ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

# Comprehensive performance assessment of the potable water treatment plants in El Fayoum governorate, Egypt

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**ABSTRACT**

With the increasing interest of the government of Egypt to the importance of the field of water production and supply, many new drinking water treatment plants (DWTPs) were either constructed or extended during the past few years to provide safe and aesthetic drinking water in sufficient quantities. Performance evaluation of these plants is an essential parameter to be monitored and evaluated for better understanding of operating difficulties in DWTPs. The treatment efficiencies of 5 conventional and 5 direct filtration DWTPs were investigated and compared. Comparative evaluation of certain physical, chemical and biological characteristics of raw and treated water has been used to show the efficiency of the removal of some pollutants. 720 treated and 648 raw water samples were collected with the rate of one treated and one raw water sample from each DWTP monthly during the period from January 2010 to December 2015. Water quality index (WQI) of treated water was calculated. The results indicated that the water treatment plants provide drinking water with acceptable quality coping with Egyptian guidelines and international standards. The exceptions are mainly concerned with the increased turbidity in direct filtration DWTPs and residual aluminum in all DWTPs, with fluctuation in non-conformity of iron and manganese due to some defects in estimation of dosage of the added chemicals, in addition to the deficiency of periodic maintenance rather than design problems. Increasing care of maintenance of water treatment units, control of added dose of alum and chlorine is advised to increase the desired water quality.

**Keywords:** Drinking water treatment, Conventional DWTPs, Direct filtration DWTPs, WQI.

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## INTRODUCTION

The provision of safe drinking water plays a critical role in preventing the incidence of many water transmissible diseases. As it interacts with the environment, water becomes polluted and laden with solids in suspension or in solution, clay particles, various salts, manufacturing residues, vegetable wastes, living organisms and organic matter [1]. The trend towards urbanization in the last century and the exposure of water sources to contamination by wastewater discharge is posing ever-increasing challenges with respect to supplying human population with safe drinking water. Over one billion of the world population lack access to safe water and more than three million die every year from water-related diseases [2]. The situation in Egypt is more stressful because of the increased rate of population growth, especially in the urban areas that far exceeds the rate of increase of the world population (~1.8%) [2].

The health-based criteria for the quality of drinking water, set by national and international health organizations, include limits on the levels of some chemicals and count of potentially harmful microbes or bacteria. Number of technical and aesthetic target values should be also considered for household water [3]. The main factors that must be considered in developing DWTPs include the raw water quality and its temporal pattern, the required treated water quality, regulatory requirements, and other factors such as plant size, site conditions, availability of skilled laborers, degree of automation required, economics, …etc [4]. The treatment assessment aims to describe the pathogens and pollutants reduction that represent the performance of DWTPs. After regular monitoring, water assessment should be done by using Water Quality Index (WQI) as a useful statistical approach for simplifying, reporting and interpreting complex information obtained from any body of water over the study period. WQI values show the rate of suitability of water for human health and consumption whether water is potable or not. It is a single numeric expression that represents a large amount of data related to water analysis [5].

The system applied for drinking water treatment in Egypt includes pre-chlorination, coagulation using aluminum sulfate, flocculation, sedimentation, filtration and post-chlorination. Substances that are removed during the process of treatment include bacteria, algae, viruses, fungi, solids, minerals such as Fe, Mn, S and other chemical pollutants. Besides treatment, a monitoring plan that includes source water protection by multi-barrier approach and maintenance of the distribution system integrity to consumers' taps is also necessary. In Egypt, a plan for big WTPs has been prepared to provide safe potable water for rural areas and secondary cities. This plan was in need of time, so a decision for using the water treatment compact units was taken as a temporary solution. Now and after about 22 years of their application, about 560 of these compact units have been constructed in Egypt [6] and the compact units become one of the options for production of potable water as a permanent solution in rural areas of Egypt for both villages and towns [7]. After progress, the technology of the water treatment compact unit has been improved and developed to be direct filtration DWTPs.

The rate of water production from the conventional treatment systems in Egypt is about 17000m$^3$/day. Coagulation-flocculation process is a major step in the production of potable water allowing the removal of colloidal particles [8]. The main difficulty is to determine the optimum coagulant dosage related to the characteristics of raw water. Coagulant overdosing resulted in high treatment costs as well as public health concerns, while insufficient dose leads to a failure to meet the water quality targets and less efficient operation of the water treatment plant [9]. These conventional DWTPs are characterized by a good intake pump station, slow and rapid mixing of coagulants added, clarifiers, sedimentation as well as slow or rapid sand filtration. In the direct filtration developed compact units, water is treated in the same manner as in conventional systems, but in the compact systems filters are reduced the sand filters [10]. Treatment consisted of direct filtration raw water enters the plant through a channel in which alum coagulant is added in-line coagulant dosing before the one stage rapid sand filter or through a two stages filtration [1]. This design is characterized by its low potable water production rate (30 l/S), with a retention time that doesn't exceed one hour. Furthermore treatment efficacy varies due to production flows, filtration backwash cycles and chemical dosing control loops (Fig.1).

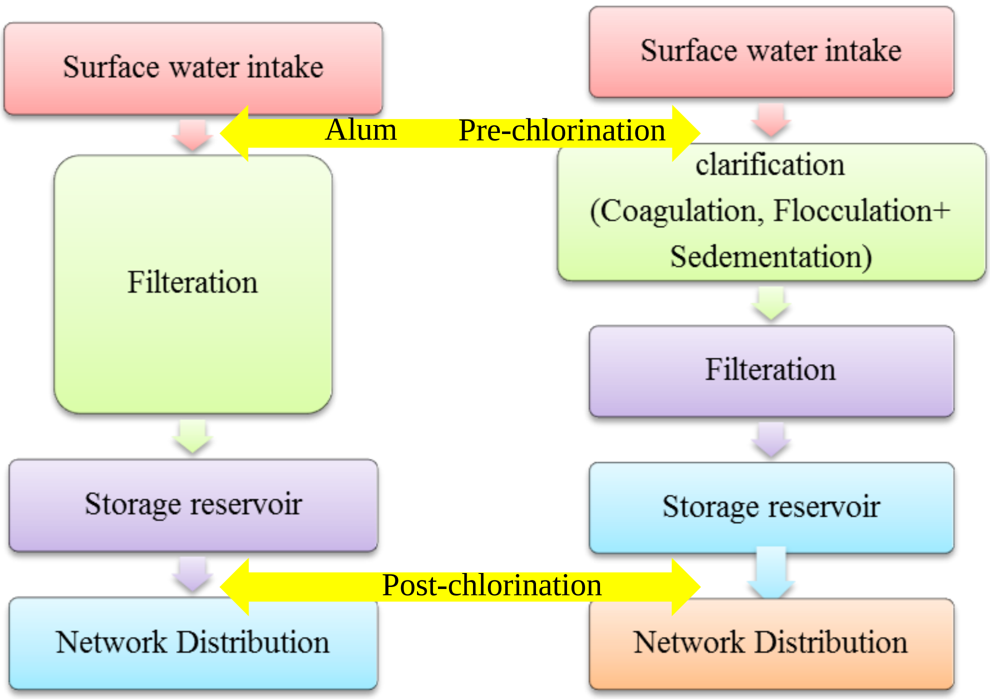



**Fig.1: Direct filtration and conventional drinking water treatment process scheme.**

A lot of studies have been conducted in DWTPs in Egypt, including Donia, 2007 [11], Abdel hamid, 2012 [12], Hegazy, 2012 [1] and Fareed, 2013 [13]**.** The current study is the first attempt to assess the quality of drinking water in El Fayoum governorate. To achieve this major objective, this study aimed to:

1. Compare the efficiency of the conventional DWTPs and the direct filtration DWTPs in removing different physical, chemical and biological contaminants.
2. Evaluate the performance of DWTPs in El Fayoum governorate based on water quality parameters throughout the study period.
3. Assess the quality of potable water based on health concerns by using WQI.

## MATERIALS AND METHODS

### The study area

El Fayoum Governorate have a rural nature with a population of 2.88 million (January 2012 census) is occupying a natural closed depression in the Western Desert of Egypt (95 km southwest of Cairo). It extends over 6068 km$^2$ between 29°20' to 29°35'N and 30°23' to 31°5'E. El Fayoum Governorate includes six districts namely; Fayoum (the town), Tamia, Sennuris, Ibshawai, Itsa and Yosef el sedek. The daily drinking water production in El Fayoum Governorate from five conventional and five direct filtration drinking water treatment plants (DWTPs) is 747,728 cubic meter. The used type of filtration is rapid sand filtration with the exception of New Quhafa DWTP is slow sand filtration (Table 1 and Fig. 2b).

**Table1: Drinking Water Treatment Plant (DWTP) description**

| Code | Name of DWTPs | Type DWTP Design | Date of operation | production capacity m$^3$/ day | Water source name | Type of water source |
|---|---|---|---|---|---|---|
| T1 | Tamia | Conventional | 2009 | 170,000 | Tirat el jizah from River Nile | Nile |
| T2 | New elazab | Conventional | 2011-1998 | 360,000 | Bahr Hassan wassef | Canal |
| T3 | Old elazab | Conventional | 1940 | ,129700 | Bahr Hassan wassef | Canal |

| | | | | | | |
|---|---|---|---|---|---|---|
| T4 | New quhafa | Conventional | 1993 | 25,920 | Bahr Yousef | Canal |
| T5 | Old quhafa | Conventional | 1926 | 25,920 | Bahr Yousef | Canal |
| T6 | Senores1,2 | Direct filtration | 1997 | 12,096 | Bahr Senors | Sub-canal |
| T7 | Kaser elbasel | Direct filtration | 1989 | 6,048 | Bahr elgarak | Sub-canal |
| T8 | El prince | Direct filtration | 2008 | 6,048 | Bahr elberns | Sub-canal |
| T9 | Abo gander | Direct filtration | 2008 | 6,048 | Bahr kasr elbanat | Sub-canal |
| T10 | El rayan | Direct filtration | 1996 | 6,048 | Bahr kasr elbanat | Sub-canal |

