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Assessment of Surface and Ground Water Quality of Uruan in Akwa Ibom State of Nigeria

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Abstract

The water quality status of rivers, streams, and underground water in Uruan Local Government Area, Nigeria was investigated in this study. Inhabitants of this region depend on these water resources for drinking and other purposes. Water samples were collected from four rivers, nine streams, six boreholes and a well from various points across three study zones in the local government. Standard analytical methods were employed for all analyses and the results are compared with water quality standards of the World Health Organisation (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ). Most quality determinands are within WHO guidelines except pH, EC, turbidity, TDS, total coliform, and Fe. The overall ionic dominance pattern for the river, stream, borehole and well follow the same trend Fe>Na>Mn>K and $Cl^- > NO_3^- > NO_2^-$. The hygienic condition of the water bodies is found to be poor. High BOD_5, coliform count and $BOD_5:NO_3$ ratio of river, stream and ground water samples are indicative of organic pollution due to faecal contamination. Multivariate statistical approach [correlation, principal component analysis (PCA), and cluster analysis (CA)] was used to identify interrelationships among physicochemical parameters and the pollution source. PCA reveals 3 extracted principal components (PCs) by river water, 6 PCs each by both stream and ground water; with the sources of pollution either from natural hydro-geochemical processes or anthropogenic pollution, or a combination of both. Based on cluster analysis results, water sample stations are classified into 6 clusters, a pointer to the fact that the clusters are peculiar and different from one another. The results imply that water bodies in Uruan are polluted and pose potential risk to humans. Institution of intervention measures including public awareness campaigns in Uruan local government area is desirable to protect the inhabitants from water-related illnesses and their consequences.

Keywords: River; Stream; Groundwater; Water quality; Organic pollution index; Multivariate analysis

1. Introduction

Water is the most important natural resource on earth. It is essential for all known forms of life, and is approximated to cover 70.9% of the earth surface (Foster, 2001; Horward *et al*., 2003; Pasquini and Alexander, 2004; Verplanck *et al*., 2006). Despite its abundance, the quality and accessibility of potable water remains a global challenge; moreso, in rural and semi-rural communities in the developing countries (Faremi and Oloyede, 2010; Foster, 2001; Lashkaripour, 2003). Poor water quality continues to pose major threats to human health. Today, contaminated water has been reported to kill more people than cancer, AIDS, war or even accident (Rail, 2000; WHO, 2011a). Diarrhoeal diseases alone account for an estimated 4.1% of total daily global burden of disease and are responsible for the deaths of 1.8million people every year; 88% of this burden is attributable to unsafe water supply, poor sanitation and hygiene(WHO, 2004). Microbial contamination of drinking water supplies especially from human faeces is a major contributor to diarrhoeal diseases that kill millions of children every year (Foppen, 2002; Horward *et al*., 2006; Verplanck *et al*., 2006; UNEP *et al.,* 2008). It is therefore important that drinking water is free from disease causing germs and toxic chemicals that endanger public health. In Nigeria, only 58% of inhabitants of the urban and semi-urban areas and 39% of the rural areas have access to potable water supply; the rest of the population depend on ground (well and borehole) and surface water (stream and river) for their domestic water supply (FGN, 2012). With a growing human population, urbanisation, pollution, atmospheric input from fossil fuel burning and environmental degradation, the threats on water supplies from chemical and biological contamination are expected to increase.

Research findings indeed reveal deteriorating surface and ground water quality in Nigeria, Uganda and India due to chemical and biological pollution and seasonal changes among others (Galadima *et al*., 2012; Kumar and Pal, 2010; Oluseyi *et al*., 2011; Sha'Ato *et al*., 2010). As water quality issues become more serious and widespread, the need for water quality monitoring as an important component of health promotion strategy in the developing countries cannot be overemphasized.

Over the past two decades, multivariate statistical analysis (PCA and CA) has been successfully applied in hydro-geochemical and biological studies (Amadi *et al*., 2012; Gauch, 1982). With this technique, large geological, hydrological and biological data are simplified, organised and classified to produce useful information (Kaiser, 1958; Rencher, 1992; Wu *et al*., 2005).

Information on the quality of surface and ground water sources of most communities in Nigeria is scanty; focus has been more on the urban and sub-urban settlements which information is still inadequate. Hence, this study to assess the quality of surface and ground water sources in some villages in Uruan Local Government Area of Akwa Ibom State.

2. Materials and Methods

2.1 Study Area

The study areas (Fig. 1) are located within Uruan Local Government Area which extends from latitude 4°52' to 5° 08' N of the equator and longitude 7° 55' to 8°10' E of the Greenwish Meridian. It is bounded on the East by Odukpani Local Government Area in Cross River State, on the South by Okobo Local Government Area, on the West by Nsit Atai and Ibesikpo Asutan Local Government Areas and on the North by Itu Local Government Area. For the purpose of sampling, the Local Government Area was divided into three zones- the northern zone (NZ), the central zone (CZ), and the southern zone (SZ) to cover a cross section of the villages in Uruan.

2.2 Water Collection and Preservation

Water samples were collected from nine streams, four rivers and six boreholes in the three zones. Well sample was available only in the central zone. The streams are located in rather serene environs with little human activities while the rivers accommodate various social and commercial activities including fishing, canoe service for traders in the riverine villages, fermentation of cassava tubers at the banks, launderings and bathing. Five of the six borehole water samples were obtained from private boreholes which serve as source of household water supply, and also income to family through sales to village buyers; the other was a public borehole situated at a market place in the northern zone. Sample containers (glass or plastic bottles) were pre-cleaned, dried and stored in a dust free environment as described by Udousoro (1997). Four composite samples of water were collected from rivers and streams for each sampling point. The samples for physicochemical parameters and metals determination were stored in 2 L plastic bottles while samples for DO, BOD_5 and microbial analyses were stored in glass bottles. Borehole water samples collected from taps were allowed to run for ten minutes before sample collection for physicochemical parameters. For DO, BOD_5 and bacteriological determinations, the mouth of the tap was heated for five minutes with a spirit lighter to destroy microorganisms, and the tap water allowed to run for 5 minutes prior to sample collection. Samples for metals were preserved using 1 ml concentrated HNO_3 per litre of sample. All water samples were stored in an insulated cooler containing ice (maintained at 4 °C) and delivered to the laboratory.

