ZIBELINE INTERNATIONAL PUBLISHING

ISSN: 2523-5664 (Print)
ISSN: 2523-5672 (Online)
CODEN: WCMABD

Water Conservation And Management (WCM)

DOI: http://doi.org/10.26480/wcm.02.2020.90.98

WATER CONSERVATION AND MANAGEMENT (WCM)

CrossMark

RESEARCH ARTICLE

PHYSICOCHEMICAL AND BIOLOGICAL PARAMETERS OF WATER AT INDUSTRIAL SITES OF METROPOLITAN CITY OF CHENNAI, TAMIL NADU, INDIA

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ARTICLE DETAILS

Article History:

Received 31 May 2020
Accepted 01 July 2020
Available online 10 July 2020

ABSTRACT

Water is essential to sustain life, and an adequate, safe and accessible supply must be available to all as improving access to safe drinking water can result in tangible benefits to health. In the present study, eighteen water samples from six different study area, *viz*., Red Hills, T. Nagar, Saidapet, Ashok Nagar, Alandur and Guindy of metropolitan Chennai were tested for their physicochemical and biological parameters, of which Red Hills served as control area. Results with regard to the physical parameters, showed no variation in the colour of water samples which was clear except for control as it appeared light brown. The odour of samples collected from all six study areas was observed to be constant and agreeable. The water temperature, turbidity, electrical conductivity and total dissolved solids for all six study areas ranged from 28.7 to 29.7°C, 3.7 to 11.7NTU, 723.3 to 1099.7µS/cm, and 396.7 to 805.0mg/L. The values of chemical parameters represented by pH, total hardness, total alkalinity, sulphates and flourides ranged from 7.7 to 8.0, 128.0 to 503.3mg/L, 13.3 to 50.0mg/L, 106.6 to 224.0mg/L, and 0.6 and 1.5mg/L. All the samples were found to be free from coliforms except for the control in the case of biological parameters. Overall results indicate that the physical and chemical parameters were found to be within the permissible limits set by standards and biological contamination was absent in the samples except in control which is a natural reservoir.

KEYWORDS

Physical, chemical, biological, water, Chennai.

1. INTRODUCTION

"Water is life" considered as one of the most important and abundant composites of the ecosystem is essential for all living organisms on the earth for their survival and growth. Increased human population, industrialization, use of fertilizers in the agriculture and anthropogenic activity have highly polluted the aquatic environment with different harmful contaminants. The availability of good quality water is an indispensable feature for improving quality of life. Natural water contains different types of impurities and are introduced into aquatic system by different ways such as weathering of rocks and leaching of soils, dissolution of aerosol particles from the atmosphere and from several human activities, including mining, processing and the use of metal based materials (Adeyeye, 1994).

The increased use of metal-based fertilizer in agriculture could result in continued rise in concentration of metal pollutions in fresh water reservoir due to the water run-off. Also, faecal pollution of drinking water causes water-borne diseases which has led to the death of millions of people (Basavaraja et al., 2011). Thus, the quality of natural water sources used for different purposes should be established in terms of the specific water-quality parameters that affect the possible use of water. Therefore, water is to be tested before it is used for drinking, domestic, agricultural or industrial purpose and its quality are determined by its physical, chemical and microbiological properties (Kazi et al., 2009). Hence, selection of parameters for testing of water solely depends upon for what purpose water is going to be used and to what extent it need its quality and purity (Patil et al., 2012).

Chennai being a metropolitan city is undergoing rapid industrialization and urbanization leading to the degradation of the drinking water quality. Consequently, it is necessary that the quality of water should be checked at regular time interval, because, due to use of contaminated drinking water, human population suffer from water-borne diseases. Therefore, in view of the above knowledge, the current study was planned to analyse the quality of water samples from six different locations (industrial area) in Chennai, Tamil Nadu, India, *viz*., Red Hills lake, T. Nagar, Saidapet, Ashok Nagar, Alandur and Guindy for physicochemical and biological characteristics with reference to the standard permissible limits of water quality.

Quick Response Code	Access this article online	
	Website: www.watconman.org	**DOI:** 10.26480/wcm.02.2020.90.98

Cite the Article: Murugesan Sakthivadivel, Arunachalam Nirmala, Jeyabharathi Sakthivadivel, Rajaratnam Rajiv Mukhilan, Samuel Tennyson (2020). Physicochemical And Biological Parameters of Water At Industrial Sites of Metropolitan City of Chennai, Tamil Nadu, India. *Water Conservation And Management, 4(2): 90-98.*

2. Materials and Methods

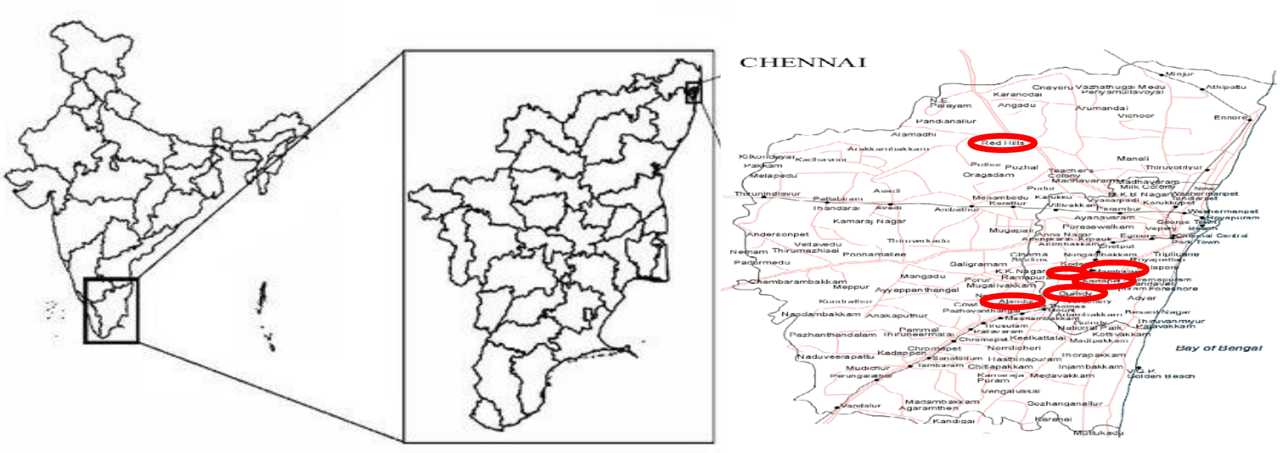

Figure 1: Sampling spots of the study area

Underground water is the only source of water for the industrial areas of Chennai. The groundwater quality of this region is continuously degrading due to industrial activities and the soils of the nearby fields are also being affected. Potable water samples from Red Hills Lake, T. Nagar, Saidapet, Ashok Nagar, Alandur and Guindy (Figure 1) were analysed for their physicochemical (physical: colour odour, temperature, electrical conductivity, turbidity, pH total dissolved solids; and chemical: total hardness, total alkalinity, sulphates, fluorides) and biological (coliforms) properties. Amongst, these six study areas, Red Hills served as control. Sampling procedures for water samples were followed according to Bureau of Indian Standard (BIS) and three samples from each location was done.