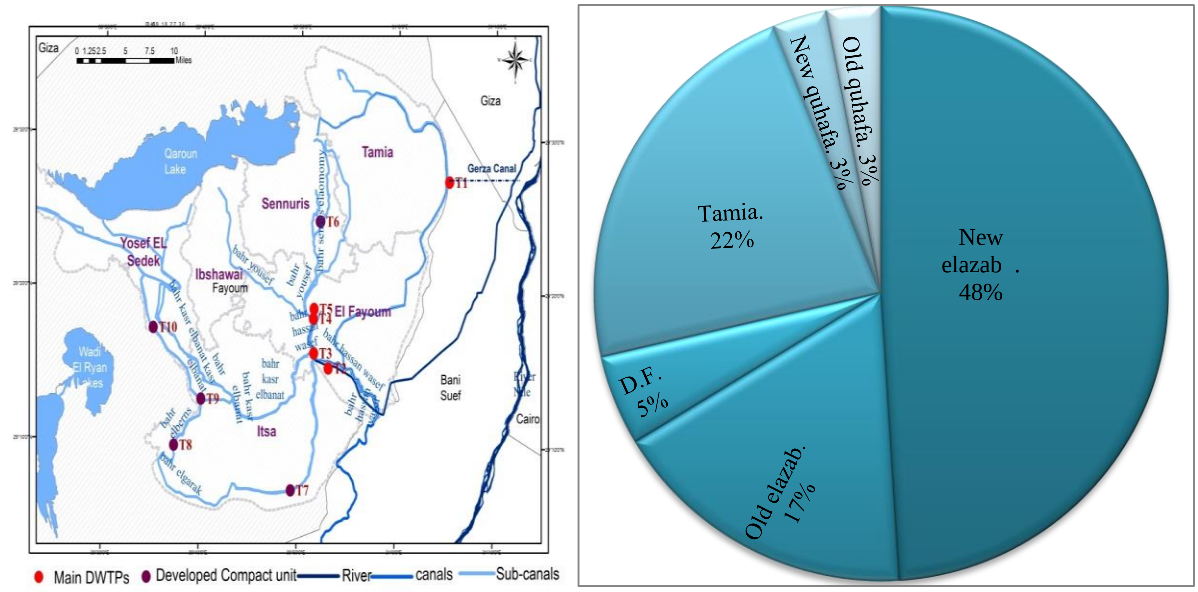



**Fig.2 (a) Map of geographical location of DWTPs in El Fayoum governorate, (b) Chart of water production percent of conventional and compact unit water treatment systems to overall water production in El Fayoum governorate.**

## Analyses

### Water analyses

Water samples were collected from five conventional (T1:T5) and five direct filtration (T6:T10) DWTPs during the period from January 2010 to December 2015. Twelve Physicochemical parameters, five major anions, four major cations, fifteen metals, four bacteriological characters and total algae count in each sample of collected water samples were evaluated according to standard methods for examination of water and wastewater [10]. All analyses were conducted at the Water Quality Central Laboratory, El Fayoum Drinking Water and Sanitation Company, El Fayoum- Egypt which is accredited according to ISO/IEC 17025.

### Water quality index

WQI was calculated by the CCME WQI model [14] which consists of three measures of variance (scope, frequency and amplitude). These three measures of variance combine to produce a value between 0 and 100 that represents the overall water quality and thus ranking it into one of the following five categories as in Table 2**.** Water samples of individual DWTPs are collected and analyzed for 41 physico-chemicals, chemicals, bacteriological characters and algae count. While it is desirable to include all variables that have a health effect in the sampling program, it is not feasible to sample DWTPs for all variables. The current list of 25 variables as listed in Table 3 was chosen after carefully reviewing background water quality and selected drinking water quality samples. The chosen 25 variables cover most standard guidelines for drinking water according to the decision of the Minister of Health no 458/2007.
The WQI comprises the following three factors.

**Factor 1**: F1 (scope)

Scope assesses the extent of water quality guideline noncompliance over the time period of interest, which means the number of parameters whose objective limits is not met.

$$F1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right) \times 100$$

Where, the variables indicate those water quality parameters whose objective values are specified and observed values at the sampling sites are available for the index calculation.

**Factor 2**: F2 (frequency)

The frequency (i.e. number of occasions where the tested value was off the acceptable limits) with which the objectives are not met, which represents the percentage of individual tests that do not meet the objectives (‘‘failed tests’’):

$$F2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of variables}}\right) \times 100$$

**Factor 3:** F3 (amplitude)

The amount by which the objectives are not met (amplitude) that represents the amount by which the failed test values do not meet their objectives, and is calculated in three steps.

The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an ‘‘excursion’’ and is expressed as follows, When the test value must not exceed the objective

$$\text{Excursion}_i = \left(\frac{\text{Failed test value}_i}{\text{Objective}_j}\right) - 1$$

For the cases in which the test value must not fall below the objective:

$$\text{Excursion}_i = \left(\frac{\text{Objective}_j}{\text{Failed test value}_i}\right) - 1$$

The collective amount, by which the individual tests are out of compliance, is calculated summing the excursions of individual tests from their objectives and then dividing the sum by the total number of tests. This variable, referred to as the normalized sum of excursions (NSE) is calculated as:

$$\text{NSE} = \frac{\sum_{i=1}^{n} excursion_i}{\text{Number of tests}}$$

F3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (NSE) to yield a value between 0 and 100.

$$F3 = \left(\frac{\text{NSE}}{0.01\text{NSE} + 0.01}\right)$$

The CWQI is finally calculated as:

$$\text{CWQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right)$$

The factor of 1.732 has been introduced to scale the index from 0 to 100. Since the individual index factors can range as high as 100, it means that the vector length can reach a maximum of 173.2 as shown below:

$$\sqrt{100^2 + 100^2 + 100^2} = \sqrt{30,000} = 173.2$$

The above mentioned formulation produces a value between 0 and 100 and gives a numerical value to the state of water quality. Note a (0) value signifies very poor water quality, a higher number is indicative of better water quality whereas values close to 100 signify excellent water quality (Table 3). The assignment of CCME WQI values to different categories is a somewhat subjective process and also demands expert judgment and public's expectations of water quality. The water quality is ranked in the following five categories (Table 2). A WQI map using Geographic information system (GIS) software (Arc 10.2.1) was created with the help of CCME WQI classification to understand the variation in the water quality throughout the study area.

**Table 2: Categories and color scheme of WQI.**

| WQI Value | Rating | Color |
|---|---|---|
| 95 - 100 | Excellent | Water quality is protected with a virtual absence of threat conditions very close to natural or healthy levels; these index values can only be obtained if all measurements are within objectives virtually all of the time. |
| 80 – 94 | Good | Water quality is protected with only a minor degree of threat conditions rarely depart from natural or desirable levels. |
| 65 – 79 | Fair | Water quality is usually protected but occasionally threatened conditions sometimes depart from natural or desirable levels. |
| 45 – 64 | Marginal | Water quality is frequently threatened conditions often depart from natural or desirable levels. |
| 0.0 – 44 | Poor | Water quality is almost always threatened conditions usually depart from natural or desirable levels. Water unsuitable for drinking purposes. |

**Table3: Variables used to calculate water quality index related to national and international standards.**

| Variables tested | unit | Criteria | Variable type | Variables tested | Unit | Criteria | Variable type |
|---|---|---|---|---|---|---|---|
| **Natural characters** | | | | **Significant health effect** | | | |
| Color | Pt/Co | | Aesthetic | **1-Inorganic parameters** | | | |
| Turbidity | NTU | 1 | Contaminant | Chlorine | mg/l | 5 | Treatment product |
| pH | - | 6.5-8.5 | Aesthetic | Lead (Pb) | mg/l | 0.01 | Contaminant |
| **Guideline related to taste and domestic uses** | | | | Cadmium (Cd) | mg/l | 0.003 | Contaminant |
| Total Dissolved Solids | mg/l | 1000 | Aesthetic | Arsenic (As) | mg/l | 0.01 | Contaminant |
| Chlorides (Cl) | mg/l | 250 | Aesthetic | Barium (Ba) | mg/l | 0.7 | Contaminant |
| Sulfates ($SO_4$) | mg/l | 250 | Aesthetic | Chromium (Cr) | mg/l | 0.05 | Contaminant |
| Total Hardness as Ca | mg/l | 500 | Aesthetic | Nitrites as ($NO_2$) | mg/l | 0.3 | Contaminant |
| Calcium Hardness | mg/l | 350 | Aesthetic | Nitrates as ($NO_3$) | mg/l | 45 | Contaminant |
| Magnesium Hardness | mg/l | 150 | Aesthetic | Fluorides (F) | mg/l | 0.8 | Contaminant |
| Sodium (Na) | mg/l | 200 | Aesthetic | Nickel (Ni) | mg/l | 0.02 | |
| Iron (Fe) | mg/l | 0.3 | Aesthetic | **2-Bacteriological indicators** | | | |
| Manganese (Mn) | mg/l | 0.4 | Aesthetic | Total bacteria | CFU/ | 50 | Contaminant |
| Aluminum (Al) | mg/l | 0.2 | Treatment | Total Coliform | CFU/ | 2 | Contaminant |
| *Copper (Cu) | mg/l | 2 | Aesthetic | Fecal Coliform | CFU/ | 0 | Contaminant |
| *Zinc (Zn) | mg/l | 3 | Aesthetic | Fecal | Organ | 0 | Contaminant |

ISSN: 0975-8585

**RESULTS**

The average values of the various physico-chemical, chemical, bacteriological parameters and total algae count of raw and treated water samples (T1:T5 for conventional and T6:T10 for direct filtration DWTPs) throughout the study period are presented in Tables 4-7. Seasonal variation of the average results compared to their permissible limits of national and international standards are shown in figure 3, while the seasonality of the removal percent of DWTPs results are presented in figure 4. Parameters that show significant percent of removal after treatment are presented in figure 5, while figure 6 shows a comparison between conventional and direct filtration DWTPs. Finally Map showing the calculated WQI of conventional and direct filtration DWTPs and its relation to its relevant values of raw water is shown in figure 7.

**Table 4 Average values of physico-chemical parameters of raw and treated water samples collected from different study sites (T1 to T10) throughout the study period from January 2010 to December 2015.**