2.3 Water and Data Analyses

All physicochemical parameters were analysed within 24 hours of sample collection. Temperature, turbidity, pH, electrical conductivity (EC) and dissolved oxygen (DO) were determined on sites using mercury glass thermometer, JENWAY 6035 turbimeter, JENWAY 3305 pH meter, HACH 44600-00 EC meter and JYD-IA DO meter, respectively. BOD_5 was measured with JYD-IA DO meter after five days incubation. Other physicochemical parameters, bacteriological evaluation and metals levels were measured in the laboratory using standard procedures (APHA, 1992).

Multivariate analysis (correlation analysis, principal component analysis and cluster analysis) was performed on a set of water quality data. The statistical software- Statgraphic® Centurion XV was used for CA while SPSS Statistics 17.0 used for Pearson's correlation coefficients analysis and PCA. To eliminate the influence of drifting units of measurement and render the data dimensionless, principal component analysis was applied to a matrix of 22 experimental data in river, stream and ground water (borehole and well) standardised through set Verimax rotation with Kaiser Normalization. Cluster analysis using Ward's method based on Squared Euclidean distance was performed on twenty water sampling stations. The analytical quality control was ensured through procedural blank measurements, duplicate analysis of water samples and standardisation of analytical instruments.

3. Results

3.1 Quality of River, Stream and Ground water from Uruan

3.1.1 Physicochemical Characteristics

Several physicochemical parameters of the different water sources (river, stream, borehole, and well) in the northern, central and southern zones of Uruan LGA were investigated. The results obtained are presented in Tables 1-6 and Figs. 2-6.

The pH levels of the water sources range from 5.50-6.80 for river, 5.30-5.86 for stream, 5.15-6.5 for borehole and 6.0 for the only well in the central zone. The water bodies in Uruan generally are slightly acidic but the acidity in the northern zone is less than in the central and southern zones. The temperatures of the water bodies range from 27.00-28.00°C for river, 27.33-29.00°C for the stream, 27.3°C-29.50°C for borehole and 29.00°C for well water.

The colour (in Hazen unit) of water samples from well in the central zone, borehole in both the central and southern zones and all the streams is 5.00. All river and borehole samples from the northern zone have higher colour values of 10.00. The turbidity of water from river in the three zones range from 16.03 NTU to 37.10 NTU, stream 1.24 NTU to 1.98 NTU, borehole 0.82 to 2.81 NTU, and 1.93 NTU for the central zone well. The river water samples are more turbid compared to the other water bodies in the zones.

Electrical conductivity is a good measure of dissolved solids; it is an important criterion in determining the suitability of a body of water for irrigation (Kumar and Pal, 2012). The values for electrical conductivity of the water sources range from 27.20 µs/cm-1080.00 µs/cm for river, 73.18 µs/cm-1429.33 µs/cm for stream and 102.81 µs/cm-6160.00 µs/cm for borehole across the three zones from north to south. The well water obtained from the central zone has conductivity of 76.64 µs/cm. The boreholes have the highest conductivity values, with extremely larger values in the southern zone (6160.00 µs/cm). Water from the rivers and streams in the southern zones also have higher values in relation to the other zones. Similarly, the total dissolved solids (TDS) range from 12.60 mg/L to 5040 mg/L (river), 36.50 mg/L to 714.63 mg/L (stream) and 51.40 mg/L to 3080.00 mg/L (borehole) from the northern to southern zones. Water from the well in the central zone has a TDS of 38.80 mg/L. Like conductivity, the southern zones record the highest TDS in all the water types. TDS in river (SZ) and Stream (CZ) was greater than EC while EC was greater than TDS in the others. Total suspended solids (TSS) range 0.72-0.75 mg/L for river, 0.58-0.62 mg/L for stream, 0.39-0.69 mg/L for borehole, and 0.48 mg/L for the well in the central zone. TSS is relatively high in river samples followed by stream.

The levels of DO recorded are low for the different water sources. A DO range of 0.10-0.20 mg/L is obtained for river and stream, 0.10-0.15 mg/L for borehole water and 0.10 mg/L for well water in the central zone.BOD_5 levels in the water bodies range from 10.27 to 18.74 mg/L for river, 12.50 to 14.35 mg/L for stream, 4.30 to 6.25 mg/L for borehole, and 13.30 mg/L for the well in the central zone. River water has the highest BOD_5 level.

Total hardness for water samples range from 11.50-30.00 mg/L for river, 12.30-15.38 mg/L for stream, 11.85-14.80 mg/L for borehole and 10.70 mg/L for well. The acidity and alkalinity levels of the water bodies in the three zones range from 0.12-0.20 mg/L and 1.50-3.00 mg/L for river, 0.14-0.17 mg/L and 1.80-2.50 mg/L for stream, 0.10-0.17 mg/L and 1.77-3.00 mg/L for borehole and 0.21 mg/L and 2.50 mg/L for well, respectively. Salinity in the different water sources is in the range 0.28-0.50% for river, 0.28-0.39% for stream and 0.25-0.40% for borehole; 0.20% is recorded for the well in the central zone. The levels of free carbon dioxide obtained from the river sources range from 1.00 to 1.20mg/L, stream 1.00 to 1.08 mg/L, borehole 1.00 to 1.40 mg/L, and 1.10mg/L for the well. Ammonia levels in samples from the three zones range from 0.60-0.65 mg/L for river, 0.40-0.60mg/L for stream, 0.30-0.45 mg/L for borehole and 0.40 mg/L for the well.

3.1.2 Anion and Metal Contents

The levels of anions in the different water sources are as follows: chloride ranges from 13.00 to 17.00 mg/L (river), 12.80 to 15.60 mg/L (stream), 10.93 to 12.00 mg/L (borehole), and 11.60 mg/L (well); nitrate ranges from 0.10 to 0.15 mg/L (river), 0.15 to 0.20 mg/L (stream), 0.11 to 0.20 mg/L (borehole), and 0.10 mg/L (well); and nitrite is in the range 0.02-0.03 mg/L (river), 0.01-0.08 mg/L (stream), and 0.02 mg/L for both borehole and well.