Water samples were collected from August 2014 to March 2015 in high-density polyethylene 'Tarson' brand bottles after 2-3 times rinsing with the sample. While for bacteriological analysis, samples were taken in sterilized Tarson bottles covered with aluminium foils. Colour odour, temperature, parameters were analyzed on site while for other parameters, water samples were brought to the laboratory at 4°C in a sampling box. All the chemicals and reagents were of analytical grade, purchased from Merck, India. Analytical grade water from Millipore water purification system (Make: Millipore, USA; Model: Elix and Synergy) was used for the preparation of all standards and solutions.

Table 1: Procedure for water quality parameters and permissible limits for each parameter set by standards

Parameter for analysis	Unit	Method	WHO	ISI	USEPA	ICMR	CPCB
Physical							
Colour	Hazen	Visual comparison	-	5	-	-	-
Odour	-	Physiological sense	Acceptable	Acceptable	-	Acceptable	Acceptable
Temperature	°C	Mercury-in-glass thermometer	-	-	-	-	-
Electrical conductivity	µS/cm	Conductivity meter-Extech EC 150	-	-	-	-	2000
Turbidity	NTU	Nephelometric turbidity meter	<5	10	-	25	10
Total dissolved solids	mg/L	Ion selective	500	500-1500	-	500	-
Chemical							
pH	-	Systronic digital pH meter	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5
Total hardness	mg/L	EDTA titration	500	300	-	600	600
Total alkalinity		Acid titration	120	200	200	-	600
Sulphates		Nephelometer and Turbidimeter	250	200	250	400	400
Fluorides		SPADNS spectrophotometer	1.5	0.6-1.2	4.0	1.5	1.5
Biological							
Coliforms	CFUs·cm^{-3}	Multiple tube fermentation technique	10	-	-	-	-

The description of procedures of water quality parameters to be analysed and compared with the standard permissible limits of water quality are tabulated and presented in Table 1 (ICMR, 1975; EPA, 1976; WHO, 1989; ISI, 1991). Statistical analysis of all data were subjected to 't' test, One Way Analysis of Variance (ANOVA), Multi Comparison Tukey HSD test, Correlation and Chi square analysis, and the differences were considered as highly significant, significant and insignificant at $P<0.001$, $P<0.05$ and $P>0.05$ level respectively. All statistics was conducted in IBM SPSS Statistics v22 with significance set at 95% confidence (SPSS, 2010).

3. Results

The results of the physicochemical and biological parameters of water quality of the study areas in Chennai are given below. The values are given for each parameter are in the order for Red Hills, T. Nagar, Saidapet, Ashok Nagar, Alandur and Guindy respectively.

3.1 Physical parameters

3.1.1 Colour

All samples were found to be clear and colourless except for the control which had light brown appearance. Chi square analysis revealed a highly significant difference between the control and samples at $P=0.001$ level (Table 2).

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Table 2: Colour parameter of water at the study area					
Study area	**Particulars**	**Colour**		**Total**	**Chi square test (*P* value)**
		Brown	**Colourless**		
Red Hills (Control)	Count	3	0	3	0.003**
	% within area	100.00	0	100	
	% within colour	100.00	0	16.7	
T. Nagar	Count	0	3	3	
	% within area	0	100	100	
	% within colour	0	20	16.7	
Saidapet	Count	0	3	3	
	% within area	0	100	100	
	% within colour	0	20	16.7	
Ashok Nagar	Count	0	3	3	
	% within area	0	100	100	
	% within colour	0	20	16.7	
Alandur	Count	0	3	3	
	% within area	0	100	100	
	% within colour	0	20	16.7	
Guindy	Count	0	3	3	
	% within area	0	100	100	
	% within colour	0	20	16.7	
Total	Count	3	15	18	
	% within area	16.7	83.3	100	
	% within colour	100	100	100	

**P value between 0.000 and 0.010 implies high significance at 1% level

3.1.2 Odour

All the 18 samples were found to be odourless and statistical analysis revealed that odour was a constant parameter (Table 3).

Table 3: Odour parameter of water at the study area				
Study area	**Particulars**	**Odour**	**Total**	**Chi square test (*P* value)**
		Odourless		
Red Hills (Control)	Count	3	3	NA
	% within area	100	100	
	% within odour	16.7	16.7	
T. Nagar	Count	3	3	
	% within area	100	100	
	% within odour	16.7	16.7	
Saidapet	Count	3	3	
	% within area	100	100	
	% within odour	16.7	16.7	
Ashok Nagar	Count	3	3	
	% within area	100	100	
	% within odour	16.7	16.7	
Alandur	Count	3	3	
	% within area	100	100	
	% within odour	16.7	16.7	
Guindy	Count	3	3	
	% within area	100	100	
	% within odour	16.7	16.7	
Total	Count	18	18	
	% within area	100	100	
	% within odour	16.7	16.7	

3.1.3 Temperature

The values were 29.7, 28.7, 29.0, 29.0, 29.3 and 28.7°C respectively (Figure 2). The t test, One Way ANOVA and Multiple Comparison Tukey HSD test did not show any significant difference between the samples and the control (Table 4-6).

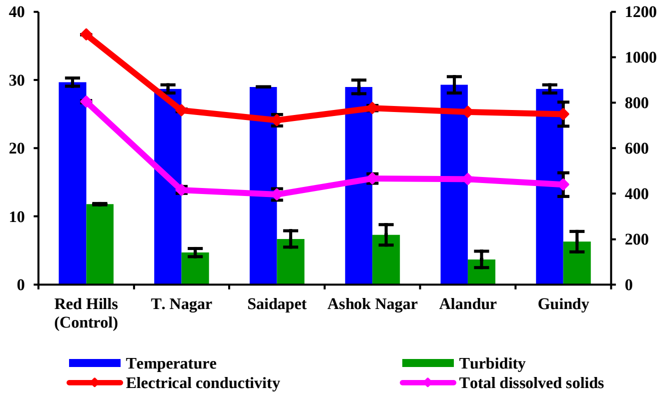

Figure 2: Physical parameters of water at the study area

Table 4: t test for physical parameters of water at the study area

Study area	Temperature		Electrical conductivity		Turbidity		Total dissolved solids	
	t value	*P* value	t value	*P* value	t value	*P* value	t value	*P* value
Red Hills (Control)	-	-	-	-	-	-	-	-
T. Nagar	2.121	0.101	99.404	0.000**	21.194	0.000**	41.848	0.000**
Saidapet	2.000	0.116	25.894	0.000**	7.640	0.002**	27.565	0.000**
Ashok Nagar	1.000	0.374	48.390	0.000**	5.023	0.007**	27.373	0.000**
Alandur	0.447	0.678	58.734	0.000**	12.135	0.000**	77.483	0.000**
Guindy	2.121	0.101	11.445	0.000**	6.156	0.004**	12.111	0.000**