| Parameters | Color (mg/l Pt/Co) | Turbidity (NTU) | Temp. (C°) | pH (µS/cm) | Electric Conductivity (mg/l) | TDS (mg/l) | Total Alkalinity (mg/l) | Total Hardness (mg/l) | Calcium Hardness (mg/l) | Magnesium Hardness (mg/l) | Chlorine (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw T1 | 12.5 | 10.39 | 24.88 | 7.84 | 424.6 | 260.5 | 129.5 | 131.2 | 90.84 | 58.51 | - |
| T1 | 4.3 | 1 | 23.5 | 7.6 | 410.9 | 243.8 | 118.7 | 127.9 | 85.1 | 56.3 | 1.9 |
| Raw T2 | 19.4 | 20.6 | 24.5 | 7.6 | 524.4 | 297.8 | 141.8 | 153.3 | 97.73 | 61.36 | - |
| T2 | 4.7 | 0.7 | 23.45 | 7.53 | 555.02 | 315.13 | 130.86 | 150.72 | 97.57 | 61.63 | 1.73 |
| Raw T3 | 17.5 | 27.11 | 24.5 | 7.71 | 529.8 | 304.2 | 142 | 155.6 | 98.09 | 65.86 | - |
| T3 | 4.1 | 0.7 | 23.46 | 7.53 | 542.03 | 314.56 | 128.65 | 150.15 | 98.25 | 63.65 | 1.88 |
| Raw T4.5 | 18 | 21.56 | 25.16 | 7.70 | 557.3 | 317.7 | 145.3 | 168.3 | 104.9 | 67.76 | - |
| T4 | 3.9 | 0.5 | 23.8 | 7.4 | 522.5 | 295.5 | 130.4 | 157.2 | 100 | 64.3 | 1.7 |
| T5 | 4.1 | 0.5 | 23.65 | 7.46 | 523.78 | 295.97 | 128.9 | 156.12 | 99.3 | 62.73 | 1.7 |
| Raw T6 | 27.8 | 39.2 | 24.8 | 7.8 | 533.6 | 312.4 | 146.7 | 154.4 | 95.1 | 68.2 | |
| T6 | 6 | 1 | 22.7 | 7.6 | 555.8 | 330.4 | 130.4 | 145.4 | 91.6 | 58.8 | 1.9 |
| Raw T7 | 27.7 | 31.72 | 24.83 | 7.7 | 675.3 | 396.9 | 146.4 | 171.4 | 106.7 | 80.92 | - |
| T7 | 3.5 | 1 | 21.8 | 7.5 | 685.2 | 400.9 | 127.5 | 170.7 | 97.4 | 75.4 | 2 |
| Raw T8 | 34.6 | 24.16 | 25 | 8 | 797.7 | 518.6 | 155.6 | 192.9 | 124.7 | 90.61 | - |
| T8 | 3.8 | 0.9 | 22.2 | 7.6 | 734.2 | 445.5 | 128.6 | 168.8 | 103.3 | 73.6 | 1.9 |
| Raw T9 | 26 | 42 | 25 | 8.0 | 703 | 415 | 150 | 179.4 | 113.3 | 80.8 | - |
| T9 | 4.64 | 1 | 22.45 | 7.51 | 643.27 | 376.39 | 121.46 | 159.89 | 93.42 | 73.65 | 1.89 |
| Raw T10 | 22.6 | 27.57 | 24.78 | 7.78 | 730.6 | 434.3 | 153.3 | 190.7 | 116.3 | 89.11 | - |
| T10 | 5.1 | 1 | 23.5 | 7.5 | 702.9 | 405.2 | 131 | 175.7 | 113.7 | 69.5 | 1.9 |

ISSN: 0975-8585

**Table 5 Average values of major anions and cations of raw and treated water samples collected from different study sites (T1 to T10) throughout the study period from January 2010 to December 2015.**

| Parameters(mg/l) | Cl | $SO_4$ | $NO_2$ | $NO_3$ | F | Ca | Mg | Na | k |
|---|---|---|---|---|---|---|---|---|---|
| Raw T1 | 23.46 | 31.7 | 0.04 | 1.32 | 0.26 | 29.58 | 10.04 | 20.86 | 1.51 |
| T1 | 25.6 | 31.8 | UDL | 1.2 | 0.2 | 28.9 | 9.9 | 20.3 | 1.4 |
| Raw T2 | 42.31 | 50.78 | 0.048 | 2.34 | 0.289 | 34.24 | 11.65 | 37 | 4.79 |
| T2 | 51.6 | 60.46 | UDL | 2.32 | 0.2 | 34.23 | 11.6 | 36.67 | 4.79 |
| Raw T3 | 42.59 | 58.45 | 0.04 | 2.39 | 0.31 | 34.27 | 11.54 | 36.75 | 4.9 |
| T3 | 53.03 | 63.86 | UDL | 2.31 | 0.22 | 32.66 | 11.12 | 36.37 | 4.69 |
| Raw T4.5 | 41.08 | 59.11 | 0.052 | 2.36 | 0.297 | 35.65 | 12.3 | 41.95 | 5.095 |
| T4 | 50.2 | 59.8 | UDL | 2.1 | 0.2 | 34.2 | 12.2 | 36.1 | 4.9 |
| T5 | 43.87 | 60.36 | UDL | 2.07 | 0.21 | 33.81 | 11.49 | 35.54 | 4.84 |
| Raw T6 | 37.4 | 53.9 | 0.1 | 2.4 | 0.3 | 35.4 | 12.5 | 32.7 | 4.7 |
| T6 | 46.6 | 66.7 | UDL | 2.4 | 0.3 | 34.9 | 12.4 | 30.9 | 3.1 |
| Raw T7 | 65.53 | 72.29 | 0.19 | 4.89 | 0.52 | 37.88 | 13.16 | 47.24 | 3.37 |
| T7 | 71.9 | 84.1 | UDL | 3.3 | 0.2 | 32.1 | 13.06 | 38.2 | 3.3 |
| Raw T8 | 84.47 | 74.19 | 0.46 | 4.93 | 0.52 | 42.42 | 14.56 | 57.58 | 2.53 |
| T8 | 87.7 | 82.8 | UDL | 4.1 | 0.31 | 38.8 | 13.8 | 49.7 | 2.5 |
| Raw T9 | 64 | 77.7 | 0.2 | 3.3 | 0.3 | 39.6 | 14.2 | 45.7 | 2.5 |
| T9 | 64.3 | 77.73 | UDL | 2.64 | 0.26 | 38.8 | 14.13 | 31.72 | 4.54 |
| Raw T10 | 75.02 | 86.19 | 0.28 | 4.62 | 0.34 | 53.75 | 15.09 | 46.34 | 1.66 |
| T10 | 79.6 | 84.5 | UDL | 4.1 | 0.2 | 38.4 | 13.4 | 39.4 | 1.6 |

**Table 6 Average values of metals parameters of raw and treated water samples collected from different study sites (T1 to T10) throughout the study period from January 2010 to December 2015.**

| Parameters(mg/l) | (Fe) | (Mn) | (Al) | (Cu) | (Pb) | (Cd) | (Co) | (Ni) | (Cr) | (Zn) | (As) | (Sr) | (Ba) | (Ti) | (v) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw T1 | 0.49 | 0.14 | 0.37 | UDL | UDL | UDL | UDL | UDL | UDL | UDL | UDL | 0.16 | UDL | 0.02 | 0.01 |
| T1 | 0.1 | 0.1 | 0.3 | UDL | UDL | UDL | UDL | UDL | UDL | UDL | UDL | 0.2 | UDL | 0.02 | 0.01 |
| Raw T2 | 1.642 | 0.104 | 1.47 | 0.006 | UDL | UDL | 0.0005 | 0.002 | UDL | 0.005 | UDL | 0.35 | 0.04 | 0.035 | 0.007 |
| T2 | 0.03 | 0.08 | 0.24 | 0.001 | UDL | UDL | UDL | UDL | UDL | 0.01 | UDL | 0.38 | 0.03 | UDL | UDL |
| Raw T3 | 1.93 | 0.13 | 2.08 | 0.01 | UDL | UDL | UDL | UDL | UDL | 0.01 | UDL | 0.36 | 0.04 | 0.03 | 0.01 |
| T3 | 0.03 | 0.06 | 0.16 | 0.01 | UDL | UDL | UDL | UDL | UDL | 0.04 | UDL | 0.33 | 0.03 | UDL | UDL |
| Raw T4.5 | 1.688 | 0.109 | 1.58 | 0.023 | 0.0003 | 0.001 | 0.0004 | 0.004 | UDL | 0.009 | UDL | 0.451 | 0.04 | 0.085 | 0.007 |
| T4 | 0.1 | 0.1 | 0.2 | 0.01 | UDL | UDL | UDL | UDL | UDL | UDL | UDL | 0.5 | UDL | UDL | UDL |
| T5 | 0.08 | 0.04 | 0.24 | 0.01 | UDL | UDL | UDL | UDL | UDL | 0.01 | UDL | 0.48 | 0.03 | UDL | UDL |

