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WATER QUALITY ASSESSMENT OF UNDERGROUND AND SURFACE WATER RESOURCES OF BAHIR DAR AND PERIURBAN AREAS, NORTH-WEST ETHIOPIA.

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ABSTRACT

Water quality assessment in the Ethiopian highlands is crucial owing to increasing competing need of water for domestic, agricultural and industrial uses. Twelve physico-chemical parameters were analyzed in water samples collected over a period of five months from three different sources; groundwater (hand dug wells and protected hand pumps) and surface water (streams and lake) in Bahir Dar and peri-urban areas. Differences in water quality parameters between the sources were compared to identify pollutant sources and level of compliance with certain water quality criteria. Based on cluster analysis, the sampling stations were classified into two major categories; inner city and outer city; with the surface waters recording far more pollution by fecal contamination. Chloride, TDS, conductivity, total hardness and all the species of nitrogen (nitrite, nitrate and ammonium) were higher in the inner city than the remaining water habitats except the outer ground water stations. Conductivity decreased along the presumptive pollution categories significantly, i.e. inner > middle > out skirt ($P< 0.05$) and showed medium to high correlation with chloride, total hardness, nitrate, nitrite, total dissolved solids in ground water ($r = 0.58 – 0.85$). Dissolved oxygen, pH and SAK_{254} were higher in the lake station than other water bodies. The results from this research would help in developing best management practices for the Bahir Dar municipal water scheme and for regional water scheme program in the future and provide information for formulating appropriate framework for an integrated water management strategy.

KEY WORDS: Underground, Surface Water, Physico-chemical, Water Quality, Ethiopia

INTRODUCTION

Rivers and lakes constitute the main water resources in inland areas for drinking, irrigation and industrial purposes. It is a prerequisite for effective and efficient water management to have reliable information of water quality (Vega et.al., 1998). Water quality in the context of this paper refers to the water that is intended for human consumption and for all domestic and drinking purposes including personal hygiene (Fawell & Miller, 1994). Water quality needs to be in relation to the use for which the water is required and the value of biological indicators needs to be judged on a similar basis (Evison & James, 1979). Thus, water quality is a dynamic balance between chemical, physical and biological factors. The microbiological quality is of greatest importance and must never be compromised in order to provide aesthetically pleasing and acceptable water (Bisson & Cabelli, 1979). The risks of infection vary with water use thus different standards are set accordingly (e.g. for drinking water, recreation and wastewater such as industrial effluents). Recreational waters, swimming, boating etc. all involve bodily contact with water and may involve also ingestion which increases risk of disease and toxin poisoning. Poor hygiene and lack of proper disposal of human fecal materials, discharge of industrial and municipal waste and manure can be considered constant polluting sources coupled with seasonal runoffs.

The quality of ground water in aquifers is related to the quality of the recharge water, the residence time in the ground water flow system, and the presence of nearby saline water. By nature, the quality of the ground water is expected to be better as compared to surface water because the vertical percolation of water through soil results in the removal of most of the microbial and organic pollution (Geldreich et al., 1988). Shallow wells are frequently grossly polluted with a variety of wastes from surface runoff. Streams and surface water sources are subjected to additions of gross amounts of sewage, industrial effluents and numerous other pollutants often because it is considered expedient and economical to have the unwanted material carried away (“out of sight”) by the flowing water (Wetzel & Likens, 1991). Therefore, the primary influence on ground water quality as well as surface water quality is the contamination brought about by human activities. Besides, there exists also natural geochemical pollution like Arsenic (WHO, 2004) or natural autochthonous microbial populations, like *C. vilolaceum* bacterium (Byamukama et al., 2005), with crucial pathogenic potential.