**P value between 0.000 and 0.010 implies high significance at 1% level
*P value between 0.011 and 0.050 implies significance at 5% level
-P value between 0.051 and 1.00 implies insignificance at 5% level

Table 5: One Way ANOVA for physical parameters of water at the study area

Study area	Temperature		Electrical conductivity		Turbidity		Total dissolved solids	
	F value	*P* value	F value	*P* value	F value	*P* value	F value	*P* value
Red Hills (Control)	0.820	0.558	97.738	0.000**	18.556	0.000**	103.503	0.000**
T. Nagar	0.820	0.558	97.738	0.000**	18.556	0.000**	103.503	0.000**
Saidapet	0.820	0.558	97.738	0.000**	18.556	0.000**	103.503	0.000**
Ashok Nagar	0.820	0.558	97.738	0.000**	18.556	0.000**	103.503	0.000**
Alandur	0.820	0.558	97.738	0.000**	18.556	0.000**	103.503	0.000**
Guindy	0.820	0.558	97.738	0.000**	18.556	0.000**	103.503	0.000**

**P value between 0.000 and 0.010 implies high significance at 1% level

3.1.4 Electrical conductivity

The mean values of electrical conductivity were 1099.7, 766.7, 723.3, 776.7, 760.0 and 750.00 µS/cm respectively (Figure 2). The t test and One-Way ANOVA showed a highly significant difference at P<0.001 in all the samples when compared with the control (Table 4 and 5). Multiple Comparison Tukey HSD test showed a highly significant difference at P<0.001 when compared with control; but the samples showed a significant difference within themselves at P>0.05 (Table 6).

Table 6: Multiple Comparison Tukey HSD test for physical parameters of water at the study area

Study area	Sample	*P* value			
		Temperature	Electrical conductivity	Turbidity	Total dissolved solids
Red Hills (Control)	T. Nagar	0.589	0.000**	0.000**	0.000**
	Saidpet	0.874	0.000**	0.001**	0.000**
	Ashok Nagar	0.874	0.000**	0.004**	0.000**
	Alandur	0.993	0.000**	0.000**	0.000**
	Guindy	0.589	0.000**	0.001**	0.000**
T. Nagar	Red Hills (Control)	0.589	0.000**	0.000**	0.000**
	Saidpet	0.993	0.332	0.319	0.928
	Ashok Nagar	0.993	0.996	0.108	0.246
	Alandur	0.874	0.999	0.879	0.306
	Guindy	1.000	0.958	0.497	0.873
Saidapet	Red Hills (Control)	0.874	0.000**	0.001**	0.000**
	T. Nagar	0.993	0.332	0.319	0.928
	Ashok Nagar	1.000	0.163	0.975	0.056
	Alandur	0.993	0.496	0.060	0.072
	Guindy	0.993	0.772	0.999	0.376
Ashok Nagar	Red Hills (Control)	0.874	0.000**	0.004**	0.000**
	T. Nagar	0.993	0.996	0.108	0.246
	Saidapet	1.000	0.163	0.975	0.056
	Alandur	0.993	0.958	0.018*	1.000
	Guindy	0.993	0.772	0.879	0.802
Alandur	Red Hills (Control)	0.993	0.000**	0.000**	0.000**
	T. Nagar	0.874	0.999	0.879	0.306
	Saidapet	0.993	0.496	0.060	0.072
	Ashok Nagar	0.993	0.958	0.018*	1.000
	Guindy	0.874	0.996	0.108	0.873
Guindy	Red Hills (Control)	0.589	0.000**	0.001**	0.000**
	T. Nagar	1.000	0.958	0.497	0.873
	Saidapet	0.993	0.772	0.999	0.376
	Ashok Nagar	0.993	0.772	0.879	0.802
	Alandur	0.874	0.996	0.108	0.873

**P value between 0.000 and 0.010 implies high significance at 1% level

3.1.5 Turbidity

Turbidity values were 11.8, 4.7, 6.7, 7.3, 3.7 and 6.3 NTU respectively (Figure 2). The t test and One-Way ANOVA showed a highly significant difference at P<0.001 in all samples when compared with control (Table 4 and 5). Multiple Comparison Tukey HSD test for all samples also showed a highly significant difference at P<0.001 when compared with control; but within themselves showed a significant difference at P>0.05 except for Ashok Nagar which showed a significant difference at P<0.05 when compared with Alandur (Table 6).

3.1.6 Total dissolved solids

The mean values for total dissolved solids were 805.0, 416.7, 396.7, 466.7, 463.3 and 440.0 mg/L (Figure 2). The t test and One-way ANOVA showed a significant difference in all the samples when compared with the control at *P*<0.001 (Table 4 and 5). Multi comparison Tukey HSD test also showed a highly significant difference at *P*<0.001 level when compared with control; but did not exhibit any significant difference when compared among themselves at *P*>0.05 level (Table 6).

3.2 Chemical parameters

3.2.1 pH

The pH values were 8.2, 7.7, 7.8, 8.0, 7.7 and 7.8 respectively (Figure 3). The t test showed an insignificant difference in Ashok Nagar and Alandur samples when compared with control, whereas the T. Nagar and Saidapet samples exhibited a highly significant difference at *P*<0.001 (Table 7). The F test showed an insignificant difference between all samples at *P*>0.05 (Table 8). Multiple Comparison Tukey HSD test also showed an insignificant difference except for the sample collected from Guindy at *P*>0.05 when compared to the control (Table 9).