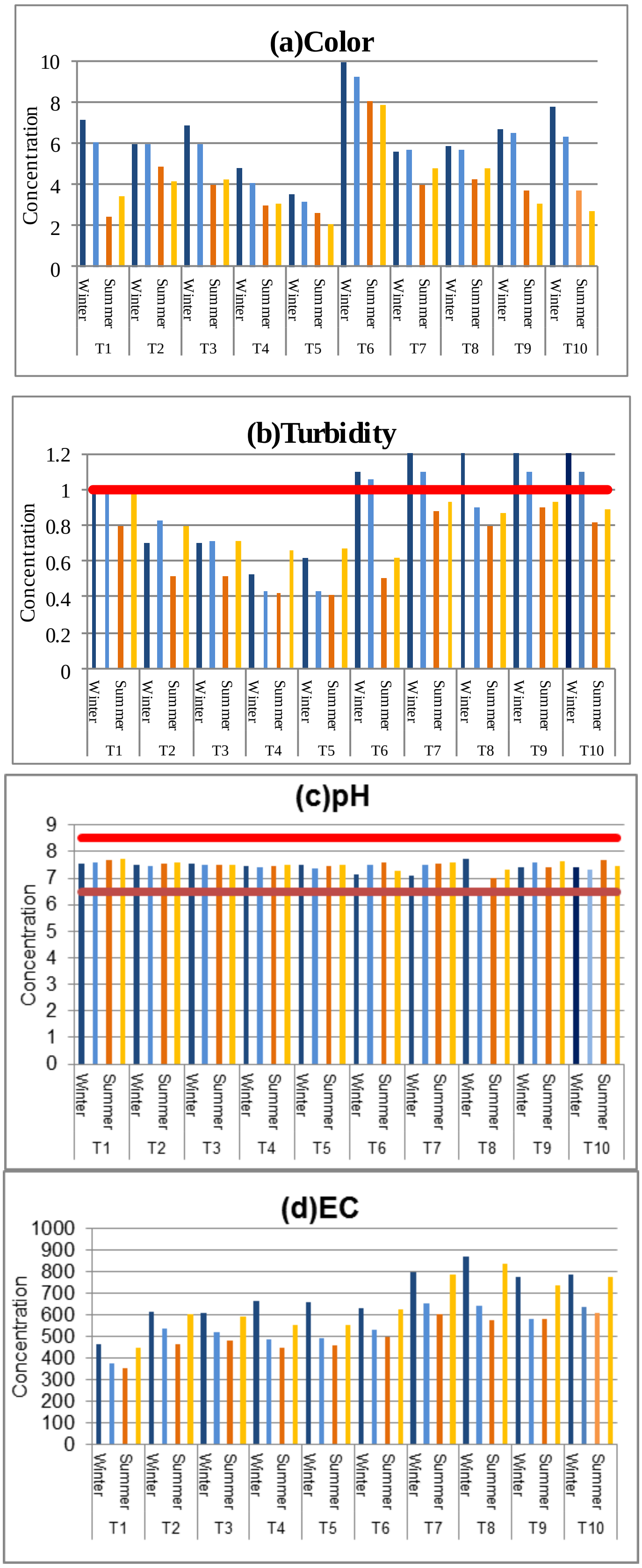
ISSN: 0975-8585

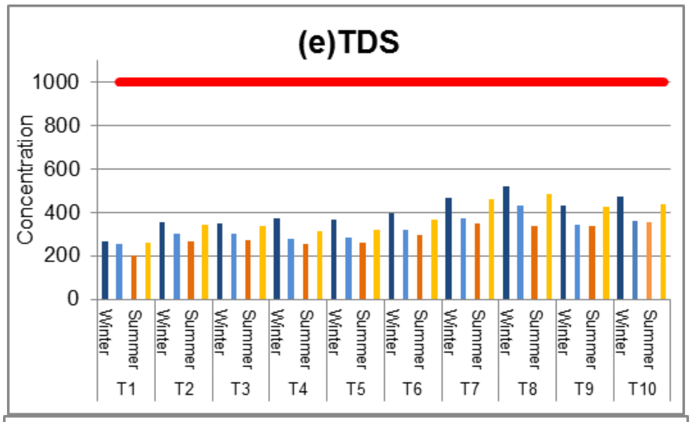
| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw T6 | 2.9 | 0.1 | 2.8 | 0.01 | UDL | UDL | UDL | UDL | UDL | 0.01 | UDL | 0.4 | 0.03 | 0.05 | 0.13 |
| T6 | 0.04 | 0.1 | 0.19 | 0.01 | UDL | UDL | UDL | UDL | UDL | UDL | UDL | 0.3 | UDL | 0.012 | 0.034 |
| Raw T7 | 2.37 | 0.16 | 2.52 | 0.01 | UDL | UDL | 0.0024 | 0.02 | 0.04 | 0.02 | UDL | 0.42 | 0.07 | 0.13 | 0.03 |
| T7 | 0.02 | 0.1 | 0.21 | 0.01 | UDL | UDL | UDL | UDL | UDL | UDL | UDL | 0.4 | UDL | 0.05 | 0.023 |
| Raw T8 | 1.82 | 0.11 | 2.11 | UDL | UDL | UDL | UDL | UDL | UDL | UDL | UDL | 0.33 | 0.06 | 0.06 | 0.01 |
| T8 | 0.1 | 0.09 | 0.7 | UDL | UDL | UDL | UDL | UDL | UDL | UDL | UDL | 0.4 | UDL | 0.08 | 0.01 |
| Raw T9 | 1.8 | 0.1 | 2.3 | 0.2 | UDL | UDL | 0.004 | 0.003 | 0.002 | 0.01 | UDL | 0.28 | 0.06 | 0.09 | 0.02 |
| T9 | 0.02 | 0.85 | 0.49 | 0.02 | UDL | UDL | UDL | UDL | UDL | UDL | UDL | 0.36 | 0.02 | 0.019 | 0.01 |
| Raw T10 | 1.56 | 0.12 | 1.6 | UDL | UDL | UDL | UDL | UDL | UDL | 0.01 | UDL | 0.29 | 0.06 | 0.05 | 0.01 |
| T10 | 0.1 | 0.09 | 0.21 | UDL | UDL | UDL | UDL | UDL | UDL | 0.01 | UDL | 0.4 | UDL | 0.008 | 0.002 |

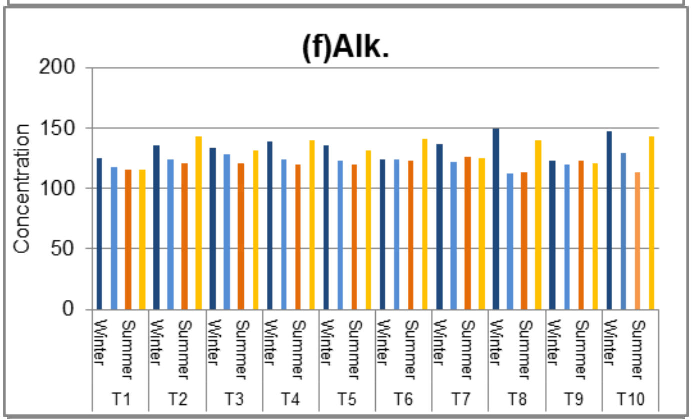
UDL: under detection level

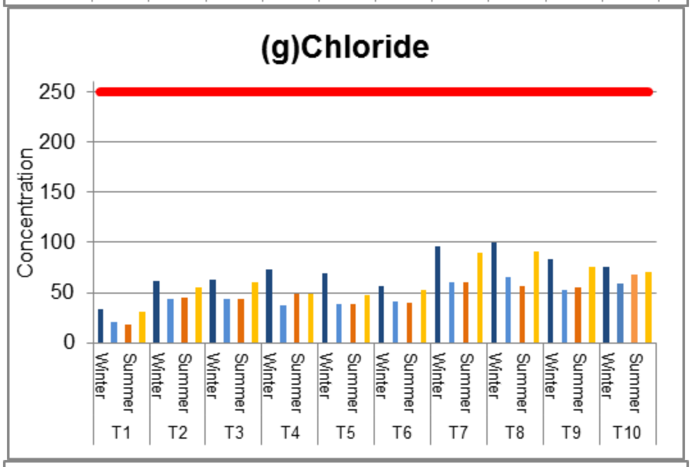
**Table 7 Average values of bacteriological characters and suspended algae of raw and treated water samples collected from different study sites (T1 to T10) throughout the study period from January 2010 to December 2015.**

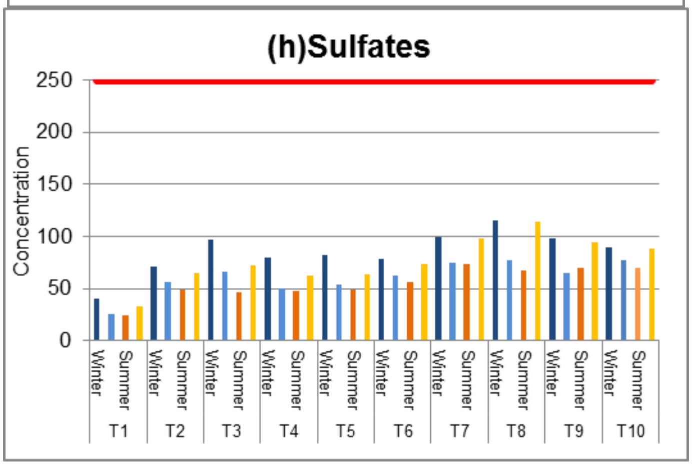
| Parameters | Total bacteria CFU/ml | Total Coliform CFU/100 ml | Fecal Coliform CFU/100 ml | Fecal Streptococcus CFU/100 ml | Total algae Count Organism/ml | WQI |
|---|---|---|---|---|---|---|
| Raw T1 | 15588 | 15150 | 1458 | 1656 | 4906 | 84.2 |
| T1 | 3 | <1 | <1 | <1 | 531 | 95.21 |
| Raw T2 | 17020 | 15170 | 5690 | 1427 | 3835 | 79.9 |
| T2 | 2 | <1 | <1 | <1 | 113 | 95.6 |
| Raw T3 | 32553 | 30118 | 4308 | 1199 | 4517 | 72.4 |
| T3 | 2 | <1 | <1 | <1 | 63 | 93.78 |
| Raw T4.5 | 51262 | 29825 | 8200 | 3531 | 3969 | 76.3 |
| T4 | 2 | <1 | <1 | <1 | 127 | 93.19 |
| T5 | 3 | <1 | <1 | <1 | 33 | 93.18 |
| Raw T6 | 35428 | 39388 | 14799 | 3034 | 3008 | 70.3 |
| T6 | 2 | <1 | <1 | <1 | 62 | 93.53 |
| Raw T7 | 48079 | 53005 | 8336 | 1886 | 2626 | 68.6 |
| T7 | 2 | <1 | <1 | <1 | 59 | 93.2 |
| Raw T8 | 24047 | 19983 | 8631 | 2352 | 2289 | 69.2 |
| T8 | 1 | <1 | <1 | <1 | 74 | 91.4 |
| Raw T9 | 42052 | 45822 | 14293 | 4804 | 1984 | 69.7 |
| T9 | 2 | <1 | <1 | <1 | 75 | 92.1 |
| Raw T10 | 30710 | 40640 | 7283 | 2309 | 2221 | 69.7 |
| T10 | 2 | <1 | <1 | <1 | 96 | 93.59 |


(a)Color
Concentration
10
8
6
4
2
0
Winter
Summer
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
(b)Turbidity
Concentration
1.2
1
0.8
0.6
0.4
0.2
0
Winter
Summer
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
(c)pH
Concentration
9
8
7
6
5
4
3
2
1
0
Winter
Summer
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
(d)EC
Concentration
1000
900
800
700
600
500
400
300
200
100
0
Winter
Summer
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10


(e)TDS
Concentration
1000
800
600
400
200
0
Winter
Summer
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10


(f)Alk.
Concentration
200
150
100
50
0
Winter
Summer
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10


(g)Chloride
Concentration
250
200
150
100
50
0
Winter
Summer
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10


(h)Sulfates
Concentration
250
200
150
100
50
0
Winter
Summer
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10

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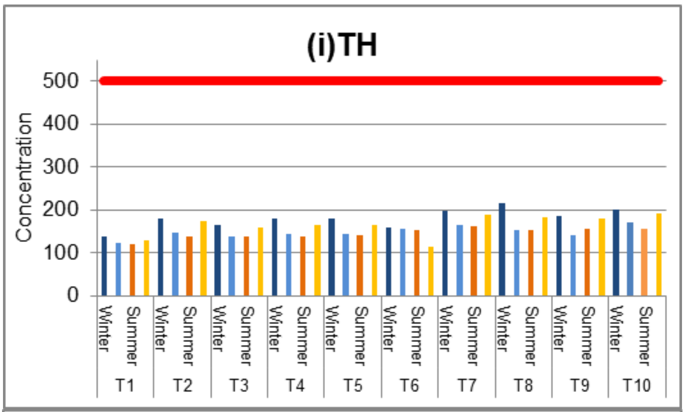