The health related quality of water can be assessed by determining physico-chemical, microbial and biological parameters. Microbial and non-microbial parameters provide a wide range of possibilities for measuring water quality changes (Edberg et al., 2000, Liu et al., 2008). Some of the major physico-chemical, parameters include temperature, dissolved oxygen, pH, electrical conductivity, total hardness, total suspended solids, chloride and different nitrogen species – nitrate, nitrite and ammonia

Study Area Description

Bahir Dar City is located at 11° 33´ 23.11´´ N and 37° 22´ 7. 35´´E. It lies on the southern shore of Lake Tana. The estimated area of the city is 0.04 km^2. It is located at an altitude of 1800m above sea level. The climate is tropical with four seasons (rainy, dry period, small rains and a dry spell between the long and small rains) and 50% of the rainfalls are in July and August and 18% falls during the October to February. The maximum rainfall (499.6 mm) was in July and the minimum was in January (1.8 mm). The mean annual relative humidity was 55%.The maximum temperature usually occurs in March to May. The mean monthly maximum was 27.7 °C and minimum was 13 °C 2001-2005.

The soils in Bahir Dar are silt clay or clay. There are no coarser soils found either in outcrops or in the deep-water well logs. The dominant soil color is red. The soil does not contain sand or silt. Therefore, permeability is assumed to be in the order of 1x 10^{-4} to 1 x 10 $^{-5}$ md^{-1}. However, the underlying rocks are quite weathered and fractured and thus have good permeability WSSA (2002) report. Bahir Dar is a fast growing city with its current status of regional state city.