Table 7: t test for chemical parameters of water at the study area

Study area	pH		Total hardness		Total alkalinity		Sulphates		Fluorides	
	t value	*P* value	t value	*P* value	t value	*P* value	t value	*P* value	t value	*P* value
Red Hills (Control)	-	-	-	-	-	-	-	-	-	-
T. Nagar	3.377	0.028*	0.227	0.831	9.449	0.001**	6.789	0.002**	12.075	0.000**
Saidapet	4.598	0.010**	14.064	0.000**	9.449	0.001**	17.342	0.000**	8.497	0.001**
Ashok Nagar	2.589	0.061	6.440	0.003**	10.394	0.000**	8.695	0.001**	21.920	0.000**
Alandur	1.843	0.139	-0.872	0.432	9.449	0.001**	81.406	0.000**	13.435	0.000**
Guindy	4.278	0.013*	-1.044	0.355	25.981	0.000**	81.406	0.000**	13.435	0.000**

***P* value between 0.000 and 0.010 implies high significance at 1% level
*P value between 0.011 and 0.050 implies significance at 5% level
-P value between 0.051 and 1.00 implies no significance at 5% level

Table 8: One Way ANOVA for chemical parameters of water at the study area

Study area	pH		Total hardness		Total alkalinity		Sulphates		Fluorides	
	F value	*P* value	F value	*P* value	F value	*P* value	F value	*P* value	F value	*P* value
Red Hills (Control)	3.032	0.054	3.935	0.024*	24.854	0.000**	29.460	0.000**	56.883	0.000**
T. Nagar	3.032	0.054	3.935	0.024*	24.854	0.000**	29.460	0.000**	56.883	0.000**
Saidapet	3.032	0.054	3.935	0.024*	24.854	0.000**	29.460	0.000**	56.883	0.000**
Ashok Nagar	3.032	0.054	3.935	0.024*	24.854	0.000**	29.460	0.000**	56.883	0.000**
Alandur	3.032	0.054	3.935	0.024*	24.854	0.000**	29.460	0.000**	56.883	0.000**
Guindy	3.032	0.054	3.935	0.024*	24.854	0.000**	29.460	0.000**	56.883	0.000**

***P* value between 0.000 and 0.010 implies significance at 1% level
**P* value between 0.011 and 0.050 implies significance at 5% level

Table 9: Multiple Comparison Tukey HSD test for chemical parameters of water at the study area

Study area	Sample	*P* value				
		pH	Total hardness	Total alkalinity	Sulphates	Flourides
Red Hills (Control)	T. Nagar	0.153	1.000	0.000**	0.000**	0.000**
	Saidpet	0.511	0.268	0.000**	0.000**	0.000**
	Ashok Nagar	0.942	0.493	0.000**	0.000**	0.000**
	Alandur	0.260	0.991	0.000**	0.000**	0.000**
	Guindy	0.048*	0.749	0.000**	0.000**	0.000**
T. Nagar	Red Hills (Control)	0.153	1.000	0.000**	0.000**	0.000**
	Saidpet	0.942	0.350	1.000	0.818	0.017*
	Ashok Nagar	0.511	0.605	0.951	0.215	0.395
	Alandur	0.999	0.966	1.000	0.935	0.017*
	Guindy	0.977	0.638	0.951	0.935	0.017*
Saidapet	Red Hills (Control)	0.511	0.268	0.000**	0.000**	0.000**
	T. Nagar	0.942	0.350	1.000	0.818	0.017*
	Ashok Nagar	0.942	0.996	0.951	0.030*	0.001**
	Alandur	0.994	0.111	1.000	0.331	1.000
	Guindy	0.613	0.031*	0.951	0.331	1.000
Ashok Nagar	Red Hills (Control)	0.942	0.493	0.000**	0.000**	0.000**
	T. Nagar	0.511	0.605	0.951	0.215	0.395
	Saidapet	0.942	0.996	0.951	0.030*	0.001**
	Alandur	0.714	0.232	0.951	0.655	0.001**
	Guindy	0.201	0.068	0.552	0.655	0.001**
Alandur	Red Hills (Control)	0.260	0.991	0.000**	0.000**	0.000**
	T. Nagar	0.999	0.966	1.000	0.935	0.017*
	Saidapet	0.994	0.111	1.000	0.331	1.000
	Ashok Nagar	0.714	0.232	0.951	0.655	0.001**
	Guindy	0.885	0.966	0.951	1.000	1.000
Guindy	Red Hills (Control)	0.048*	0.749	0.000**	0.000**	0.000**
	T. Nagar	0.977	0.638	0.951	0.935	0.017*
	Saidapet	0.613	0.031*	0.951	0.331	1.000
	Ashok Nagar	0.201	0.068	0.552	0.655	0.001**
	Alandur	0.885	0.966	0.951	1.000	1.000

**P value between 0.000 and 0.010 implies high significance at 1% level
*P value between 0.011 and 0.050 implies significance at 5% level
-P value between 0.051 and 1.00 implies insignificance at 5% level

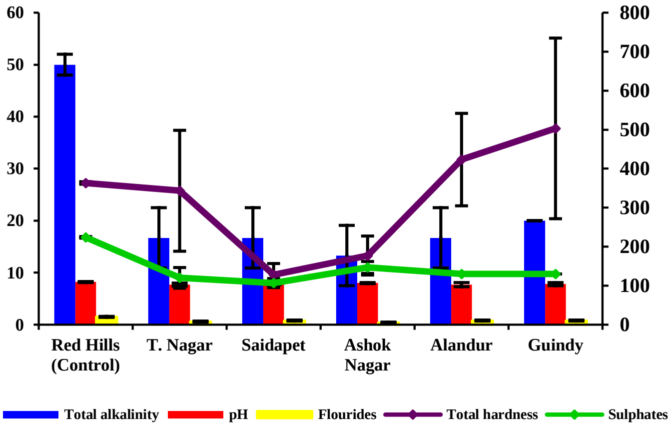

Figure 3: Chemical parameters of water at the study area

3.2.2 Total hardness

The values of total hardness were 363.7, 343.3, 128.0, 177.3, 423.3 and 503.3 mg/L respectively (Figure 3). The t test showed a highly significant difference in the samples collected from Saidapet and Ashok Nagar at *P*<0.001, while other samples showed an insignificant difference at *P*>0.05 when compared with control (Table 7). One Way ANOVA also showed a significant difference at *P*<0.05 (Table 8). Multiple Comparison Tukey HSD test of the water samples collected from different areas did not show any significant difference at *P*>0.05 except for Saidapet which showed a significant difference at *P*<0.05 when compared with Guindy (Table 9).

3.2.3 Total alkalinity

Total alkalinity values were 50.0, 16.7, 16.7, 13.3, 16.7 and 20.0 mg/L respectively (Figure 3). The t test and F test showed a highly significant difference in all the samples when compared with the control at *P*<0.001 (Table 7 and 8). Multiple Comparison Tukey HSD test showed a highly significant difference at *P*<0.001 when compared with control; but showed an insignificant difference when compared among themselves at *P*>0.05 (Table 9).

3.2.4 Sulphates

The respective mean values for sulphates were 224.0, 120.7, 106.7, 146.7, 130.0 and 130.0 mg/L (Figure 3). The t test and F test showed a highly significant difference in all the samples when compared with control at *P*<0.001 (Table 7 and 8). Multiple Comparison Tukey HSD test showed a highly significant difference at *P*<0.001 when compared with control; but Saidapet showed a significant difference at *P*<0.05 when compared with Ashok Nagar (Table 9).

