*). This indicates that Pb is the main contributory parameters. In addition, the correlation between Pb, HPI and HEI is negative significant (Table 4). Correlation analysis provides an effective way to reveal the relationships between multiple variables and thus have been helpful for understanding the influencing factors as well as the sources of chemical components [13,14].

Table 1: Mean concentration of heavy metals (mg/L) in water samples.

| Parameters | Site 1 | Site 2 | Site 3 | Mean |
|------------|--------|--------|--------|------|
| Cadmium    | 0.002  | 0.002  | 0.001  | 0.0016 |
| Lead       | 0.001  | 0.002  | 0.002  | 0.0016 |
| Chromium   | 0.003  | 0.003  | 0.003  | 0.003  |
| Arsenic    | 0      | 0      | 0      | 0     |
| Copper     | 0.003  | 0.002  | 0.013  | 0.006  |
| Mercury    | 0      | 0      | 0      | 0     |
| Selenium   | 0      | 0      | 0      | 0     |
| Zinc       | 0.006  | 0.004  | 0.004  | 0.004  |
| Nickel     | 0.001  | 0.005  | 0.002  | 0.002  |

Table 2: Heavy metal pollution indices (HPI, HEI and Cd) of water samples.

| Metals | Site 1 | Site 2 | Site 3 | I_i | S_i | Q_i | W_i | W_i*Q_i | HEI | Cd | MEI |
|--------|--------|--------|--------|-----|-----|-----|-----|---------|-----|-----|-----|
| Cd     | 2      | 2      | 1      | 3   | 5   | 50  | 0.3 | 15      | 0.66 | -0.3 | 0   |
| Pb     | 1      | 2      | 2      | 10  | 100 | 10  | 0.7 | 7       | 0.1  | -0.9 | -0.95 |
| Cr     | 3      | 3      | 3      | 50  | 50  | 0   | 0.02| 0       | 0.06 | -0.9 | -0.82 |
| As     | 0      | 0      | 0      | 0   | 0   | 0   | 0   | 0       | 0    | 0    | 0   |
| Cu     | 3      | 2      | 13     | 1000| 1000| 0   | 0.001| 0      | 0.001| -0.9 | -0.98 |
| Hg     | 0      | 0      | 0      | 0   | 0   | 0   | 0   | 0       | 0    | 0    | 0   |
| Se     | 0      | 0      | 0      | 0   | 0   | 0   | 0   | 0       | 0    | 0    | 0   |
| Zn     | 6      | 4      | 4      | 3000| 5000| 149.8| 0.0002| 0.02   | 0.002| -0.9 | -0.99 |
| Ni     | 1      | 5      | 2      | 20  | 20  | 0   | 0.05 | 0       | 0.05 | -0.9 | -0.6 |
| HPI = 20.57 | 1.07  | 22.02  | -     | -   | -   | -   | -   | -       | -    | -    | -   |

Table 3: One-Way ANOVA among heavy metals and three sites in water samples.

| Metals | Cd | Pb | Cr | As | Cu | Hg | Se | Zn | Ni |
|--------|----|----|----|----|----|----|----|----|----|
| Variance | 0.3 | 0.3 | 3  | 3  | 3  | 3  | 1.3| 4.3|    |
| Mean    | 1.6 | 1.6 | 3  | 0  | 6  | 0  | 4.6| 2.6|    |
| f-value | 2.84| p-value | 0.03|
| At the 0.01 level, the means are **NOT** significantly different |

| Variance | Site 1 | Site 2 | Site 3 |
|----------|--------|--------|--------|
| Site 1   | 3.9    | 3.2    | 16.6   |

| Mean | Site 1 | Site 2 | Site 3 |
|------|--------|--------|--------|
| 1.7  | 2      | 2.7    |

| F-value | 0.31163| p-value | 0.73517|
| At the 0.01 level, the means are **NOT** significantly different |

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Table 4: correlation matrix among heavy metals and indices.

| Metals | Cd    | Pb    | Cu   | Ni   | HEI   | CdI   |
|--------|-------|-------|------|------|-------|-------|
| Cd     | 1     | -     | -    | -    | -     | -     |
| Pb     | -0.5  | 1     | -    | -    | -     | -     |
| Cu     | -0.997* | 0.427 | 1    | -    | -     | -     |
| Ni     | 0.277 | 0.693 | -0.355 | 1    | -     | -     |
| HEI    | 0.551 | -0.998* | -0.48 | -0.649 | 1     | -     |
| CdI    | 0.5   | -1.000** | -0.427 | -0.693 | 0.1   | 1     |

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Conclusion

Heavy metal pollution was not observed in any sites. According to the water quality indices, water samples of the study area have been identified suitable for drinking. Therefore, the water quality indices proved to be a very useful tool in evaluating overall pollution of the ground water. However, the values of these three indices in totally below the critical values but severe precautions consideration such as manage the use of agricultural inputs, prevention of use of wastewater and sewage sludge in agriculture, control of overuse of organic fertilizers and establishment of pollutant industries are recommended in this area.

Acknowledgement

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Conflict of Interest

None.

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