Manganese levels range from 0.007 to 0.01 mg/L (river), 0.02 to 0.095 mg/L (stream), 0.07 to 0.30 mg/L (borehole), and 0.163 mg/L (well). For potassium, the range is 0.10-0.15 mg/L (river), 0.10-0.26 mg/L (stream), 0.10 to 0.25 mg/L (borehole), and 0.10 mg/L (well). Sodium values are in the range 1.65-2.20 mg/L (river), 1.00-1.86 mg/L (stream), 1.80-2.07 mg/L (borehole), and 1.80 mg/L (well). The range for iron is 0.352 mg/L-1.249 mg/L in river, 0.15 mg/L-2.98 mg/L in stream, 0.59 mg/L-9.21 mg/L in borehole, and 6.23 mg/L in well.

3.1.3 Total Coliform Count

The water sources in all the zones have very high levels of coliform count (Table 2). In river water, 573MPN/100mL is obtained for the central zone, 490 MPN/100mL for the southern zone and 985 MPN/100 mL for the northern zone. In stream water, 810 MPN/100mL is obtained for the central zone, 73600 MPN/100mL for the southern zone and 2370 MPN/100mL for the northern zone. For borehole water, 2570 MPN/100mL is obtained for the central zone, 1560 MPN/100mL for the southern zone, and 800 MPN/100mL for the northern zone. For well water in the central zone, 210 MPN/100mL is obtained. Borehole water from the central zone has the highest coliform count followed by stream water. In the southern zone, stream records the highest coliform count followed by borehole, while in the northern zone, the stream records the highest count followed by river.

3.2 Index of Organic Pollution

$BOD_5:NO_3^-$ ratio is used as an index to measure organic pollution of water bobies from Uruan. $BOD_5:NO_3^-$ ratio ranges from 103 in NZ to 187 in SZ (river); 66.2 in SZ to 83.2 in NZ (stream); 31.2 in NZ to 44.6 in CZ (borehole) and 133 in CZ for the only well water (Table 6). River water in the southern zone contains the highest organic load while borehole in the northern zone records the lowest.

3.3 Multivariate Statistical Analysis

3.3.1 Correlation Analysis of Investigated Parameters

Pearson's correlation coefficients (2-tailed) are computed to deduce common source of water quality parameters in the river, stream and borehole/well (Tables 3-5). Significant correlations (r) are provided in bold face at $\alpha=0.05(*)$ and $\alpha=0.01$ (**). High positive correlations ($r>0.900$) are found in river between TDS and EC, Cl and TH, Cl and CO_2, Mn and EC; Mn and Cl; Fe and CO_2 at $\alpha=0.05$; DO and colour, TDS and temp, TH and TDS, ALK and BOD_5, Mn and TH, Fe and Cl at α=0.01. Significant negative correlations (r>0.900) are found between EC and temp, K and turbidity, K and TSS at α=0.05; TH and temp, Mn and temp, Mn and TDS at α=0.01. In stream, there are high positive correlations (r>0.670) between NH_3 and turbidity, NO_3 and DO at α=0.05; TDS and EC, Mn and colour at α=0.01 while significant negative correlations (r>0.670) are obtained between TH and TSS, ALK and CO_2, NO_3 and pH, K and turbidity, Na and EC, Na and TDS at α=0.05; acidity and CO_2 at α=0.01. In ground water (borehole/well), high positive correlations (r>0.760) are found between salinity and colour, ALK and turbidity, ALK and TSS, NO_3 and TSS, colour and pH, turbidity and colour, DO and NH_3, TSS and pH, at α=0.05; pH and turbidity, TSS and colour, TSS and turbidity, NO_3 and colour, NO_3 and salinity, Mn and EC at α=0.01; and negative significant correlations (r>0.809) between K and Cl, Fe and TH at α=0.05.

3.3.2 Principal Component Analysis (PCA)

Principal component analysis (PCA) reduces the multidimensionality of data set by a linear combination of original data to generate new latent variables which are orthogonal and uncorrelated to each other (Guller *et al*., 2002; Nkansah *et al*., 2010). The principal components (PCs) resulting from PCA are sometimes not readily interpreted and verimax rotation with Kaiser normalization is executed to reduce the dimensionality of the data, identify most significant variables and infer the processes that control water chemistry (Saima *et al*., 2009). Verimax factor loading coefficient (Liu *et al*., 2003) with a correlation of:

>0.75 are explained as strong significant factor loading (FL);
0.75-0.50 are considered as moderate FL; and
0.50-0.30 are considered as weak FL.

Only FL>0.75 which could be positive or negative are used in this study to explain the sources of contamination of the river, stream and borehole/well. The PCA is applied to 22 physicochemical parameters in river, stream and borehole/well water. The rotated component matrix statistics revealed that 3 PCs are extracted for river water, 6 PCs for stream water and 6 PCs for borehole/well which have eigenvalues >1. These explain 100%, 92.33% and 100% of total variance, respectively for river, stream and borehole/well (Tables 7).

For river water, the 3 PCs extracted and the corresponding component plot in rotated space are shown in Table 8 and Fig. 7. The first principal component, PC1 which explains 49.33% of total variance, has strong FLs on EC, TDS, Cl, NO_2, Mn, Na and Fe. PC2 explains 29.27% of the total variance and is characterized by strong FLs on BOD5, alkalinity, colour and DO, while PC3 accounts for 21.39% of the total variance with strong FLs on turbidity, TSS and K.

Six PCs extracted for stream water with their corresponding component plot in rotated space are presented in Table 9 and Fig. 8. PC1 explains 21.66% of the total variance with strong significant FLs on EC, TDS, K, and Na. PC2 explains 17.85% of the total variance with strong significant FLs on colour, Cl and Mn. PC3 explains 15.42% of the total variance with strong significant FLs on salinity, acidity and alkalinity. PC4 accounts for 14.38% of the total variance with strong significant FLs on turbidity, TSS and TH. PC5 accounts for 13.95% of the total variance with strong significant FLs on pH and NO_2. PC6 accounts for 9.07% of the total variance with strong significant FL on BOD_5 only.