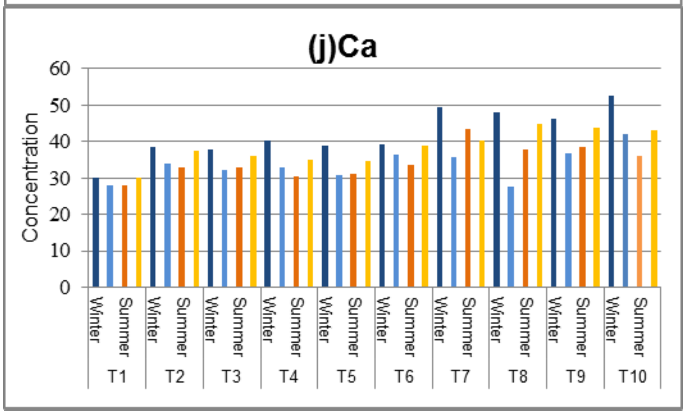


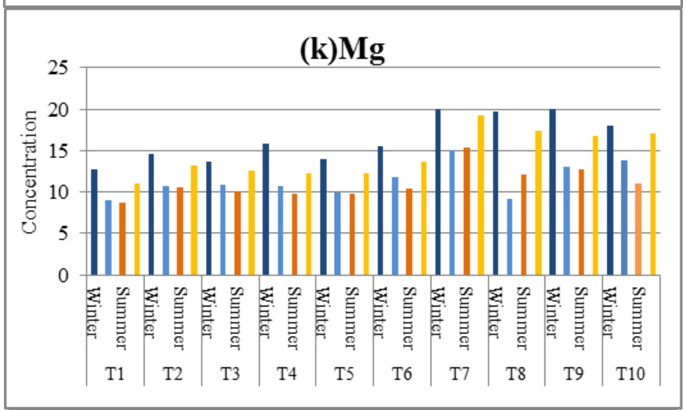


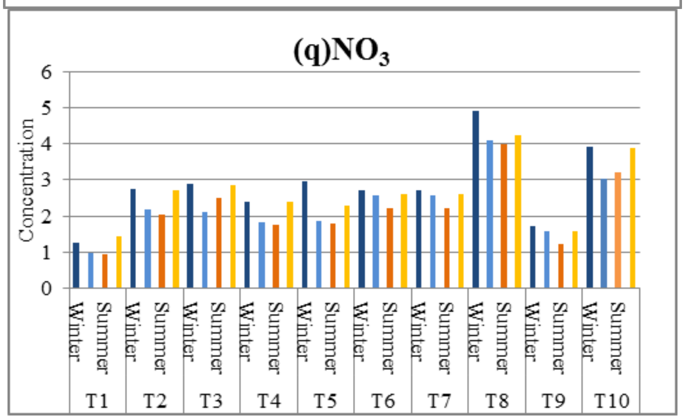

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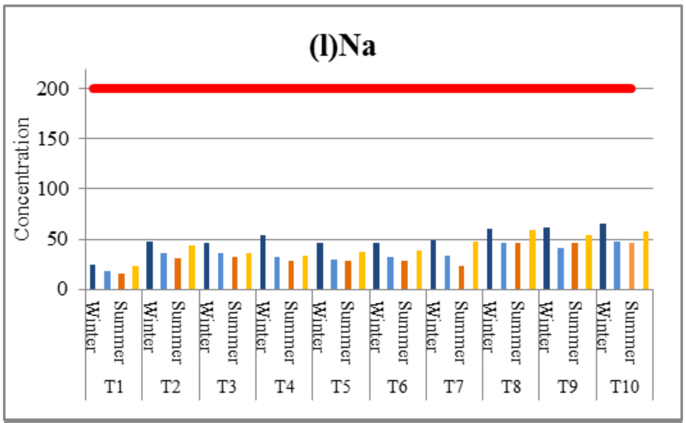
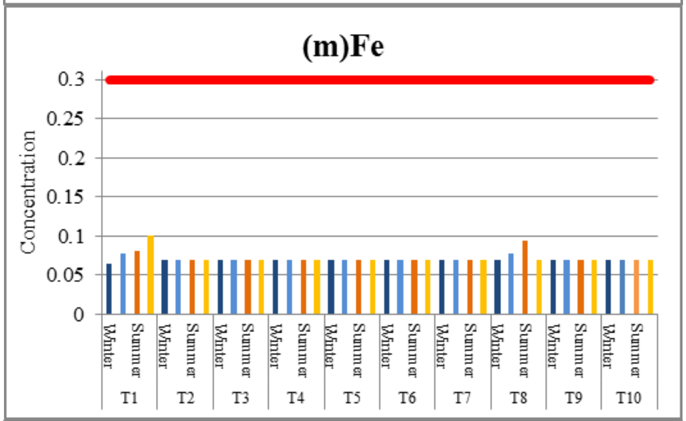
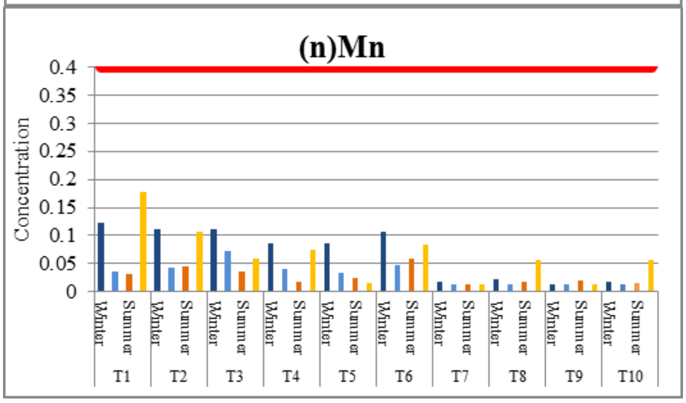


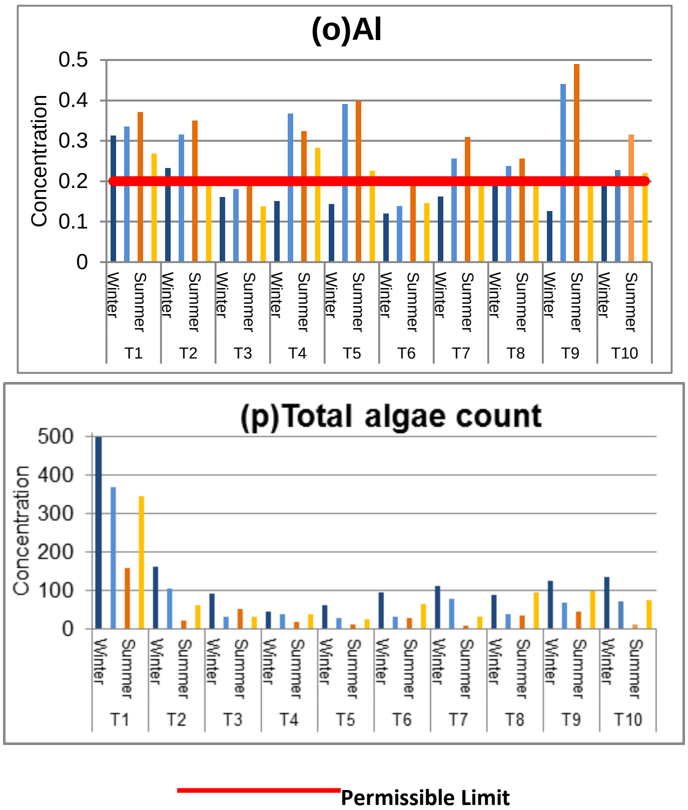
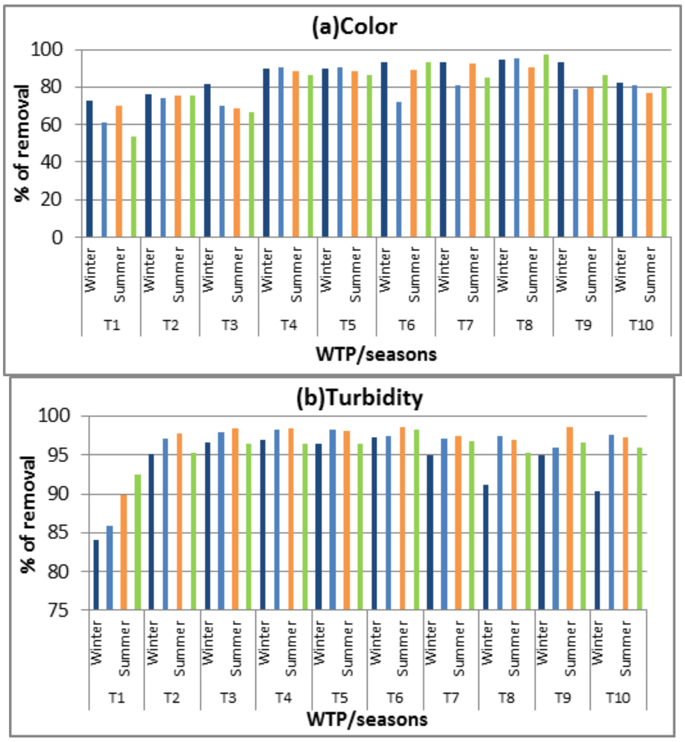



**Fig.3: Seasonal variation of drinking water parameters compared to their permissible limits of drinking water standards.**