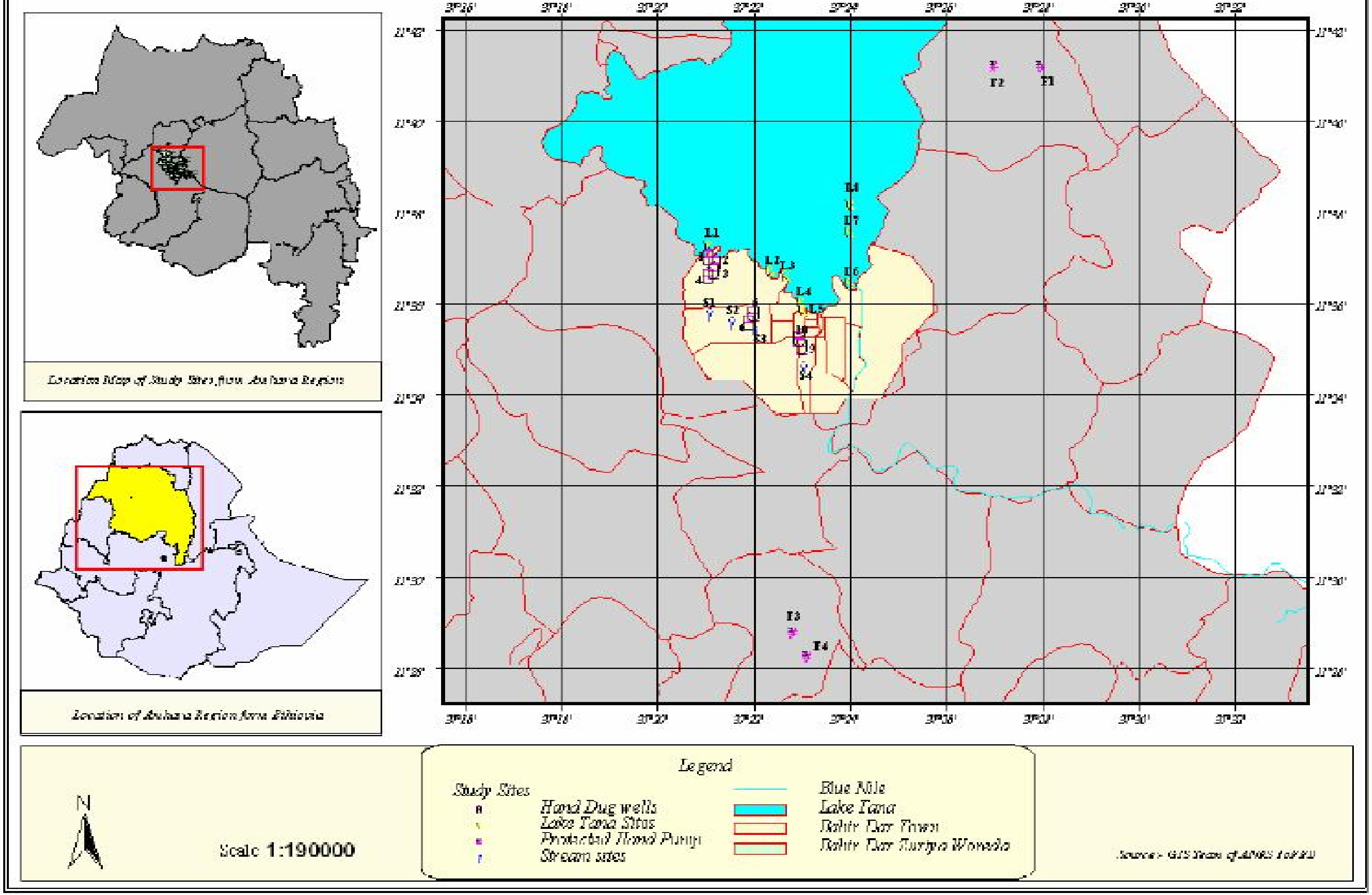
MATERIALS AND METHODS

Sampling sites and sampling design A total of twenty-four sampling sites from two water source types including surface and ground water were sampled. Eight of the sites were hand dug wells, four were protected hand pumps, and four sites were from streams and eight from lake (Figure 1). The ground water samples and stream sites were collected once almost every 15 - 20 days between October 2006 and February 2007 and the lake sites were sampled occasionally. The coordinates of sampling locations (shown in Table 1) were determined by a Garmin Global positioning system and plotted on a map of Bahir Dar city and peri-urban areas with Arc view GIS version 3.2 software (ESRI, Redlands, Calif.)

Table 1: GPS reading of sampling sites with brief descriptions

Site	Northing 00°00´00˝	Easting 00°00´00˝	Description	Relative location
1	11°36´54.8˝	37°21´49.7˝	Ground water, middle city	Near Bata Church
2	11°36´48˝	37°21´46.2˝	Ground water, middle city	“
3	11°36´46.9˝	37°21´46.5˝	Ground water, middle city	“
4	11°36´44.5˝	37°21´45.7˝	Ground water, middle city	“
5	11°35´29.8˝	37°22´17.8˝	Ground water, inner city	Near Kidanmehert Church
6	11°35´29.7˝	37°22´17.7˝	Ground water, inner city	“
9	11°34´58.5˝	37°23´19.4˝	Ground water, inner city	Back of Papyrus Hotel
10	11°35´43.8˝	37°23´19.4˝	Ground water, inner city	Back of Papyrus Hotel
S1	11°35´43.8˝	37°21´45.7˝	Gudo Bahir, upstream site 1	Near Kiflom garage
S2	11°35´35.4˝	37°22´24.7˝	Gudo Bahir, upstream site 2	Near Kidanmehert Church
S3	11°35´19.4˝	37°22´24.7˝	Gudo Bahir, upstream site 3	Near NOC fuel station
S4	11°34´34˝	37°23´40.9˝	Gudo Bahir, downstream site1	Near BDU main gate
F1	11°41´4.4˝	37°27´32.9˝	Ground water, outer city	Robet Bata
F2	11°41´4.6˝	37°28´23.8˝	Ground water, outer city	“
F3	11°28´23.8˝	37°23´10.9˝	Ground water, outer city	Wondata Mariam
F4	11°28´21.3˝	37°23´18.2˝	Ground water, outer city	“
L1	11°37´1.66˝	37°21´8.34˝	Lake reference site 1	Near Medhalelem orphanage
L2	11°36´37.1˝	37°22´24.7˝	Lake influenced site 2	Hospital effluent
L3	11°36´37.2˝	37°22´40.2˝	Lake influenced site 3	Near fish production and marketing enterprise
L4	11°35´56.4˝	37°23´04˝	Lake influenced site 4	Near Hidar 11 recreational center
L5	11°35´47.7˝	37°23´22.5˝	Lake influenced site 5	Near mango recreational center
L6	11°36´21.6˝	37°24´5.2˝	Lake influenced site 6	Near prison
L7	11°37´28.7˝	37°24´5.2˝	Lake influenced site 7	Near Blue Nile outlet
L8	11°38´05˝	37°24´25.5˝	Lake influenced site 8	“

Location Map of Study Site



Measurement of Water Quality Parameters

Water samples from ground and surface source were collected based on standard procedures (APHA, 1995) using glass bottles with butyl rubber stoppers. Samples from open waters were taken with sterile glass bottles 30 cm under the water surface to avoid the effect of UV radiation. The sample bottles were immediately kept in icebox and transported to laboratory to be analyzed within 6 hours.