In ground water (borehole and well), six PCs extracted with their corresponding component plot in rotated space are presented in Table 9 and Fig. 9. PC1 explains 31.17% of the total variance and is characterized by significant FLs on colour, turbidity, TSS, salinity, NO_2 and Fe. PC2 explains 17.37% of the total variance and is characterized by significant FLs on acidity, NO_2 and Mn. PC3 explains 16.32% of the total variance and is characterized by significant FL on BOD_5 only. PC4 explains 13.06% of the total variance and is characterized by significant FLs on temp, NH3 and DO. PC5 explains 11.15% of the total variance and is characterized by significant FL on Na only. PC6 explains 10.93% of the total variance and is characterized by significant FL on CO_2 only.

3.3.3 Cluster Analysis (CA)

Cluster analysis of river, stream, borehole and well water sampling stations in Uruan Local Government Area using Ward's method based on Square Euclidean distance is presented as a dendrogram (Fig.10). The "phenon line" is chosen at a linkage distance of 200 and the interpretation is subjective (Oyebog *et al*., 2012). CA used in identifying the similarities between the sampling stations based on the levels of 22 physicochemical parameters, groups the 20 stations into six clusters. Cluster 1 has five members-R1, S5, S6, B17, B19. R1, S5 are located in the CZ; S6, B17 in the SZ; and B19 in the NZ. The determinands K and Na have the highest mean values in this cluster. Cluster 2 identifies eight member stations-R4, S7, S8, S9, S10, S11, S12, S13. Located in the SZ are S7, S8 while R4, S9, S10, S11, S12, S13 in NZ. The cluster has the highest number of members and means for DO, Cl^-, NO_3^-, and K. Cluster 3 has one member, R2 from the CZ; it has the highest mean values for pH, colour, turbidity, NH_3, TSS, BOD_5, alkalinity and NO_3^-. Cluster 4 has four members-R3, B16, B14, B18. Located in the SZ are R3, B14, B18 and B16 in CZ. The highest levels of EC, DO, TDS, TH, salinity and Mn are found in this cluster. Clusters 5 and 6 are one member cluster B15 and W20, respectively from the CZ. Cluster 5 has the highest mean values for temperature, free CO_2 and K, while Cluster 6 has the highest mean values for pH, temperature, acidity and Fe. These two clusters also record the lowest mean values for most of the determinands in the study: pH, colour, turbidity, NH_3, DO, TSS, BOD_5, TH, and NO_3^- for Cluster 5; and colour, EC, NH_3, DO, TDS, salinity, NO_3^- and K for Cluster 6.

4. Discussion

Maximum benefit is derived from water usage when it is within the accepted quality standards; however, where there are alterations in the physiochemical parameters, it is imperative that it goes through processes to improve quality prior to such usage, especially for drinking.

The pH of rivers, streams, boreholes and well water from all the zones (CZ, SZ and NZ) in Uruan is neither within the Nigerian standard for Drinking Water Quality (NSDWQ, 2007) safety range (6.5-8.5) nor the WHO (2011a) limit (Table 1and Fig. 2a).With the exception of river water from the central zone with a pH of 6.8, other water sources are acidic, the most acidic being borehole water from the central zone with an average level of 5.15. The pH values for boreholes and well in Uruan are similar to those reported by Longe and Balogun (2010) for water near municipal landfill in Lagos, Nigeria. European Union (EU) protection pH limit for aquatic life and aquaculture is in the range 6.6-9.0 (Chapman, 1992). The pH obtained for surface and ground water is outside this range. Based on these guidelines, these water sources would not be suitable for domestic use, and to the aquatic ecosystem. The acidic nature of the water sources can be attributed to a number of factors. In shallow wells, the acidity might be due to the drainage of metal-rich rocks (Essumang *et al*., 2011). In the rivers, streams and boreholes, the presence of organic acids from decaying vegetation (Paschke *et al*., 2001; Verplanck *et al*., 2006), as well as dissolved carbon dioxide and the dissolution of sulphide minerals may play a significant role in the low levels of water pH (Todd, 1980). Furthermore, acid rain caused by industrial gas flaring as is the case in the environs of Uruan, could contribute to the acidic pH of ground and surface waters (Udousoro *et al*., 2010).

Temperature plays a critical role in the metabolic activities of organisms in water (Gopalkrushna, 2011a). The temperature of the different water sources are similar, ranging from 27°C to 29.5°C (Fig. 2a). Apart from the borehole water from the central zone with a slightly higher temperature (29.50°C), water temperature of the rivers, streams, boreholes and well are within the recommended limits of NSDWQ and WHO. The turbidity values for streams, boreholes and well are within the WHO recommended limit of <4NTU in all the zones. However, high turbidity values in magnitude greater than 4-9 folds of the WHO limit but twice as much as those recorded by Sha'Ato *et al.* (2010) are observed in the river water samples (Fig. 2a). Rivers from the southern (37.10 NTU) and northern (35.87 NTU) zones have very high turbidity values due to contamination from soil runoff, and the various human activities like bathing, laundering, cassava fermentation (a process of preparing garri and fufu-local diets) and sand dredging. High turbidity is usually associated with high levels of disease-causing microorganisms such as bacteria and parasites. Howard *et al.* (2003) noted that high turbidity values even in the absence of faecal indicator bacteria indicate a breach of sanitary integrity. Increase in turbidity may be caused by large amount of silt, microorganisms, plants, fibers, chemicals, etc. The most frequent causes of turbidity in ground (borehole, well) and surface water (river, stream and lake) are plankton, and soil erosion from logging, mining, and urbanization operations (AGWT, 2013). Therefore, water from these rivers would not be suitable for drinking and most domestic purposes (APHA, 1992; WHO, 2011a). The study also reveals high positive correlation between turbidity and total suspended solids in boreholes ($r=0.959$) at $\alpha=0.01$(Tables 5) implying that soil particles could be the cause of ground water turbidity. From the study, the colour of all water samples does not exceed the limit prescribed by WHO (15 Hazen Unit) (Table 1). The colour of the ground and surface water are similar to that obtained for water in Abeokuta, Nigeria (Shittu *et al*., 2008).