3.2.5 Fluorides

The respective mean values for fluorides were 1.5, 0.6, 0.8, 0.4, 0.8 and 0.8 mg/L (Figure 3). The t and F tests showed a highly significant difference in all the samples when compared with the control at *P*<0.001 (Table 7 and 8). Multiple Comparison Tukey HSD test showed a highly significant difference at *P*<0.001 when compared with control. Also a significant difference at *P*<0.05 was observed in the samples from Saidapet, Alandur and Guindy when compared with T. Nagar. A significant difference at *P*<0.05 was also observed in the sample from Alandur when compared with Saidapet (Table 9).

Correlation coefficients between physicochemical parameters in the study area based on Spearman's correlation indicated significant and high positive correlation (r≥0.60) (Table 10).

Table 10: Correlation matrix of physicochemical parameters in study area

Parameters	Temperature	Electrical conductivity	Turbidity	Total dissolved solids	pH	Total hardness	Total alkalinity	Sulphates	Flourides
Temperature	1								
Electrical conductivity	0.801	1							
Turbidity	0.626	0.861	1						
Total dissolved solids	0.841	0.992	0.855	1					
pH	0.672	0.842	0.955	0.853	1				
Total hardness	-0.006	0.163	-0.145	0.191	-0.176	1			
Total alkalinity	0.762	0.970	0.851	0.963	0.770	0.245	1		
Sulphates	0.794	0.974	0.859	0.985	0.893	0.188	0.918	1	
Flourides	0.764	0.853	0.714	0.859	0.584	0.308	0.944	0.770	1

Values in bold denote good correlation (r≥0.60)

3.3 Biological parameters

All samples from the study area were found to be free from coliforms except for control. Chi square analysis revealed a highly significant difference between the control and samples at *P*<0.001 (Table 11).

Table 11: Chi square test for biological parameter of water at the study area

Study area	Particulars	Coliforms		Total	Chi square test (*P* value)
		Present	Absent		
Red Hills (Control)	Count	3	0	3	0.003**
	% within area	100.00	0	100	
	% within coliform	100.00	0	16.7	
T. Nagar	Count	0	3	3	
	% within area	0	100	100	
	% within coliform	0	20	16.7	
Saidapet	Count	0	3	3	
	% within area	0	100	100	
	% within coliform	0	20	16.7	
Ashok Nagar	Count	0	3	3	
	% within area	0	100	100	
	% within coliform	0	20	16.7	
Alandur	Count	0	3	3	
	% within area	0	100	100	
	% within coliform	0	20	16.7	
Guindy	Count	0	3	3	
	% within area	0	100	100	
	% within coliform	0	20	16.7	
Total	Count	3	15	18	
	% within area	16.7	83.3	100	
	% within coliform	100	100	100	

**P value between 0.000 and 0.010 implies high significance at 1% level

4. Discussion

Water is an indispensable natural resource on earth for life since it is the primary need of every human being. Water as an environmental resource is regenerative in the sense that it could absorb pollution loads up to certain levels without affecting its quality. Potable water supports public health and ensures economic growth (Fadaei and Sadeghi, 2014), and supply of drinking water is important to the development of any country, but when polluted it may become the source of undesirable materials hazardous to human health. The control of water pollution is therefore to reduce the pollution loads from anthropogenic activities to the natural regenerative capacity of the resource. Water also becomes a source of diseases after contamination caused mainly by the impact of different anthropogenic activities, and thereby transmits infectious diseases, which result from the infiltration of pathogenic germs as they present a danger to the consumer ranging from simple diarrhoeas to much more serious diseases such as meningitis (WHO, 2008).

Drinking water quality is a relative term that relates the composition of water with effects of natural processes and human activities and its deterioration arises from introduction of chemical compounds into the water supply system (Napacho and Manyele 2010). The quality of water is affected by an increase in anthropogenic activities and any pollution either physical or chemical causes changes to the quality of the receiving water body (Aremu et al., 2011). Chemical contaminants occur in drinking water which could possibly threaten human health. Urbanization, overpopulation, and environmental pollution pose a risk towards safe drinking water (Jackson et al., 2001). Fresh water has become a scarce commodity due to over exploitation and pollution of water. Groundwater is the major source of drinking water in both urban and rural areas, and is the most important source of water supply for drinking, irrigation and industrial purposes, but increasing population and its necessities have led to the deterioration of surface and sub-surface water (Gupta et al., 2009a; Dhivyaa et al., 2011).

Industrial development results in the generation of industrial effluents, and if untreated, results in water, sediment and soil pollution. Excessive amounts of heavy metals from industrial processes are of special concern because their presence in water produce chronic poisoning in aquatic animals (Ellis, 1989). Besides, high levels of pollutants mainly organic matter in river water cause an increase in biological oxygen demand, chemical oxygen demand, total dissolved solids, total suspended solids and faecal coliform, make water unsuitable for drinking, irrigation or any other use (Hari, 1994; Kulkarni, 1997).

Correlation coefficient established the relationship between the variables by Spearman's correlation matrix. The strong significant correlation of a particular parameter revealed that they influenced the water quality in the study area and the variations of these relationships may indicate the complexity of hydrological components which influences the water quality.

4.1 Physical parameters

Temperature is an important environmental factor that intervenes in the chemical and microbiological transformations in the waters with effect on plants and animals (Benrabah et al., 2016). Water has several unique thermal properties which combine to influence temperature change and in the present study they ranged between 28.7 and 29.7°C. Water temperature depends on the depth of the water column, climatic and topographic changes, since it controls the rate of all chemical reactions (WQA, 1992; Patil et al., 2012). Electrical conductivity of water samples in the present study varied between 723.33 and 1099.67µS/cm and the values were within the permissible limits. Electrical conductivity reflects the water mineralization and it varies according to the concentration of dissolved salts and is often influenced by temperature because it acts on the dissolution of salts in water (Benrabah et al., 2016). Pure water is not a good conductor of electric current rather a good insulator. Increase in ions concentration enhances the electrical conductivity of water. Hence, the amount of dissolved solids in water determines the electrical conductivity as it measures the ionic process of a solution that enables it to transmit current (Meride and Ayenew, 2016).