In-situ measurements of temperature, electrical conductivity (EC), pH, dissolved oxygen (DO), total dissolved solid (TDS) were measured with probes for surface water samples. EC and TDS were measured with EC/TDS meter (Hanna, Model H1 98312) and dissolved oxygen with Elimeiron oxygen meter, Model CO-411. Total suspended solids (TSS) were determined in the laboratory by gravimetric method (APHA, 1995).

The chemical analyses for determination of Chlorides, Total Hardness, Ammonia, Nitrite and Nitrates were done in accordance with the manufacturer instruction (Palintest Transmittance - display photometer) for all above mentioned chemical parameters. Aliquots of water sample were collected and filtered through 0.45µm pore size, 47-mm diameter filter paper. Samples from stream water and some lake samples were diluted so that they could be measured within the linear detectable range. Filtered water sample was used as a blank for each site. The absorbance of the developed color complex was measured under a specified wavelength (640 nm for NH_3, 520nm for chloride and NO_2, 570 nm for total hardness and NO_3).

Specific absorption at 254nm (SAK_{254} / UV_{254}) was measured for the water samples. UV absorbing organic compounds in a water sample absorbs UV light in proportion to their concentrations. The procedure of SAK_{254} / UV_{254} determination was according to the manual on chemical water analysis by Kreuzinger & Matssche (2001).

Data from the different habitats were pooled and range and median values presented. Non-parametric Mann Whitney U tests were used to compare median vales of physico-chemical parameters. General significant level of $P < 0.05$ was set for all tests.

ground water and lake and stream stations for surface water) are shown in Table 2. There was no considerable difference in water temperature between lake and stream stations ($P > 0.05$) but ground water was significantly different from stream stations ($P < 0.05$). Water temperature in ground, stream and lake water stations ranged from 18.6 – 25.2 °C, 21.1 –27.4 °C and 16.4 – 27.4 °C, respectively. The median temperatures were 22.6°C ($n = 60$), 19.1°C ($n = 16$) and 23.2 °C ($n = 22$), respectively. The ground water temperature was expected to be lower compared to surface water without any geothermal energy in the area. The level of protection of the ground water sampling sites 5 and 6 was very minimal and methodological constraints of ground water sampling might have resulted in a slight increase of temperature in ground water than expected.

Measured dissolved oxygen ranged from 0.9 to 5 mgl^{-1} (median = 2.3mgl^{-1}) for ground water stations, from 1.1 to 5.9 mgl^{-1} (median = 4.5mgl^{-1}) for stream station, and from 1.5 to 8 mgl^{-1} (median 3.8mgl^{-1}) for lake station. There was significant difference between reference lakeshore and influenced lake sites ($P < 0.05$). Anaerobic condition was not observed during the study phase for all the investigated sampling stations.

A lower value of DO in the influenced (1.5 mgl^{-1} and 8.0 mgl^{-1}) lake station was likely because it accommodates sites receiving heavy organic load. To the contrary, relatively higher DO in reference sites (8.0mgl^{-1}) were attributable to increased photosynthetic activity; owing to the fact that DO and pH are influenced by photosynthesis and respiration (oxygen being a product of photosynthesis also increases the pH) in most natural aquatic systems under the prevailing condition (Wetzel, 1975).The same pattern was well corroborated in the present study as DO and pH followed similar trend of variation. Ground water as compared to surface water showed lower pH values ranging from 5.8 - 7.8 (median 6.6). Pooled stream sites had an intermediate pH range of 6.3 – 8.0 (median 7.1) and the lake stations revealed a higher pH values which ranged from 6.8 - 8.8 (median 8.1) that could be explained by the photosynthetic process which