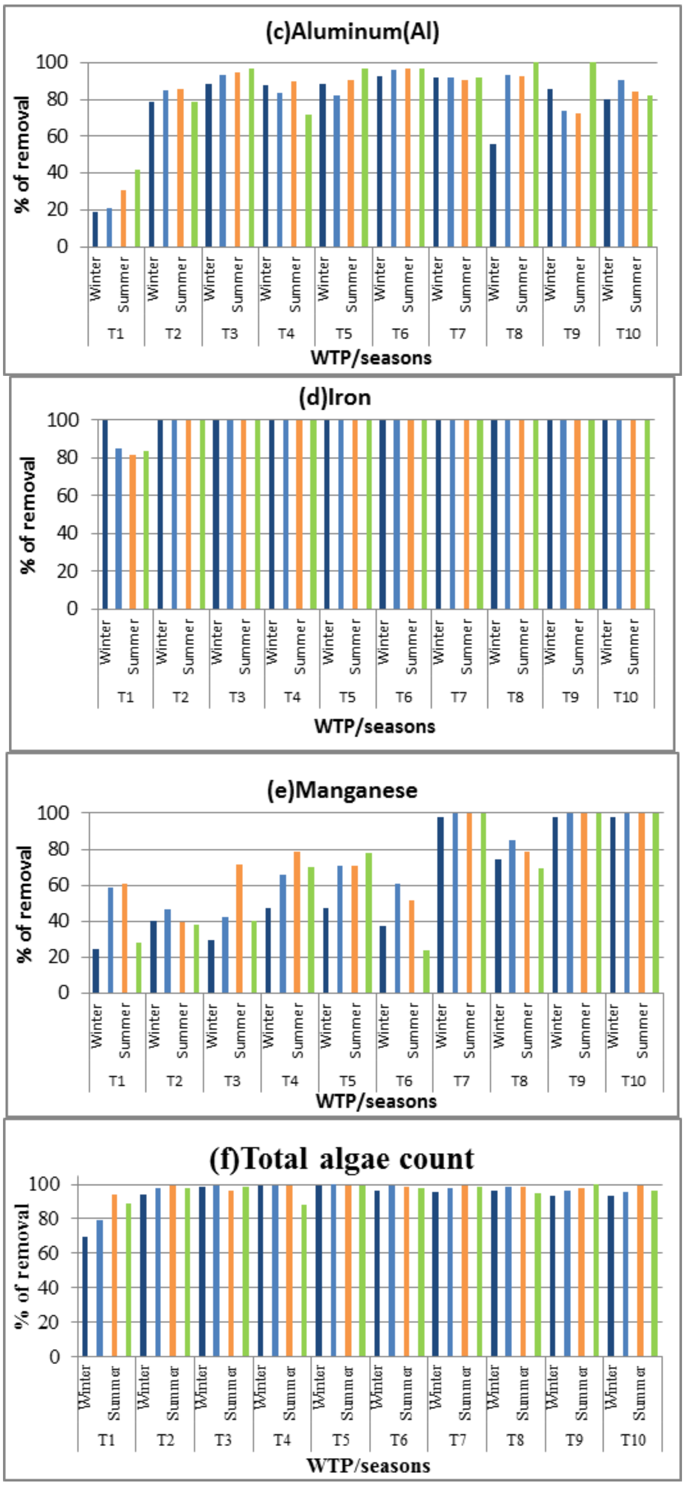



**Fig.4: Removal percent of DWTPs with seasonal variation.**

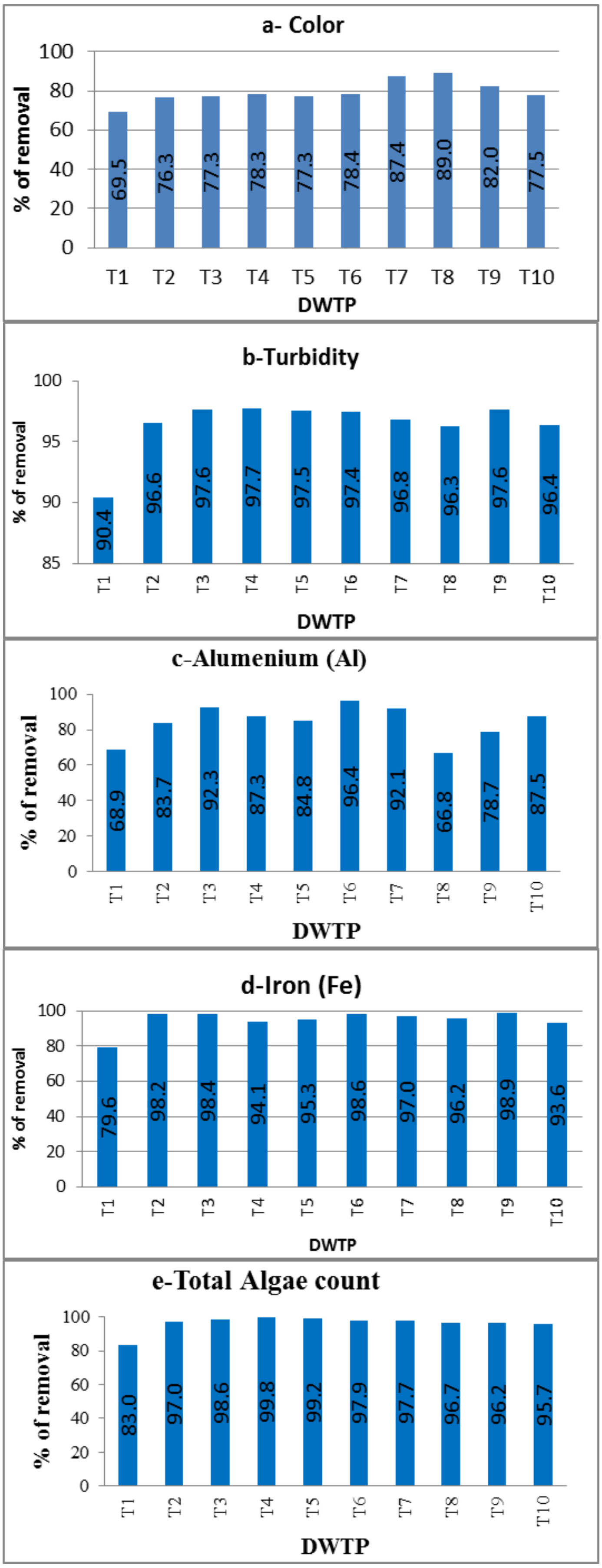



**Fig. 5: parameters that show significant Percent of removal after treatment.**

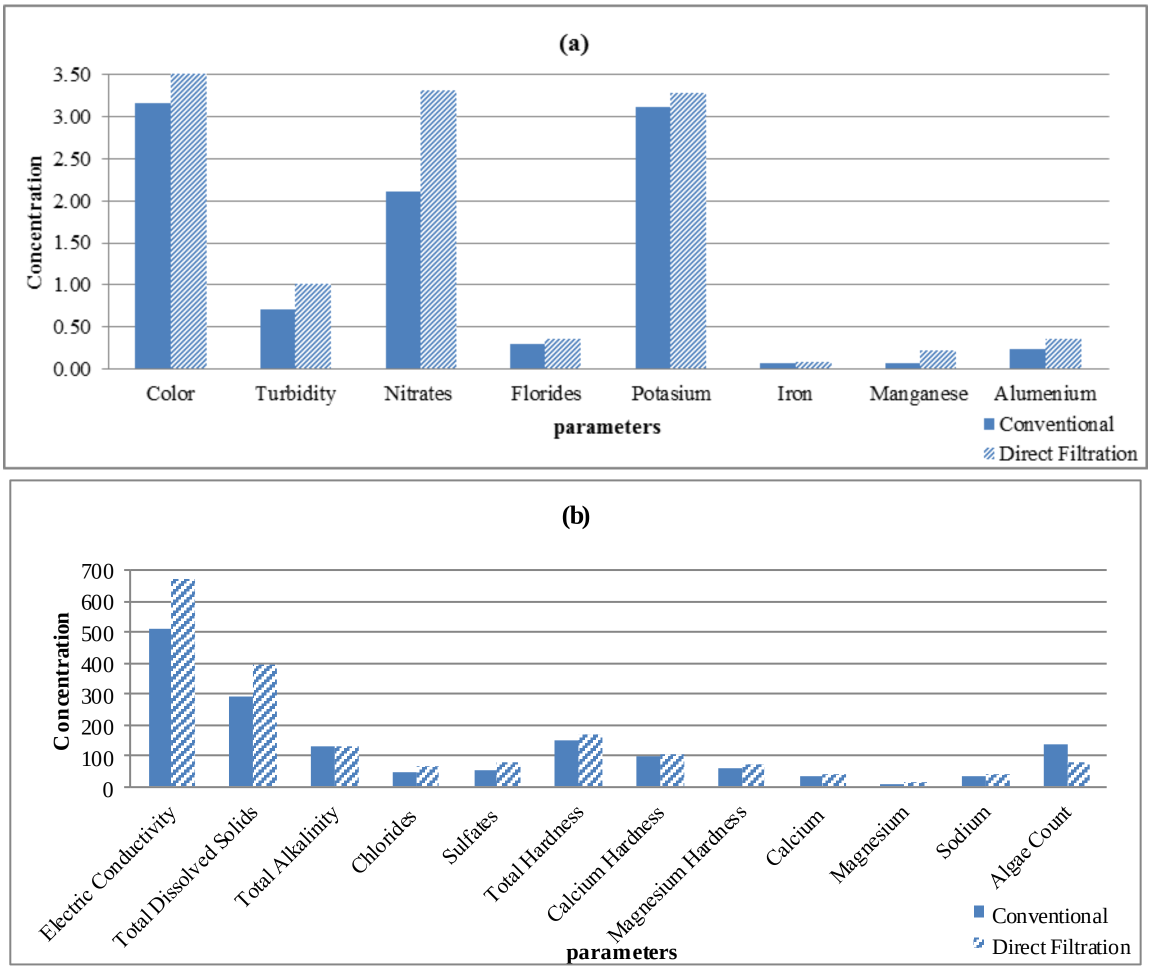
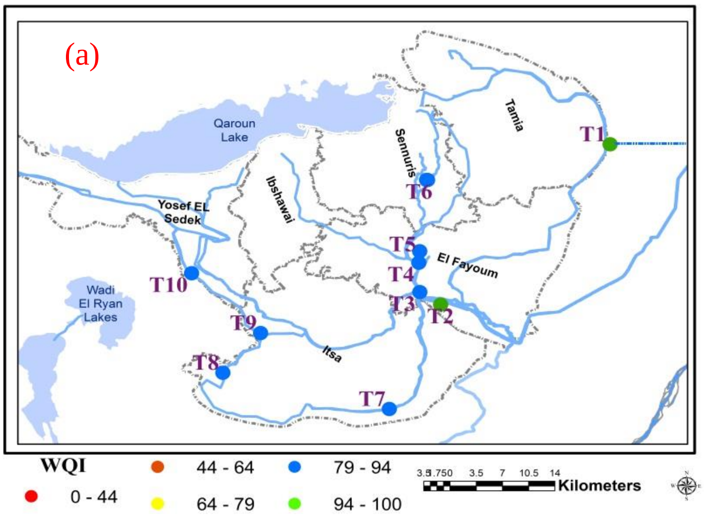



**Fig. 6 (a, b): Comparison between conventional and direct filtration DWTPs.**

### 3.5. Water quality index



(b)

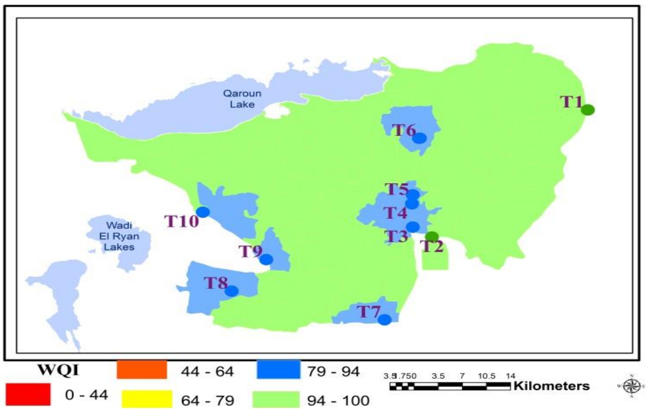



**Fig.7: a) Water quality index map of conventional and direct filtration DWTPs, (b) Water quality index of service area in each DWTP.**

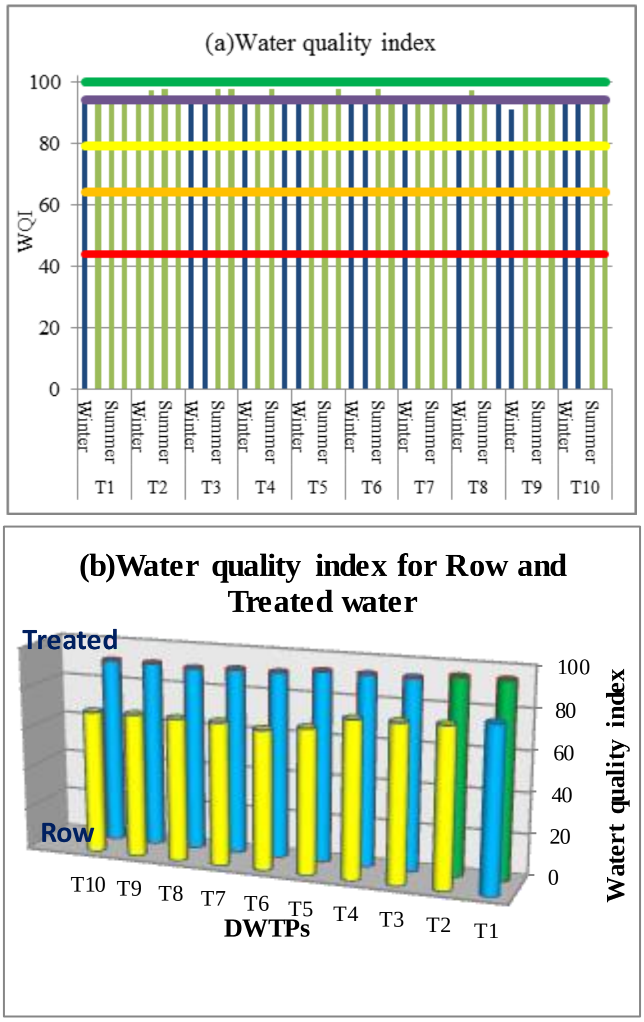



**Fig.8: a) Water quality index with seasonal variation. b) Water quality index chart of treated and raw water.**

**Physico-chemical parameter**

Color

The color intensity of treated water samples ranges from UDL to 15 Pt/Co mg/l for both the conventional and direct filtration DWTPs with an average value 3.16 for conventional DWTPs and 3.63 for direct filtration DWTPs. Water sampled from all DWTPs are under the permissible limit of color (color < 15 Pt/Co mg/l) as seen in Table 4. At seasonal scale, maximum color values of all DWTPs have been noticed in winter season (Fig.3a). Figure 4a reveals higher percent of color removal in winter season, meanwhile Figure 5a shows the maximum percent of total removal (89.0%) at T8 and the minimum percent (69.5%) at T1.