The turbidity of water depends on the quantity of solid matter present in the suspended state. It is a measure of light emitting properties of water and the test is used to indicate the quality of waste discharge with respect to colloidal matter (Meride and Ayenew, 2016). Increase in turbidity of water results due to interference of light penetration. This will damage the aquatic life and also deteriorate the quality of surface water. High values of turbidity minimize the filter runs which cause pathogenic organisms to be more hazardous to the human life. Highly turbid waters cause a decrease in free residual chlorine and therefore a high demand for chlorination for their treatment and prevention of contamination. This could lead to the production of organohalogenous substances such as chloroform in the case of high organic turbidity (Guergazi et al., 2006). Studies proved that the consumption of a high turbid water causes liver, thyroid, dermal and ocular diseases and also many alterations on immunological and reproductive systems (Kodavanti and Loganathan, 2017). However, in the present study, the values ranged from 3.7 to 11.8NTU and were within the permissible limits except for the control which slightly crossed the limit.

Total dissolved solids is an important parameter which imparts a peculiar taste to water and reduces its potability and is determined for measuring the amount of solid materials dissolved in the water. Total dissolved solids varied between 396.67 and 805.00mg/L in the present study and was within the permissible limits. Water has the ability to dissolve a wide range of inorganic and some organic minerals or salts such as potassium, calcium, sodium, bicarbonates, chlorides, magnesium and sulphates. These minerals produced unwanted taste and dilute the colour in appearance of water. The presence of synthetic organic chemicals even in small concentrations imparts objectionable and offensive tastes and odours (Chang, 2005). The water with high total dissolved solids value indicates that water is highly mineralized (Meride and Ayenew, 2016). Water containing high solids may cause laxative or constipation effects. High values of total dissolved solids in ground water are generally not harmful to human beings, but high concentration of these may affect persons who are suffering from kidney and heart diseases, provoking paralysis of the tongue, lips, and, face, irritability, dizziness and at times even disturbing the central nervous system. (Sasikaran et al., 2012).

4.2 Chemical parameters

pH is an important parameter in evaluating the acid-base balance of water as it plays a vital role in the physicochemical balance of water and varies according to the minerals' dissolution and precipitation (Belghiti et al., 2013; Benrabah et al., 2016; Meride and Ayenew, 2016). The pH is influenced by the origin of water and the nature of the crossed terrain, volume of water and soil type. pH of water may be due to dissolved carbon dioxide and organic acids like fulvic and humic which are derived from decay and subsequent leaching of plant materials (Langmuir, 1997; De, 2000). pH is positively correlated with electrical conductance and total alkalinity and is also important in determining the corrosive nature of water as low pH values indicate high corrosiveness nature of water (Gupta et al., 2009b). pH of ground water samples is in the range of 6.9-8.2 and the acceptable range of pH for drinking water is 6.5-8.5 (ISI, 1991). In the present study, pH was within the permissible limit as it fell between 7.7 and 8.2. If the pH is less than 6.5, it discontinues making of vitamins and minerals in the human body and values above 8.5 cause the taste of water more salty and causes eye irritation, and skin disorder for pH of more than 11; and low pH of groundwater can cause gastrointestinal disorders especially hyperacidity, ulcers and burning sensation (Laluraj and Gopinath, 2006; Leo and Dekkar, 2000). The total hardness of the water represents the concentration of calcium and magnesium and in the present study they ranged from 128.0 to 503.3mg/L (Matini et al., 2009). Consumption of hard water has an undesirable taste and can bring the daily needs of calcium and magnesium, and little utility (Pradeep and Chourasia, 2000).

The main sources of natural alkalinity are rocks, which contain carbonates, bicarbonates, hydroxide compounds and phosphates. Since, alkalinity is composed primarily of carbonates and bicarbonates, it acts as a stabilizer for pH and together with hardness, affect the toxicity of many substances in the water (Patil et al., 2012). Alkalinity in itself is not harmful to human being, but in large quantity, alkalinity imparts bitter taste to water and may cause eye irritation in human and in the present study they varied between 13.3 and 50.0mg/L (Buridi et al., 2014). Sulphate is the ionic form of sulphur after its combination with oxygen and exists in soil and rocks in organic or mineral forms and mainly is derived from the dissolution of salts of sulphuric acid and abundantly found in almost all water bodies (Derwich et al., 2010). High concentration of sulphate may be due to oxidation of pyrite and mine drainage and they affect the taste of water, cause corrosion of pipes, and reduce the effectiveness of chlorination, and in the present study, they ranged from 106.7 to 224.0mg/L (Guergazi and Achour, 2005; Meride and Ayenew, 2016). The fluoride content in the present study fell around 0.1mg/L and was well within the permissible limits set by standards. When fluoride concentration in drinking water is greater than 2mg/L, it may cause fluorosis which increases the resistivity of tooth enamel against acids which cause initiation of tooth decay (Minczewski et al., 1982).

4.3 Biological parameters

Water, although an absolute necessity for life, can be a carrier of many diseases. Paradoxically, the ready availability of water makes possible the personal hygiene measures that are essential to prevent the transmission of enteric diseases. Infectious water related diseases can be categorized as water-borne, water-hygiene, water-contact and water-habitat vector diseases (UNEP/WHO, 1996). The type and number of microorganisms present in the water determine the potability and sanitary states of water. A diversity of microorganisms can be present even in very good quality domestic waters. Most of these microorganisms are harmless but if the water is polluted, the most common indicator microorganisms used for domestic water quality assessment are total coliforms and faecal coliforms (Pokhriyal et al., 2019).

If large numbers of coliforms are found in water, there is a high probability that other pathogenic bacteria or microorganisms also exist. However, in the present study no such critical situations was found at any of the sampling stations. Factors that affect the microbiological quality of surface waters are discharges from sewage works and runoff from informal settlements and contamination by faecal waste of human and animal origin. Water is said to be contaminated when it contains infective and parasitic agents. Faecal coliforms are the most commonly used bacterial indicator of faecal pollution and hence used to assess the microbiological quality of drinking water (Arora and Arora, 2016). As per WHO standards, any microorganism known to be pathogenic or any bacteria indicative of faecal pollution should not be present in drinking water (WHO, 1993).

The great majority of evident water-related health problems are the result of microbial (bacteriological, viral, protozoan or other biological) contamination (Ayenew, 2004). The presence of bacteria and pathogenic (disease-causing) organisms is a concern when considering the safety of drinking water. The principal groups of microorganisms in natural water include bacteria, viruses and protozoa which are causative organisms for virulent diseases transmitted to humans directly through water. The presence of total germs in drinking water is an indicator of pollution indicating a contamination possibly due to the infiltration of germs from faeces of animals or the non-coverage of wells (El Haissoufi et al., 2011). Presence of faecal coliforms is a direct indicator of faecal contamination that could be of human or animal origin (Aka et al., 2013). Faecal bacterial are a major risk for gastroenteritis for consumers. Presence of sulphite-reducing *Clostridium* spores show a sign of groundwater vulnerability (Ayad and Kahoul, 2016).