Electrical conductivity EC values observed for the lake stations ranging between 130 - 1200µScm^{-1} (median = 140µScm^{-1}). However, a ten fold variation could be seen from this range mainly because the lake stations accommodated both influenced and referenced sites. The median values for ground water and stream stations were (465 and 333µScm^{-1}) and ranged from 50 – 1500µScm^{-1}, respectively. Within the ground water station, conductivity decreased along the presumptive pollution categories significantly, i.e. inner > middle > out skirt ($P< 0.05$). Conductivity measurements showed medium to high correlation with chloride, total hardness, nitrate, nitrite, total dissolved solids in ground water ($r = 0.58 – 0.85$) (Table 2) and low to medium correlation with TDS, ammonium and total hardness ($r = 0.27 – 0.73$). Generally, chloride also followed the same trend as conductivity. The median chloride concentration for the lake stations was 4 mgl^{-1} and ranged from not detectable to 162 mgl^{-1}. This was less than ground water (inner and middle stations) of 25 mg Cl l^{-1} median values ranging from, not detectable up to 50 mgl^{-1}. The inner city station had the highest median chloride concentration of 129 mgl^{-1} and a range of 46 - 270 mgl^{-1}. Conductivity showed significant correlation with total dissolved solids (TDS), chloride (Cl), total hardness (TH) and two nitrogen species - NO_2, and NO_3. From the above result one can infer that Conductivity, TH, Cl, NO_2, NO_3 and TDS probably indicated increased human and agricultural activities, which is also likely associated with other pollution activities.

Total Dissolved solids (TDS) also showed similar trend with conductivity and chloride. The highest median value was recorded in the ground water of 0.41 gl^{-1} (inner station) and a range of 0.32– 0.64 gl^{-1}. Within the ground water habitat TDS increased again along the transect from inner to outer city. The median TDS values recorded were 0.08 and 0.30 gl^{-1}, respectively. The median TDS recorded for stream station and lake stations were 0.22 gl^{-1} ($n = 16$) and 0.07 gl^{-1} ($n = 22$) respectively. The TDS ranged in stream and lake stations were 0.10 – 0.52 gl^{-1} and 0.04 – 0.42 gl^{-1}, respectively. Nitrate, nitrite and ammonia generally showed a decreasing trend as we go from inner to outer city within the ground water habitat and showed more or less no significant difference between lake and stream stations except for NO_3. There was very low correlation among different nitrogen species in both groundwater and surface waters (Tables 3 and 4).

The maximum SAK_{254} value (48 m^{-1}) was measured at the polluted shore site of the lake station (L2) which was significantly higher than any other sites ($P< 0.05$) where the hospital has released effluent into the lake.

The minimum SAK_{254} value (5.4 m^{-1}) was observed in the inner city ground water station. The highest median value 18.2 m^{-1} for the ground water habitat was observed at the outer stations. The inner city station had the lowest SAK_{254} .The maximum SAK_{254} at L2 site could be explained by the high content of not readily degradable organic matter from the hospital effluent. The higher value also in the outer city station of ground water could be the result of erosion bringing agricultural inputs like fertilizers, pesticides and insecticides from the catchment.

In general, chloride, TDS, conductivity, total hardness and all the species of nitrogen (nitrite, nitrate and ammonium) were higher in the inner city than the remaining water habitats except the outer ground water stations. This is likely because of anthropogenic influence from higher population density. An alternative, but less likely explanation might be because of the different geological condition of the area. Dissolved oxygen, pH and SAK_{254} were higher in the lake station than other water bodies. Dissolved oxygen and pH could be mainly due to the influence of photosynthetic activity by planktonic algae found in the lake. SAK_{254} and total suspended solids higher values of Lake Station (L2) were most probably as a result of the discharge of hospital effluent.

Cluster analysis of sampling sites by physico chemical parameters is shown in figure 2. The median values of conductivity, total suspended solids, chloride, total hardness, nitrate, nitrite, ammonium, total dissolved solids and specific absorbance at 254nm were used.