Turbidity

The turbidity values of treated water sampled from the conventional DWTPs ranges from 0.1 to 1.0 NTU with an average value 0.71 NTU, while it ranges from 0.2 to 4.0 NTU for the direct filtration DWTPs with an average value 1.1 NTU. At seasonal scale, minimum turbidity values are recorded in summer season (Fig. 3b). Figure 4b reveals the highest percent of removal of all DWTPs is recorded in summer season. The maximum total percent of removal (97.6%) was recorded at T4 while the minimum removal is recorded at T1 (Fig, 5b). Water samples from all conventional DWTPs are under the permissible limit of turbidity (Turbidity < 1NTU), while samples collected from direct filtration DWTPs don't comply with the permissible limit by 17% especially in winter and spring seasons (Table 4).

Temperature

Temperature of treated water samples ranges from 11.9 to 29.8 °C for the conventional DWTPs and from 14.3 c to 29.0 °C for the direct filtration DWTPs (Table 4). At seasonal scale, minimum temperature values are recorded in winter season and maximum at summer season.

The negative logarithm of hydrogen ion concentration (pH)

pH values of water samples ranges from 7 to 8 for the conventional DWTPs and from 6.8 to 8.5 for the direct filtration DWTPs. pH values of all treated samples are under permissible limit [8.5 <pH> 6.5] throughout the study period (Fig. 3c). The pH values show a remarkable decrease from slightly alkaline in raw water to neutral after clarification and filtration in both conventional and direct filtration outlet water (Table 4).

Electrical conductivity (EC)

The EC of treated water samples ranges from 510 to 1017µS/cm for the conventional DWTPs with an average value 510 µS/cm and from 655 to 1263µS/cm for the direct filtration DWTPs with an average value 667 µS/cm (Table 4). On seasonal scale, maximum EC value is recorded in winter season (Fig. 3d). Results show low percent of removal in all DWTPs.

Total Dissolved Solids (TDS)

The TDS values of treated water samples ranges from 290 to 580 mg/l for the conventional DWTPs with an average value 292 mg/l and from 383 to 986mg/l for the direct filtration DWTPs with an average value 392 mg/l (Table 4). All the detected values are under the permissible limit (TDS< 1000mg/l). The maximum TDS values of all DWTPs are recorded during the winter season (Fig.3e). Results show low percent of removal in all DWTPs.

Total Alkalinity (TA)

The TA values of treated water samples ranges from 127 to 187mg/l for the conventional DWTPs with an average value 127.7 mg/l and from 128 to 201mg/l for the direct filtration DWTPs with an average value 127.9 mg/l (Table 5). At seasonal scale, maximum alkalinity values of all DWTPs are recorded in winter season (Fig. 3f). Alkalinity values in treated water of conventional and direct filtration are effectively lower than that in raw water.

Total Hardness as (Ca $CO_3$), Ca Hardness and Mg Hardness.

The total Hardness values of treated water samples ranges from 150 to 383 mg/l for the conventional DWTPs with an average value 150 mg/l and from 166 to 395 mg/l for the direct filtration DWTPs with an average value 167 mg/l. The Ca hardness values of the conventional DWTPs samples ranges from 13.4 to 147 mg/l with an average value 33 mg/l, and that of the direct filtration DWTPs samples ranges from 15 to 148 mg/l with an average value 39 mg/l. Mg hardness values of the conventional DWTPs samples ranges from 35.6 to 142 mg/l with an average value 62 mg/l and that of the direct filtration DWTPs samples from 2 to 143 mg/l with an average value 72 mg/l. All results are under the permissible limit (Total hardness < 500 mg/l, Calcium Hardness< 350 mg/l, Magnesium Hardness< 150 mg/l) (Table 4). At seasonal scale, maximum TH values at winter season (Fig. 3h. Results show low percent of removal in all DWTPs.

Residual chlorine

Residual chlorine values of treated water samples ranges from 0.5 to 2.4 mg/l for the conventional DWTPs and from 0.2 to 2.5 mg/l for the direct filtration DWTPs (Table 4), which is under permissible limit (R. chlorine < 5 mg/l) for all samples sites.

**Anions parameters**

Chlorides

The Cl values of treated water samples ranges from 44 to 180 mg/l for the conventional DWTPs with an average value 44 mg/l and from 65 to 183 mg/l for the direct filtration DWTPs with an average value 66 mg/l. Treated water shows higher levels of chlorine but still under permissible limit (Cl< 250 mg/l) (Table 5). At seasonal scale, maximum Cl value at winter season (Figure 3g).

Sulfates

The $SO_4$ values of treated water samples ranges from 53 to 150 mg/l for the conventional DWTPs with an average value 55 mg/l and from 75 to 160 mg/l for the direct filtration DWTPs with an average value 77 mg/l. Concentrations increase in treated water in relative to raw water but still under permissible limit ($SO_4$< 250 mg/l) (Table 5). At seasonal scale, maximum of $SO_4$ at winter season (Fig. 3h.

Nitrites as ($NO_2$) and Nitrates as ($NO_3$)

The $NO_2$ values of treated water samples ranges from under detection level of the instrument to 0.06 mg/l for the conventional DWTPs and from under detection level of the instrument to 0.07mg/l for the direct filtration DWTPs. all the results are under permissible limit recommended ($NO_2$ < 0.3 mg/l) (Table 5). $NO_3$ values of treated water samples range from 2.12 to 10.9 mg/l for the conventional DWTPs with an average value 2.11 mg/l and from 3.2 to 23.6 mg/l for the direct filtration DWTPs with an average value 3.3 mg/l. All the results are under permissible limit ($NO_3$ < 45mg/l) (Table 5). On seasonal scale, maximum of $NO_3$ was recorded in the winter season (Fig. 3q). $NO_{3.}$ Results show low percent of removal in all DWTPs.

Florides (F)

The treated water samples have F concentration ranges from 0.3 to 0.78 mg/l for the conventional DWTPs with an average value 0.3 mg/l and from 0.27 to 0.8 mg/l for the direct filtration DWTPs with an average value 0.35 mg/l (Table 5). The F concentration in all water samples are under the permissible limit (F < 0.8 mg/l). The results show low percent of removal in all DWTPs.

**Cations parameter**

Calcium (Ca)

The Ca values of treated water samples ranges from 33.5 to 59.5 mg/l for the conventional DWTPs with an average value 33 mg/l and from 39.3 to 65.3mg/l for the direct filtration DWTPs with an average value 39 mg/l (Table 5). At seasonal scale, maximum Ca value at winter season (Fig. 3j). Results show low percent of removal in all DWTPs.

Magnesium (Mg)

The Mg values of treated water samples ranges from 11.6 to 27.8 mg/l for the conventional DWTPs with an average value 11.3 mg/l and from 14.2 to 37.2 mg/l for the direct filtration DWTPs with an average value 14.1 mg/l (Table 5). At seasonal scale, maximum Mg values at winter season (Fig. 3k). Results show low percent of removal in all DWTPs.

Sodium (Na)

The Na values of treated water samples ranges from 34 to 161mg/l for the conventional DWTPs with an average value 33.7 mg/l and 40 to 162 mg/l for the direct filtration DWTPs with an average value 38.4 mg/l. All results are under permissible limit (Na < 200 mg/l) (Table 5). At seasonal scale, maximum Na values at winter season (Fig. 3l). Results show low percent of removal in all DWTPs.

Potassium (k)

The K values of treated water samples ranges from 4.3 to 11.3mg/l for the conventional DWTPs with an average value 3.12 mg/l and 3.4 to 25.5mg/l for the direct filtration DWTPs with an average value 3.28 mg/l (Table 5). Results show low percent of removal in all DWTPs.

**Metals parameters**

Iron (Fe)

The Fe values of treated water samples ranges from 0.05 to 0.8mg/l for the conventional DWTPs with an average value 0.07 mg/l and from 0.04 to 0.9mg/l for the direct filtration DWTPs with an average value 0.08 mg/l (Table 6). The recorded Fe levels exceed the permissible limit (Fe < 0.3 mg/l) for all DWTPs with percent 2.8% except T1, T2 and T9. Fe results did not show any Seasonal variation (Fig. 3m and Fig. 4d). The maximum total percent of removal (98.9%) was recorded at T9 (Fig. 5d).

Manganese (Mn)

The Mn values of treated water samples ranges from 0.06 to 0.82 mg/l for the conventional DWTPs with an average value 0.07 mg/l and from 0.1 to 1.27mg/l for the direct filtration DWTPs with an average value 0.21 mg/l (Table 7). The both ranges are over the permissible limit recommended in national and international standards (Mn< 0.4 mg/l) for all sampling sites with an average 3.8%. On seasonal scale, maximum Mn was recorded in winter and autumn (Fig. 3n). Figure 4e reveals the lowest percent of removal of all DWTPs in winter season.

Aluminum (Al)

The Al values of treated water samples ranges from ND to 0.99 mg/l for the conventional DWTPs with an average value 0.24 mg/l and from ND to 0.85 mg/l for the direct filtration DWTPs with an average value 0.36 mg/l (Table 6). Such values are over the permissible limit recommended in national and international standards (Al< 0.2mg/l) for all DWTPs with total percent of removal 40.2%. At seasonal scale, maximum Al values in all DWTPs is shown in summer season (Fig. 3o). Figure 4c reveals no seasonality of percent of removal, meanwhile Figure 5c shows maximum total percent of removal (96.4 %) at T6.

Values of all other detected metals such as Cu, Ni, Zn, Pb, Cd, Co, As, Sr, Ba, Ti and V are under detection limit of the instrument.

**Bacteriological Characteristics**

Treated water sampled from the 10 DWTPs is free from total bacteria, coliforms bacteria, fecal coliforms and fecal streptococci (Table 7).

**Total algae count**

Total algae count varies from 232 to 5132 organism/ml at conventional DWTPs samples with an average value 136 organism/ml and from 81 to 818 organism/ ml at direct filtration DWTPs samples with an average value 73 organism/ ml (Table 7). At seasonal scale, maximum algae count in all sampling sites is recorded during the winter season (Fig. 3p). Figure 4f reveals the lowest percent of removal in winter season, while Figure 5f shows maximum total percent of removal (99.8%) at T4.