Coliform microorganisms have been used to determine the biological characteristics of natural waters. The total coliform group has been selected as the primary indicator bacteria for the presence of disease-causing organisms in drinking water. It is a primary indicator of suitability of water for consumption. If large numbers of coliforms are found in water, there is a high probability that other pathogenic bacteria or organisms exist (Meride and Ayenew, 2016). The coliform group of bacteria are aerobic and/or facultative Gram negative, non-spore forming, rod shaped bacteria that ferment lactose to gas. *Escherichia coli* is commonly used as an indicator organism. This organism is present in the intestine of warm-blooded animals, including humans.

Therefore, the presence of *Escherichia coli* in water samples indicates the presence of faecal matter and then the possible presence of pathogenic organisms of human origin (EPA, 2002). Coliform bacteria may not cause disease but used as one of the indicators of pathogenic contamination that can cause diseases such as intestinal infections, dysentery, hepatitis, typhoid fever, cholera and other illnesses (Emmanuel et al., 2009). Bacterial flora of water includes, natural water bacteria such as *Micrococcus*, *Pseudomonas*, *Serratia*, *Flavobacterium*, *Chromobacterium*, *Acinetobacter* and *Alcaligenes*, soil bacteria such as *Bacillus subtilis*, *Bacillus megaterium*, *Bacillus mycoides*, *Enterobacter aerogenes* and *Enterobacter cloacae* and sewage bacteria such as *Escherichia coli*, *Enterococcus faecalis*, *Clostridium perfringens*, *Salmonella typhi*, *Vibrio cholerae*, *Proteus vulgaris*, *Zoogloea ramigera*, *Sphaerotilus natans*, *Haliscomenobacter hydrossis*, *Nostocoida limicola*, *Microthrix parvicella*, *Flexibacter*, *Microscilla* and *Nocardia* (Arora and Arora, 2016).

5. Conclusion

Water is essential to sustain life, and a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking water can result in tangible benefits to health. The physicochemical parameters were found to be within the permissible limits set by standards, and biological contamination was absent in the present study except for the control which is a natural reservoir. However, in general, excessive amount of physical, chemical and biological parameters accumulated in drinking water sources, leads to affect human health. Diseases related to contamination of drinking water constitute a major burden on human health. Interventions to improve the quality of drinking water provide significant benefits to health. Thus, in future, it will be necessary not only to assess the health risks related to the level of contamination of water, but also to proceed with their treatment before supplying them to consumers as further studies are required as it is difficult to understand the biological phenomenon fully since the chemistry of water reveals much about the metabolism of the ecosystem and explains the general hydro-biological relationship.

References

Adeyeye, E.I., 1994. Determination of heavy metals in *Illisha africana*, associated water, soil sediments from some fishponds. International Journal of Environmental Studies, 45, Pp. 231-240.

Aka, N., Bamba, S.B., Soro, G., Soro, N., 2013. Étude hydrochimique et microbiologique des nappes d'alterites sous climat tropical humide: cas du département d'Abengourou (sud-est de la cote d'ivoire) [Hydro-chemical and microbiological study of alterite aquifers in humid tropical climate: case of Abengourou department]. Larhyss Journal., 16, Pp. 31-52.

Aremu, M.O., Olaofe, O., Ikokoh, P.P., Yakubu, M.M., 2011. Physicochemical characteristics of stream, well and borehole water sources in Eggon, Nasarawa state, Nigeria. Journal of Chemical Society of Nigeria, 36 (1), Pp. 131-136.

Arora, D.R., Arora, B.B., 2016. Bacteriology of water milk and air. Text book of microbiology, 5th Edition. CBS publishers and Distributers Pvt. Ltd., Pp. 639.

Ayad, W., Kahoul, M., 2016. Evaluation de la qualité physicochimique et bactériologique des eaux de puits dans la region d'El-Harrouch (N.E-Algérie) [Assessment of physico-chemical and bacteriological quality of well water in the region of El-Harrouch (N.E- Algeria)]. Journal of Materials and Environmental Science, 7, Pp. 1288-1297.

Ayenew, T., 2004. Environmental implications of changes in the levels of lakes in the Ethiopian Rift since 1970. Regional Environmental Change, 4, Pp. 192-204.

Basavaraja, Simpi, S.M., Hiremath, Murthy, K.N.S., Chandrashekarappa, K.N., Patel, A.N., Puttiah, E.T., 2011. Analysis of water quality using physico-chemical parameters Hosahalli tank in Shimoga district, Karnataka, India. Global Journal of Science Frontier Research, 1 (3), Pp. 31-34.

Belghiti, M.L., Chahlaoui, A., Bengoumi, D., Moustaine, E.R., 2013. Etude de la qualité physico -chimique et bactériologique des eaux souterraines de la nappe plio-quaternaire dans la région de Meknès (Maroc) [Study of the physico-chemical and bacteriological quality of the groundwater of the plioquaternary aquifer in the region of Meknès (Morocco)]. Larhyss Journal, 14, Pp. 21-36.

Benrabah, S., Attoui, B., Hannouche, M., 2016. Characterization of groundwater quality destined for drinking water supply of Khenchela city (eastern Algeria). Journal of Water and Land Development, 30, Pp. 13-20.

Buridi, K.R., Gedala, R.K., 2014. Study on determination of physicochemical parameters of ground water in industrial area of Pydibheemavaram, Vizianagaram district, Andhra Pradesh, India. Austin Journal of Public Health and Epidemiology, 1 (2), Pp. 1008.

Chang, H., 2005. Spatial and temporal variations of water quality in the Han river and its tributaries, Seoul, Korea, 1993-2002. Water Air Soil Pollution, 161, Pp. 267-284.

De, A.K., 2000. Environmental chemistry, 4th Edn. New Age International Publishers. Pvt. Ltd., New Delhi.

Derwich, E., Benaabidate, L., Zian, A., Sadki, O., Belghity, D., 2010. Caractérisation physico-chimique des eaux de la nappe alluviale du haut Sebou en aval de sa confluence avec oued Fes [Physicochemical characterization of the waters of the alluvial aquifer of the upper Sebou downstream from its confluence with Oued Fes]. Larhyss Journal, 8, Pp. 101-112.

Dhiviyaa, P.T.S., Venkatesa, R.T., Punithavathi, L., Karunanithi, S., Bhaskaran, A., 2011. Groundwater pollution in the Palar riverbed near Vellore, Tamil Nadu, India. Indian Journal of Science and Technology, 4 (1), Pp. 19-21.