Electrical Conductivity (EC) is a measure of the capacity of a water sample to conduct electric current as well as the relative level of dissolved salts in the water (Gopalkrushna, 2011b). In the present study, EC of rivers and streams in the central and northern zones, borehole in the northern zone and well in the central zone are below the WHO recommended limit. However, levels of EC higher than the WHO limit (1000 µs/cm) are observed for all rivers, streams and boreholes from the southern and central zones, with the highest value recorded in the borehole water (Fig.2b) from the southern zone (6160.0 µs/cm) as supported by TDS (Table 1). This signifies high levels of contamination due to dissolved ions (Essumang *et al*., 2011; Gopalkrushna, 2011a,b), thus rendering them unfit for human consumption. EC correlates positively and significantly at $\alpha = 0.05$ with the higher TDS in rivers ($r=0.971$, $\alpha=0.05$) and streams ($r=0.986$, $\alpha=0.01$) (Tables 3 and 4), and is in agreement with those reported by Sha'Ato *et al*. (2010) for water in Benue State, Nigeria.

Total Dissolved Solids (TDS) is a measure of both anions and cations concentration in a water body. The major anions and cations of TDS include bicarbonates, sulphates, hydrogen, silicate, chloride, calcium, magnesium, manganese, sodium, potassium, nitrates, and phosphates (Mahananda *et al*., 2010). TDS in ground and surface water could come from natural and/or anthropogenic sources such as industrial waste water, sewage, urban runoff, and the chemicals used in the treatment of water (Gopalkrushna, 2011a). Water containing more than 600 mg/L of TDS is considered unfit for drinking (WHO, 2004). TDS of all water sources from the southern zone are higher than the acceptable limit of WHO (Table 2). Boreholes from the central zone also contain undesirable level of TDS (1461.5 mg/L). This could be due to tidal influence, soil weathering, leaching and percolation of dissolved ions from waste dumps, and industrial discharges, and acid rain from petroleum activities. Low TDS values are observed in river, stream and borehole from the northern zone. Higher Values of TDS than EC in river and stream from SZ and CZ respectively, could result from uncharged dissolved species in water that did not contribute to EC measurement. There is also the possibility of reduction in EC from water contaminated with dissolved hydrocarbons due to higher resistivity of the hydrocarbon component. Enhanced EC in water could result from polar organic compounds like organic acids and biosurfactants produced during degradation (Atekwana *et al.*, 2004, Cassidy *et al.*, 2001). Generally, the mean values of TDS in Uruan follow the trend borehole>river>stream>well (Fig. 2b). Total suspended solids (TSS) in water affect the aesthetic appeal of bathing water. Water that is high in TSS is more of an aesthetic than a health hazard (APHA, 1992). TSS is a precursor to turbidity due to silt and organic matter (Mahananda *et al*., 2010). The 1 mg/L level of TSS obtained is lower than the WHO limit (<10 mg/ L).TSS is relatively higher in river water (0.72-0.75 mg/L) than other water types (Fig.2c) but 26-83 folds lower than TSS in Lakhya River, Bangladesh (range19-62 mg/L) (Islam *et al*., 2010).

DO levels in surface and underground water depend on the physical, chemical, and biological activities of water body (Gopalkrushna, 2011b; Mulla *et al*., 2012). DO range obtained in river, stream, borehole and well water is very low (0.1-0.2 mg/L) (Fig. 2c), indicating anaerobic and unhealthy state of Uruan surface and underground water. There is no remarkable difference among the zones. Low levels of DO in both surface and groundwater could probably result from presence of materials of high organic content leading to oxygen depletion (Gasim *et al*, 2007). Lack of oxygen indicates a higher rate of deoxygenation due to biological decomposition of organic matter compared to reoxygenation from atmosphere or probably due to the presence of oxidizable minerals in the aquifer (Mahananda *et al*., 2010).This finding implies a high degree of organic pollution in Uruan water.BOD_5indicates the amount of organic waste present in water (Usharani *et al*., 2010). BOD_5 value of 3 mg/L in surface water has been reported to show sewage contamination through runoff (Pradhan *et al*., 1998). It can be inferred from this that contamination of the rivers, streams, boreholes and well water from all the zones is through runoff containing organic pollutants; the rivers, streams and well being more impacted than the boreholes. The low DO and high BOD_5 indicate influx of organic pollutants into the water bodies in Uruan

Alkalinity (Alk) of water indicates the buffering capacity of water against extreme pH changes. Alkalinity in water is primarily a function of carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and hydroxide (OH^-) ions and other basic compounds like borates, phosphates and silicates if present (Gopalkrushna, 2011a,b; Mahananda *et al*., 2010). Alkalinity level in river, stream, borehole and well do not exceed 3.00 mg/L, but are less than the WHO recommended limit (Table 1). The river and well water samples have relatively higher mean values than borehole and stream (Fig.2c). Alkalinity in borehole and well in the present study is lower than that reported for borehole (11.55-14.65 mg/L) and well (11.75-13.17 mg/L) water in Orissa, India (Mahananda *et al*., 2010); well water (15.0-180 mg/L) in Ghana (Essumang *et al*., 2011) and in Ken river water (182-192 mg/L) in India (Kumar and Pal, 2012). Hardness of water is the property that decreases the lather formation of soap, and increases scale formation in hot-water heaters and low-pressure boiler at high levels. Total hardness (TH) is mainly due to calcium and magnesium salts (Gopalkrushna, 2011a,b; Kumar and Pal, 2012; Mulla *et al*., 2012) and is derived from dissolved limestone or industrial effluents. TH values in this investigation (Table 1) do not exceed the WHO recommended limit (100-300 mg/L). The highest value is in the river water (30.00 mg/L) and the lowest in well water (10.70 mg/L) all from the central zone. TH in ground water are similar. The general pattern of TH in water obtained from the mean values is River>Stream>Borehole>Well (Fig. 2d). WHO (2004) classifies hardness of water into several categories: Soft water (0-50 mg/L $CaCO_3$); moderate soft (50-100 mg/L $CaCO_3$); slightly hard (100-150 mg/L $CaCO_3$); moderate hard (150-200 mg/L $CaCO_3$); hard (200-300 mg/L $CaCO_3$) and very hard (over 300) mg/L. On the basis of this classification, all the water sources could be described as soft water. The range of TH obtained in the present study is similar to that reported by Essumang (2011) for ground water (19.21-32.98 mg/L) but lower than (102-199.33 mg/L) reported by Mulla *et al*. (2012) for ground water; and 348-678 mg/L reported by Gopalkrushna (2011b) for river.