Average values of all treated water parameters in direct filtration DWTPs are shown to be higher than that recorded at the conventional DWTPs except total algae count.

**Water quality index (WQI)**

WQI calculation shows excellent WQI in the water samples collected from two of the conventional DWTPs (T1 and T2) while the direct filtration DWTPs samples reflect good WQI (Fig. 7a and 7b). Figure 7b shows that most distribution zones of T1 and T2 are provided by excellent water quality. At seasonal scale, minimum WQI is recorded in winter season (Fig. 8a). The WQI of treated water sampled from all DWTPs are effectively higher than that calculated for raw water (Fig. 8b).Highest water quality of raw water was recorded in intake of T1 and T2.

**DISCUSSION**

In the present study, the efficiency of five conventional (T1:T5) and five direct filtration (T6:T10) DWTPs were checked out through the assessment of treated water quality in comparison to their relevant values of raw water. The performance was evaluated in the current study according to compliance with national and international standards of drinking water which represents the main focus of WQI values. The present study proved that drinking water obtained from all DWTPs are free from nitrite-N, bacteria and almost free from algae. Such findings were similar to that reported by **Abdel hamid, 2012[12]** reflecting high removal efficiency of all sampled DWTPs. Obtaining potable water free from nitrite-N and bacteria that maintain potential health hazards **[15,16]** could be explained by the significant role of chlorine **[12,15]** . **Abdel hamid, 2012[12]** Also notified that the physical processes including mixing and aeration in addition to other chemical and biological factors may play additional roles in eliminating nitrite-N from potable water. **AL-**Niaimi **2012** [**17]** observed high percent of removal of algae and turbidity at DWTPs with slow sand filtration witch represent in this study by T4. This could be explained by the effective filtration process due to slow sand filtration and the successful operating system. **Abdel hamid, 2012[12]** reported that under optimum performance of coagulation process, the removal of the rest suspended algae by granular media may reach 99.99%.

Conventional and direct filtration DWTPs showed poor removal efficiency of color, TDS, EC, total hardness, nitrate, F, Ca, Mg, Na and K. On the other side noticeable decrease in pH and alkalinity of treated water was noticed. Similar findings were reported by **Malakootian and Fatehizadeh 2010[23]** for color**; AL-**Niaimi **2012 [17], Abdel hamid, 2012[12] and Fareed 2013 [13]** for turbidity, pH and alkalinity**; AL-Niaimi 2012[17] and Fareed 2013[13]** for TDS; **Fareed 2013[13]** for hardness, Ca and Mg and **Abdel hamid, 2012[12]** for nitrate, Na and K. The exceptional high percent of color removal recorded during winter season could be explained by the temporal increase of the true color level in raw water that cannot be separated by filtration. The noticed decrease of pH and alkalinity in treated water could be explained by the addition of alum that has acidic nature. The recorded poor removal efficiency of TDS and EC indicated the inability of DWTPs to remove their levels completely. The recorded TDS levels in water sampled from the conventional DWTPs are still safe for drinking as supported by **Ranjana et al. 2001[22]**who clarified that gastrointestinal irritation could be induced if drinking water contains more than 500 mg/L TDS. Recommended treatment process for the elevated TDS levels depends on the nature of the cations and anions. If the increased TDS levels are due to Ca, Mg, and Fe; it is advised to use a water softener. If the problem is related to Na, Cl or K; the primary recommendations would include a reverse osmosis system or distillation unit. Although of the poor efficiency of the removal of hardness levels, Ca and Mg decreased in the two types of DWTPs to reach the limit that make treated water ready for domestic use; similar findings were reported by **Fareed 2013[13]. AL-Niaimi 2012[17]** reported that CaO must be added during the treatment process to precipitate the hardness salts as $CaCO_3$ in clarifying baths. Finally the poor removal of nitrate, Na and K could be explained by the deficiency of treatment technology that may remove the three mentioned parameters **[12]**.

The noticed increase in the concentrations of chloride and sulfate in water sampled from all studied DWTPs was also reported by **Hegazy 2012 [1] and Fareed 2013[13]** who explained such increase by the use of aluminum sulfate as coagulant in the flocculation step and the use of chlorine in the oxidation and disinfection process. The levels of the residual chlorine in treated water sampled from all DWTPs contain ideal dose of residual chlorine ranged from 0.2: 2.5 mg/l. **Cem Koc 2010 [18]**reported that the ideal residual concentration of chlorine ranges from 0.2 to 0.5 mg/l. **WHO 2011[15] reported that the concentrate of the free residual chlorine shouldn't exceed** 5 mg/l. TDS, total alkalinity, total hardness, nitrate, chlorides, sulfates, Fe and Mn showed their maximum values during winter season similar to the findings of **Geriesh et al. 2008[20]**and **Shamrukh and Abdel-Wahab 2011[19]**for nitrate this could be related to the increase of such parameters in raw water because of the low water flow and the inflow of wastewater discharge which confirm the decrease of water quality index in such season. Similar to what has been mentioned by **Fareed 2013[13],** summer season was characterized by the lowest values of turbidity and highest values of aluminum. This could be explained by the increase of turbidity in water intake during summer season and the consequent usage of alum that causes a remarkable increase of aluminum in such season with higher removal of turbidity. Temperature values reveal high seasonality and this could be explained by the positive correlation between air and water temperatures. This indicates that the water temperature is affected only by the ambient air temperature reflect the absence of any reason for thermal water pollution **[10].** Shortly, The observed better efficiency of the conventional treatment could be related to the combined processes of coagulation, flocculation, sedimentation and filtration that are highly effective in removing suspended organic and inorganic matters from water and eliminating waterborne diseases such as cholera and typhoid as mentioned by **WHO 2004[4]**. The exception of algae count increase in treated water sampled from the conventional DWTPs could be explained by the relative increase of algae count in the conventional DWTPs intake compared to that of direct filtration DWTPs intake.

To evaluate the performance of DWTPs, all results of treated water were compared to permissible limits (PL) of drinking water in Egypt as mentioned in the Egyptian law and decision of the Ministry of Health no 458/2007, such limits are identical to the international standard of world health organization **[15].**

Poor performance of DWTPs has been noticed in eliminating turbidity, Al, Fe and Mn that showed levels above the PL. The detected levels of turbidity exceeded the PL in only direct filtration DWTPs, while levels of Al, Fe and Mn exceeded the PL in all DWTPs except T1 and T2 of conventional DWTPs and T9 of direct filtration DWTPs for Fe levels. Similar findings were reported by **Donia 2007[11]; Hegazy 2012[1] and AL-Niaimi 2012 [17] for** turbidity and **Schutte 2006[4]; Donia 2007[11] and Fareed 2013[13] for** Al, Fe and Mn. The noticed increase of turbidity in direct filtration DWTPs could be explained by its high values in raw water intake which induced a load on the filtration process used to remove turbidity. This necessitates the need of back washing of filters regularly to remove the accumulated flocs in order to restore the filtering capacity of the sand as suggested **by Hegazy 2012[1].** The increased turbidity in raw water enhances the coagulation process by increasing the weight of formed flocs that speeds up the process of sedimentation, and this may explain the increase of the removal of turbidity in direct filtration DWTPs in relative to T1in conventional DWTPs.

With the increased turbidity, alum sulphate is used in high concentration and this may explain the recorded increase of Al in all DWTPs. Al as a harmful neurotoxic metal that may induce Alzheimer's disease must be allowed to precipitate completely as Al hydroxide **[4]**. The recorded increase of Fe and Mn could be related to their increased levels in raw water that limit the ability of DWTPs to remove completely these elements by traditional treatment and chemical dose **[21]**. This is also supported by the fact that conventional and direct filtration DWTPs are designed to remove certain levels as mentioned in the European 1975 Surface Water Directive/1989 Regulations. With respect to Fe remarkable increase in its level was detected in water sampled from all the conventional DWTPs except T1 and T2 and from all direct filtration DWTPs except T9, A short term solution to increase the removal of Fe and Mn when high concentrations are in water intake is to increase the dose of chlorine and contact time to oxidize the detected metals to ferric hydroxide and manganese dioxide as supported by **Fareed, 2013[13].** As a long term solution aeration system can be modified to oxidase Fe, Mn after sedimentation and convert them to non-soluble form that can removed by filtration process**.** Finally It worth to mention that turbidity, Fe and Mn don't have health impact except at higher levels of Mn that has not been recorded in this study **[4]**.

WQI is highly correlated with the physico-chemical and bacteriological results. It represents a value of water quality with respect to compliance with national and international standards to produce healthy water without any health impact and also according to frequency of noncompliance **[14].** WQI values of the current study proved excellent quality of the water produced from conventional DWTPs especially T1 and T2 when compared to good quality of water produced from other conventional treatment plants (T3:T5) and all direct filtration DWTPs, this could be explained by the good quality of water intake. WQI values for the first record in El Fayoum governorate reflected that 70% of the governorate is provided with excellent water quality that is safe for human consumption, the rest 30% provided with good water quality that is suitable for human consumption.

## CONCLUSION

The selected water treatment plants provide nontoxic potable water with properties largely coping with the standard guidelines of drinking water. Factors that can result in poor treatment efficiency include variable plant flow rates, degree of raw water intake contamination, improper dose of coagulant, poor process control with little monitoring, inappropriate mixing of chemicals, poor mixing of chemicals with water during flocculation and inadequate sludge removal. In concise and precise words, the results of chemical analysis indicated high overall performance of the investigated DWTPs that resulted in obvious improvement of physicochemical, chemical and biological of the finally treated drinking water. Also it may be concluded that the deviation and variations of results are related mostly to maintenance and operation problems rather than design and construction shortage and this appear in small variation in water quality in some conventional and direct filtration DWTPs.

## RECOMMENDATIONS

Good water quality from all studied DWTPs could be attained by a good operation, maintenance, spare parts storage and control of added dose of treatment chemicals, including alum and chlorine. Under the normal conditions, the conventional plant is the most appropriate alternative at the least cost at large communities. Also, at large communities, the compact plant is more operational expensive alternative and its usage should be limited to solve the need for drinking water in villages and small communities, taking into consideration its low spacing, low capital costs and ease of operation. Use aeration system before filtration process to remove Fe and Mn through oxidation by air and precipitation. Direct filtration DWTPs depends mainly on low turbidity of the raw inlet water throughout the year, so it is possible to stop the addition of coagulant in the inlet because there is no time for the floc to be formed. Affording qualified trainees to operate and to support the maintenance of direct filtration DWTPs.

## 7. ACKNOWLEDGEMENT

We thank all staff members working at Water quality and Environmental Affairs department, Holding Company for Water and Wastewater (HCWW) and Water Quality Central Laboratory, El Fayoum, Egypt for their technical support and invaluable help during samples collection and analysis. We thank our anonymous reviewers for their helpful input to improve the paper.

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