El Haissoufi, H., Berrada, S., Merzouki, M., Aabouch, M., Bennani, L., Benlemlih, M., Idir, M., Zanibou, A., Bennis, Y., El Oualilalami, A., 2011. Pollution des eaux de puits de certains quartiers de la ville de Fes, Maroc [Pollution of the well water of certain districts of the city of Fes, Morocco]. Revue de Microbiologie Industrielle Sanitaire et Environnementale, 5 (1), Pp. 37-68.

Ellis, K.V., 1989. Surface water pollution and its control. MacMillan Press Ltd., Hound Mill, Basingstoke, Hampshire, London, Pp. 3-208.

Emmanuel, E., Pierre, M.G., Perrodin, Y., 2009. Groundwater contamination by microbiological and chemical substances released from hospital wastewater and health risk assessment for drinking water consumers. Environment International Journal, 35, Pp. 718-726.

EPA., 1976. Quality criteria for water. EPA-440/9-76-023, United States Environmental Protection Agency, Washington, D.C.

EPA., 2002. Guidelines for ensuring and maximizing the quality, objectivity, utility, and integrity of information disseminated by the Environmental Protection Agency.

Fadaei, A., Sadeghi, M., 2014. Evaluation and assessment of drinking water quality in Shahrekord, Iran. Resources and Environment, 4 (3), Pp. 168-172.

Guergazi, S., Achour, S., 2005. Caractéristiques physico-chimiques des eaux d'alimentation de la ville de Biskra. Pratique de la chloration [Physico-chemical characteristics of the drinking water of the city of Biskra. Practice of chlorination]. Larhyss Journal, 4, Pp. 119-127.

Guergazi, S., Harrat, N., Achour, S., 2006. Paramètres organiques et potentiels de formation du chloroforme d'eaux de surface de l'est algérien [Organic parameters and chloroform formation potentials of eastern Algerian surface waters]. Courrier du Savoir, 7, Pp. 45-50.

Gupta, D., Sunita, P., Saharan, J.P., 2009a. Physiochemical analysis of ground water of selected area of Kaithal city (Haryana) India. Researcher, 1 (2), Pp. 1-5.

Gupta, S., Dandele, P.S., Verma, M.B., Maithani, P.B., 2009b. Geochemical assessment of groundwater around Macherla-Karempudi area, Guntur district, Andhra Pradesh. Journal of the Geological Society of India, 73, Pp. 202-212.

Hari, O.S., Nepal, Aryo, M.S., Singh, N., 1994. Combined effect of waste of distillery and sugar mill on seed germination, seeding growth and biomass of okra. Journal of Environmental Biology, 3 (15), Pp. 171-175.

ICMR., 1975. Manual of standards of quality for drinking water supplies. Indian Council of Medical Research.

ISI., 1991. Indian standard drinking water specifications. New Delhi, 5, Pp. 16.

Jackson, R.B., Carpenter, S.R., Dahm, C.N., McKnight, D.M., Naiman, R.J., Postel, S.L., Running, S.W., 2001. Water in changing world. Issues in Ecology. Ecological Society of America, Washington, 9, Pp. 1-16.

Kazi, T.G., Arain, M.B., Jamali, M.K., Jalbani, N., Afridi, H.I., Sarfraz, R.A., Baig, J.A., Shah, A.Q., 2009. Assessment of water quality of polluted lake using multivariate statistical analysis: a case study. Ecotoxicology and Environmental Safety, 72, Pp. 301-309.

Kodavanti, P.R.S., Loganathan, B.G., 2017. Organohalogen pollutants and human health. In: The international encyclopedia of public health. Quah, S.R., Cockerham, W.C. (Eds.). 2nd Ed., 5, Pp. 359-366.

Kulkarni, G.J., 1997. Water supply and sanitary engineering. 10th Edn., Farooq Kitabs Ghar, Karachi, Pp. 497.

Laluraj, C.M., Gopinath, G., 2006. Assessment on seasonal variation of groundwater quality of phreatic aquifers - a river basin system. Environmental Monitoring and Assessment, 117, Pp. 45-57.

Langmuir, D., 1997. Aqueous environmental chemistry, Prentice-Hall. Inc., New Jersey, Pp. 660.

Leo, M.L., Dekkar, M., 2000. Hand book of water analysis. Marcel Dekker, New York.

Matini, L., Moutou, J.M., Kongo-Mantono, M.S., 2009. Evaluation hydro-chimique des eaux souterraines en milieu urbain au Sud-Ouest de Brazzaville, Congo [Hydro-chemical evaluation of groundwater in urban areas south-west of Brazzaville, Congo]. Afrique Science, 5 (1), Pp. 82-98.

Meride, Y., Ayenew, B., 2016. Drinking water quality assessment and its effects on residents health in Wondo genet campus, Ethiopia. Environmental Systems Research, 5, Pp. 1-7.

Minczewski, J., Chawastowska, J., Dyebeynski, R., 1982. Separation and preconcentration methods in inorganic trace analysis. Ellis Horwood Limited, Chichester.

Napacho, A., Manyele, V., 2010. Quality assessment of drinking water in Temeke district (Part II): characterization of chemical parameters. African Journal of Environmental Science and Technology, 4 (11), Pp. 775-789.

Patil, P.N., Sawant, D.V., Deshmukh, R.N., 2012. Physico-chemical parameters for testing of water – A review. International Journal of Environmental Sciences, 3 (3), Pp. 1194-1207.

Pokhriyal, A., Uniyal, D.P., Aswal, J.S., Singh, P., Dobhal, R., 2019. Water quality assessment of drinking water sources of district Nainital in Uttarakhand, India. Journal of Environment and Biosciences, 33 (1), Pp. 67-76.

Pradeep, K.J., Chourasia, L.P., 2000. Hydrogeological studies of upper Urmil river basin, Chhatarpur district, central India. Ecology Environment and Conservation, 6 (2), Pp. 272-275.

Sasikaran, S., Sritharan, K., Balakumar, S., Arasaratnam, V., 2012. Physical, chemical and microbial analysis of bottled drinking water. Ceylon Medical Journal, 57 (3), Pp. 111-116.

SPSS., 2010. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.

UNEP/WHO., 1996. Water quality monitoring - A practical guide to the design and implementation of freshwater quality studies and monitoring programmes. United Nations Environment Programme and the World Health Organization.

WHO. 1989. Health guidelines for the use of wastewater in agriculture and aquaculture. Technical Report Series, No. 778. World Health Organization, Geneva.

WHO., 1993. WHO guidelines for drinking water quality, Vol.1, Geneva, World Health Organization, Pp. 1-29.

WHO., 2008. Guidelines for drinking-water quality. Vol. 1. Recommendations. Geneva. World Health Organization, Pp. 668.

WQA., 1992. Water Quality Assessment - A guide to use of biota, sediments and water in environmental monitoring, 2nd Edition, UNESCO/WHO/UNEP.