The acidity of water is its quantitative capacity to react with a strong base. Strong mineral acids and weak acids such as carbonic and acetic, and hydrolysing salts such as aluminium or iron sulphates may contribute to measured acidity (APHA, 1992). Acidity and free CO_2 in rivers, streams, boreholes and well in all the zones are shown in Table1 and Fig. 2c.The mean value of acidity of water samples is 0.16 mg/L in river, 0.15 mg/L in stream, 0.14 mg/L in borehole, and 0.21 mg/L in well. These are lower than the WHO range (4.5-8.0 mg/L) and the NSDWQ (0.3 mg/L) guidelines for potable water. Free CO_2 in water from the different sources is similar and does not exceed the WHO guideline (1.8 mg/L). The water pH could be lowered if the free CO_2 released during respiration of aquatic organisms react with water, producing carbonic acid. This may explain the lowering of the pH of water in Uruan.

Chloride level higher than 10 mg/L is a result of anthropogenic source of pollution by sewage, septic systems, landfill, or fertilizers (Essumang, 2011; Gopalkrushna 2011a,b; Mahananda *et al*., 2010). Higher chloride concentration in water causes laxative effects. The range of Cl^- in river, stream, borehole and well are 13.00-

17.00 mg/L, 12.8-15.60 mg/L, 10.93-12.00 mg/L and 11.60 mg/L, respectively (Fig.2d). Cl^- content in water from all the zones is lower than the limit (250 mg/L) set by WHO for drinking water. The Cl^- content in borehole in the present study is higher than that for water from Lagos State, Nigeria (2.84-13.47 mg/L) but lower than for water from Akot, India (290-308 mg/L) (Gopalkrushna, 2011a; Longe and Balogun, 2010). Low levels of Na^+ and Cl^- in Uruan water sources are an indication of the absence of intrusion of sea water (Essumang, 2011). Salinity in water follows the sequence River>Stream>Borehole>Well (Fig. 3). In comparison, water from rivers and streams in the southern zones have the highest mean salinity values of 0.50% and 0.39%, respectively, while the highest in borehole water is from the northern zone (0.40%) (Table 1).

Nitrate, nitrite and ammonia levels in river, stream, borehole and well water in all the zones are presented in Table 1. Nitrates are the final product of the biochemical oxidation of ammonia (Mahananda *et al*., 2010). The determination of level of nitrates in water is necessary because of its implication for human health. It serves as an indicator of the degree of organic pollution of the water source (Eletta *et al*., 2010; Gopalkrushna, 2011a,b; Mahananda *et al*., 2010). High nitrate concentration in drinking water has detrimental effects on pregnant women and babies less than six months old (Longe and Balogun, 2010). The stream water samples contain the highest level of NO_3^- (Fig. 4). Nitrites occur as an intermediate product of conversion of ammonium ion to nitrate as well as in the nitrification process of ammonia (Eletta *et al*., 2010). Nitrites can be more harmful than nitrates in drinking water supply as nitrites can oxidize haemoglobin to methaemoglobin in the body and hinder the transportation of oxygen around the body (Alsabahi *et al*., 2009; Chapman, 1992). The mean values for all the water sources are 0.02 mg/L (river), 0.04 mg/L (stream), 0.02 mg/L (borehole) and 0.08 mg/L (well). These values are lower than the WHO prescribed limit of less than 3.0 mg/L. Like NO_3^-, the highest value of NO_2^- is observed in stream sample (Fig. 4). The mean levels of ammonia in river, stream, borehole, and well water samples are 15, 3, 9 and 4 times greater than the levels of NO_3^-, and 92, 13, 61 and 20 times greater than NO_2^-, respectively. The river water samples are observed to have the highest level of ammonia.

Na and K levels are below the WHO recommended limit of 250 mg/L (Table 1). The highest level of Na is observed for river water samples and the lowest for stream water samples (Figure 5a). K on the other hand is highest in borehole water samples but lowest in well water sample (Fig. 5b). High levels of Mn in water result in taste and precipitation problems (Longe and Balogun, 2010). In uncontaminated water, Mn is usually present at 0.02 mg/L or less. Large amounts of Mn are usually found in acidic water (USEPA, 1979). The WHO recommended limit for drinking water is 0.1 mg/L. Levels of Mn in most of the water samples do not exceed the WHO recommended level (Table 1) except for river water in the SZ (0.160 mg/L), borehole water in both the CZ (0.160 mg/L) and SZ (0.30 mg/L), and well water (0.163 in CZ). Variations of Mn in the different water sources are shown in Fig. 5b. The level in well water is highest while the lowest is in stream water. Fe is essential in the metabolism of plants and animals. If present in excessive amounts however, it forms oxyhydrate precipitates that stain laundry and porcelain. The WHO recommended limit for drinking water supplies is 0.3 mg/L. Only streams from the CZ have Fe levels below the WHO limit, others have higher values. The order of magnitude of mean levels of Fe higher than the WHO limit is 1-4, 3-10, 2-31, and 35 for river, stream, borehole and well, respectively. The well water sample contains the highest level of Fe (10.6 mg/L), and the lowest in river water sample (0.67 mg/L) (Fig. 5a). Most of the rivers and streams in these zones are major fishing points hence their banks are littered with broken down boats undergoing repairs, and rusted metals and pipes. This may have contributed to the high level of Fe in the sampling points. Also, the acidic nature of the water could positively affect the increase in the level of Fe in both ground water and surface water (Edmunds *et al*., 1992; Paschke *et al*., 2001; Verplanck *et al*., 2006). The overall ionic dominance pattern for the river, stream, borehole and well water samples follow the same trend Fe>Na>Mn>K and $Cl^- > NO_3^- > NO_2^-$. The borehole and well water samples contain more Fe than Mn (Fig. 5a,b) which is in agreement with USEPA (1979) report.