The result showed that the stream stations as well as the inner city sampling sites could be clustered perfectly in related or similar pollution categories and the respective water source types' stream and ground water. The lake sampling sites were also clustered separately but some ground water sites (middle station) which were physically located adjacent to the lake were included in the lake cluster. This likely indicated the hydrological connection and the ground water exchange between the lake and the adjacent ground water sites.

From the physico chemical characterization and cluster analysis, it was possible to see a range of differing habitats, land use and pollution pattern in the investigated water systems.

Table 2: Physico-chemical characteristics of the examined water habitats *

	I (n = 20)		M (n = 20)		O (n = 20)		L(n = 22)		S (n =16)	
Parameters	MD	Range	MD	Range	MD	Range	MD	Range	MD	Range
Temp. (°C)	21.3	18.6 - 25.2	22.1	21.0 - 23.6	23.5	22.5 - 23.9	18.7	16.4 - 27.4	18.7	16.4 -27.4
DO (mgl^{-1})	1.5	0.9 - 3.0	2.6	1.3 - 4.0	3.3	1.3 - 5.0	4.0	1.5 - 8.0	4.8	1.1 - 5.9
Cond (μScm^{-1})	1003	650 - 1362	166	50 - 347	386	50 - 1516	140	130 - 1200	445	270- 810
pH	6.7	6.5 - 7.7	6.3	5.8 - 6.7	6. 7	6.0 - 7.6	8.1	6.8 - 9.0	7.1	6.3 - 9.0
Cl^- (mgl^{-1})	131	46 - 270	19	0 - 50	10	0 - 40	4	0 - 162	42	16 -78
TH (mgl^{-1})	650	100 - 1150	80	0 - 180	255	10 - 700	60	0 - 100	215	0 - 420
NO_3 (mgl^{-1})	41.80	0.66 - 57.2	2.02	0.18 - 7.66	1.45	0.08 - 8.89	1.63	0.03 - 3.61	0.84	0.30- 9.50
NO_2 (mgl^{-1})	0.10	0.06 - 1.70	0.02	0.00 - 0.36	0.01	0.00 - 0.63	0.04	0.00 - 0.37	0.05	0.003- 0.99
NH_3 (mgl^{-1})	0.72	0.0 - 12.0	0.42	0.0 - 12.00	0.54	0.0 - 12.0	0.66	0.0 - 12.00	4.02	0.0 - 12.0
SAK_{254} (m^{-1})	10.7	5.4 - 19.8	19.0	9.9 - 35.2	18.3	13.7 - 21.8	16.9	8.2 - 48.0	14.4	4.2 - 19.8
TDS (g / l)	0.48	0.32 - 0.6	0.09	0.02 - 0.16	0.20	0.02 - 0.35	0.07	0.04 - 0.42	0.22	0.10 - 0.41

*Abbreviations: I – inner city ground water station, M – middle city ground water station, O – outer city ground water station, L – lake stations, S - stream station, MD – median

Table 3: Pearson correlation matrix between various physico-chemical parameters for ground water (n=60)

	T	DO	Con	pH	Cl^-	TH	NO_3	NO_2	NH_3	SAK_{254}
T										
DO	0.19									
Con	-0.17	-0.45								
pH	0.03	0.04	0.52							
Cl^-	-0.25	-0.58	0.79	0.17						
TH	-0.04	-0.56	0.80	0.40	0.78					
NO_3	-0.13	-0.44	0.57	0.09	0.68	0.68				
NO_2	-0.24	-0.22	0.58	0.13	0.61	0.49	0.36			
NH_3	-0.05	0.14	-0.09	0.19	-0.08	-0.05	-0.18	-0.17		
SAK_{254}	0.16	0.17	-0.32	-0.30	-0.26	-0.32	-0.35	-0.02	-0.16	
TDS	-0.17	-0.52	0.97	0.50	0.85	0.84	0.63	0.61	-0.06	-0.35

Table 4 Pearson correlation matrix between physico-chemical parameters for surface water (n=38)