The results obtained for microbial analyses are shown in Fig. 6. The highest coliform count of 7.36 x 10^4 MPN/100 ml is in stream water at the SZ, and the lowest count of 2.10 x 10^2 MPN/100 ml is in well water at the CZ. The high coliform count obtained from all surface and ground water analysed in this study implies poor sanitary conditions of the water bodies, and is also an indication of pollution by organic materials (APHA, 1992; Mahananda *et al*., 2010; Sha'Ato *et al*., 2010; WHO, 2011a). It is common practice for those living along the river catchment to discharge domestic waste, agricultural waste as well as human faeces into rivers and streams. Total coliform count exceeds the WHO limit of 200 MPN/100 ml and 0.00 MPN/100 ml for both surface and underground sources of drinking water, respectively.

$BOD_5:NO_3^-$ ratio is a measure of organic pollution for stream water (Obunwo *et al*., 2012; Orhon *et al*., 1997). Water with $BOD_5:NO_3^-$ ratio <4 is considered potable while >4 is polluted. This ratio is used to classify stream, river, borehole and well water in the present study. It is found that all the water bodies are polluted, having $BOD_5:NO_3^-$ ratio >4 with mean values of 131, 74, and 38 for river, stream and borehole, respectively. The only well has a value of 133. The study reveals heavy organic pollution of all water bodies (Table 6). Organic load is higher in the river and well water.

PC1 can be interpreted as mineral component of the river water in Uruan due to high FLs on TDS and TH (r =

0.995**). High loadings on NO_2, Mn, Na, Fe and Cl^- may suggest leachates from domestic waste water, decomposition of abandoned electronic and metal scraps. Therefore, the source of pollution is both natural (from hydro-chemical processes) and anthropogenic (from leaching and leakages). PC2 represents anthropogenic input of organic matter runoff in contact with human and animal faeces or waste disposal (Yeung, 1999) and PC3 indicates pollution from surface runoff from forest and agricultural areas into the river.

In the stream, PC1 signifies natural mineralization of stream water; the high FL on EC indicates inorganic compounds in water (Vega *et al*., 1998). PC2 may indicate pollution by sewage; Mn is found both in animal and human faeces. PC3 could suggest atmospheric acidic deposition (acid rain). The stream water has low alkalinity (<< 24 mg/l as $CaCO_3$) and consequently, a low buffering capacity. Therefore, it is susceptible to alteration in pH from atmospheric acidic deposition (Cobbina *et al*., 2012). PC4 suggests the influence of erosion of surface soil into stream water; the high FL on TSS largely confirms natural erosion from surface soils. PC5 can be ascribed to the effect of drainage of agricultural area by storm water. In PC6, BOD_5 a single dominate variable represents anthropogenic input of organic origin which could come from runoff or waste disposal activities.

In ground water (borehole and well), PC1 suggests turbidity could be associated with mineral matter suspension. Leaching and weathering through the overlying lateritic soil can increase the Fe level of ground water with the process enhanced by low pH. High concentration of Fe could impart colour, deposition and turbidity (Adekunle *et al*., 2007). PC2 may explain the effect of industrial activities on ground water. Percolation of acid rain due to gas flaring activities into the ground water table may result in the enrichment of NO_2 and Mn in ground water. It has been reported that the divalent form, Mn^{2+}, predominates in most water at pH=4.0-7.0 (WHO, 2011b). Acid rain water in contact with human and animal excreta and spent batteries may influence leaching of these ions. PC3 high loading on BOD_5 is clearly an organic pollution index derived from human and animal faeces and waste. PC4 presents as rural domestic source of pollution such as ascribed to leakages from septic tank and pit latrines (Geiser *et al*., 2008). PC5 could be ascribed to domestic and industrial waste water effluents into ground water system. PC6 could be due to natural conditions that affect the CO_2 gas concentrations in ground water. It has been reported that the main sources of CO_2 in ground water are from plant-root respiration processes and the oxidation (decay) of organic carbon in both the soil and in the aquifer matrix (Macpherson, 2009).

The cluster membership shows that strong associations exist among the sampling stations and probably, are impacted from common source. Cluster 2, characterized by the highest number of members suggests uniformity in the degree of impact on the parameters identified. Cluster 4 is very unique in that it has the highest content of dissolved inorganic materials; and the highest mean values for EC, DO, TDS, TH, salinity, and Mn. The six clusters sampling stations reveal that each cluster has its peculiar quality different from other clusters. Therefore, CA offers useful and reliable classification of river, stream, borehole and well water in Uruan Local Government Area.

5. Conclusions

The physicochemical and microbial analyses of potable water sources in Uruan communities of Akwa Ibom State reveal that river, stream, borehole and well water are acidic. The turbidity, electrical conductivity (EC), Fe and total coliform levels are higher than the WHO recommended limits. The BOD_5:NO_3^- ratio-an index of organic pollution, imply that the water bodies are heavily polluted with materials of organic origin. River water from the southern zone is most impacted with organic pollution. Sources of the pollution may include among others, wastes from domestic and agricultural activities, leachates from waste dumps and sewer tanks. These water bodies invariably, are unfit for human consumption. There is therefore need for the existence of a statutory unit charged with responsibility for continuous monitoring of water bodies, sensitization and education of the rural populace in Uruan on the adverse health implications of the presence of toxic materials in their water supply sources.