	T	DO	Con	pH	Cl^-	TH	NO_3	NO_2	NH_3	SAK_{254}
T										
DO	0.15									
Con	-0.48	-0.36								
pH	0.35	0.55	-0.40							
Cl^-	-0.25	0.09	0.06	0.30						
TH	-0.38	-0.18	0.32	0.37	0.21					
NO_3	-0.18	-0.06	0.00	0.15	0.02	0.05				
NO_2	-0.21	-0.14	0.20	0.12	-0.10	0.23	-0.02			
NH_3	-0.57	-0.23	0.43	0.40	0.15	0.23	-0.03	0.27		
SAK_{254}	0.14	-0.29	0.25	0.07	-0.24	-0.39	-0.11	-0.07	0.11	
TDS	-0.59	-0.37	0.66	0.67	0.20	0.46	0.01	0.27	0.73	0.20

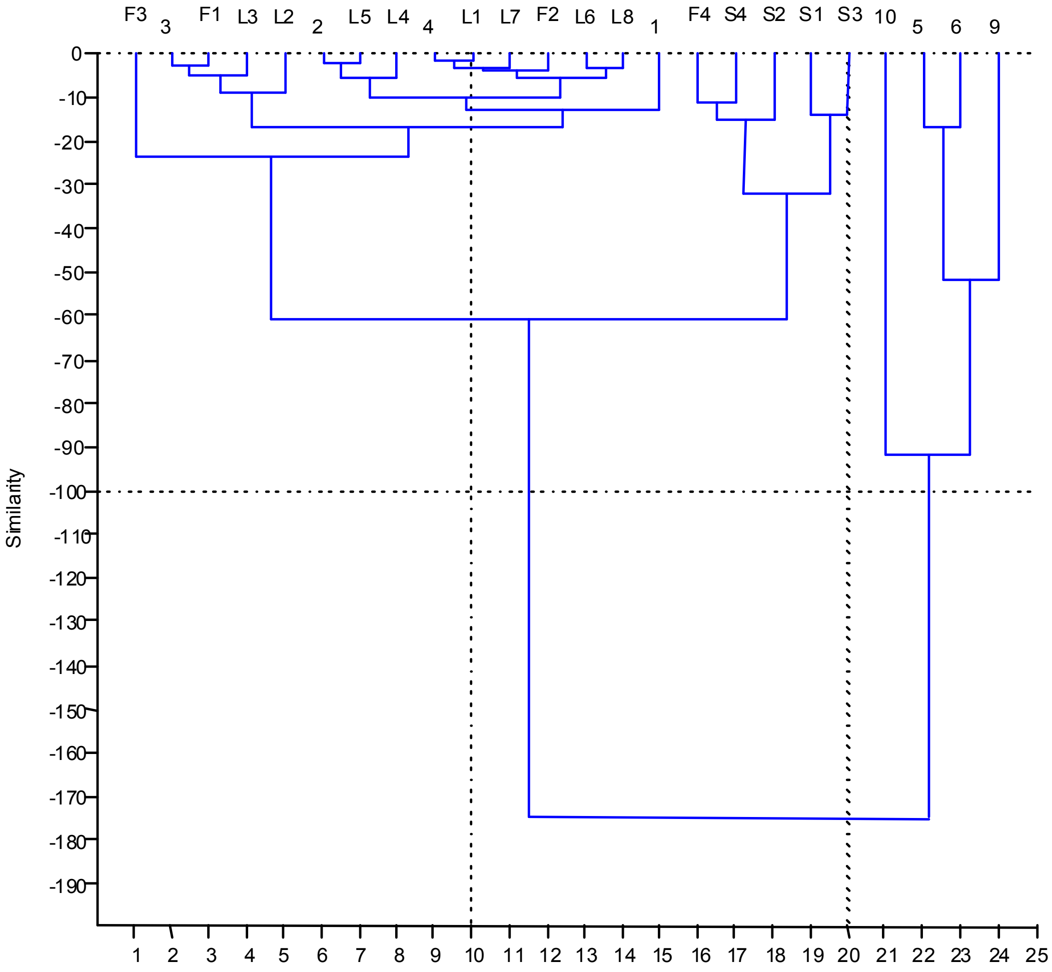


Figure 2: Dendrogram showing groups of sites as classified by cluster analysis

The result showed that the stream stations as well as the inner city sampling

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