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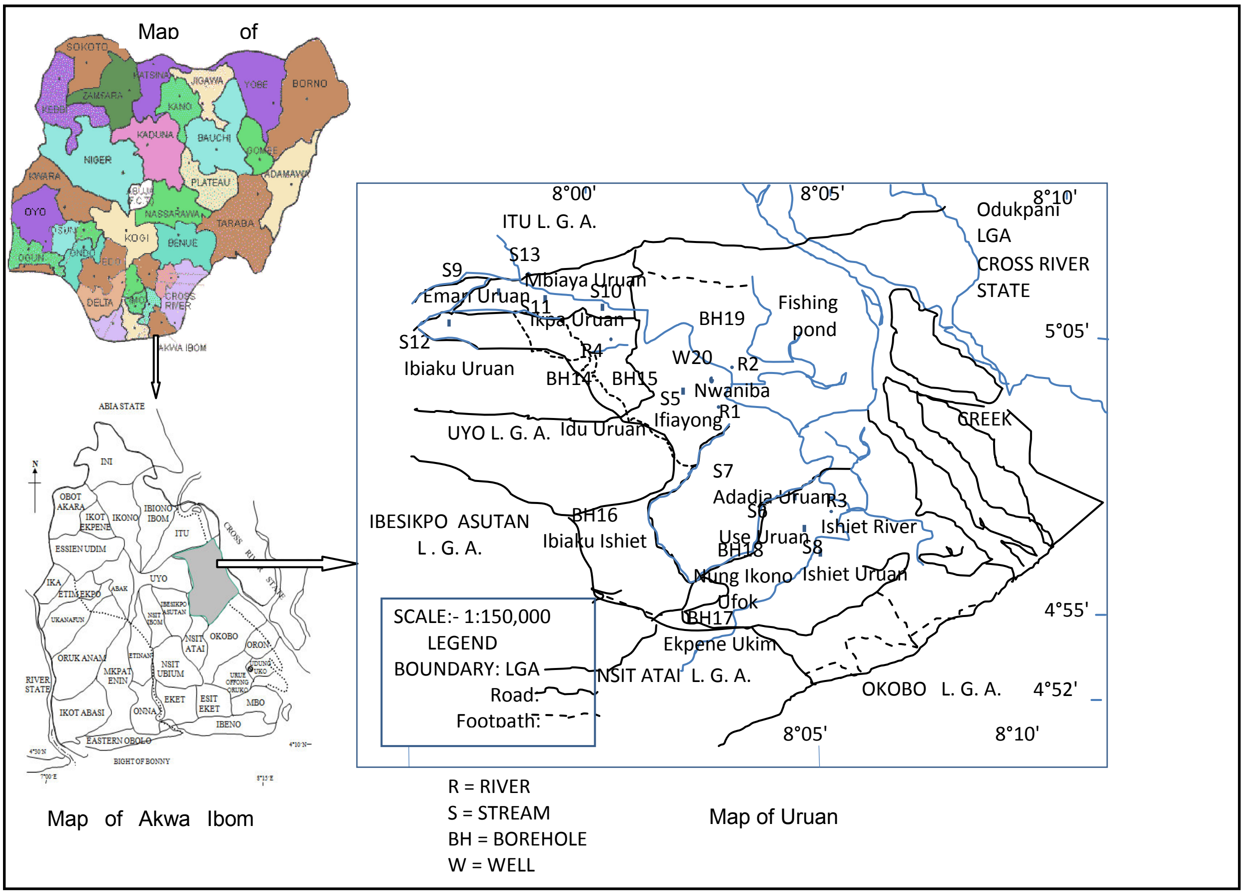


Figure 1. Location of Sampling Points in the Map of Uruan.

Table 1. Physiochemical parameters of river, stream, borehole and well water samples for each zone in Uruan LGA

Physicochemical parameters	River				Stream				Borehole				Well			WHO (2011)
	CZ	SZ	NZ	Range	CZ	SZ	NZ	Range	CZ	SZ	NZ	Range	CZ	SZ	NZ	
pH	5.75	5.50	6.80	5.50 – 6.80	5.30	5.57	5.86	5.30 – 5.86	5.15	5.53	6.50	5.15 – 6.50	6.00	-	-	6.5 – 8.5
Temperature (°C)	28.00	27.00	28.00	27 – 28	29.0	27.33	28.00	27.33 – 29.00	29.50	27.33	28.00	27.33 - 29.50	29.00	-	-	27 – 29
Colour (Hazen Unit)	10.00	10.00	10.00	0	5.00	5.00	5.00	0	5.00	5.00	10.00	5.00 - 10.00	5.00	-	-	<15
Conductivity (µs/cm)	172.30	1080.00	27.20	27.20 – 1080.00	147.70	1429.33	73.18	73.18 – 1429.20	2923.00	6160.00	102.81	102.81 – 6160.00	76.64	-	-	1000
Turbidity (NTU)	16.03	37.10	35.87	16.03 – 37.10	1.74	1.98	1.24	1.24 – 1.98	0.82	0.86	2.81	0.82 – 2.81	1.93	-	-	<4
Ammonia (mg/l)	0.65	0.60	0.60	0.60 – 0.65	0.60	0.57	0.40	0.40 – 0.60	0.45	0.37	0.40	0.30 – 0.45	0.40	-	-	–
DO (mg/l)	0.10	0.10	0.20	0.10 – 0.20	0.20	0.13	0.10	0.10 – 0.20	0.15	0.10	0.10	0.10 – 0.15	0.10	-	-	–
TDS (mg/l)	72.50	5040.00	12.60	12.60 – 5040.00	295.40	714.63	36.50	36.50 – 714.63	1461.50	3080.00	51.40	51.40 – 3080.00	38.80	-	-	> 600
TSS (mg/l)	0.72	0.74	0.75	0.72 – 0.75	0.62	0.62	0.58	0.58 – 0.62	0.41	0.39	0.69	0.39 – 0.69	0.48	-	-	> 10
BOD_5 (mg/l)	15.56	18.74	10.27	10.27 – 18.74	14.35	12.58	12.50	12.50 – 14.35	4.90	4.30	6.25	4.30 – 6.25	13.30	-	-	–
Total Hardness (mg/l)	12.25	30.00	13.00	12.25 – 30.00	12.30	13.00	15.38	12.30 – 15.38	11.85	12.90	14.80	11.85 – 14.80	10.70	-	-	100 – 300
Salinity (%)	0.28	0.50	0.35	0.28 – 0.50	0.28	0.39	0.31	0.28 – 0.39	0.28	0.25	0.40	0.25 – 0.40	0.20	-	-	–
Free CO_2 (mg/l)	1.05	1.20	1.00	1.00 – 1.20	1.00	1.03	1.08	1.00 – 1.08	1.40	1.00	1.00	1.00 – 1.40	1.10	-	-	1.8
Acidity (mg/l)	0.16	0.12	0.20	0.12 – 0.20	0.15	0.17	0.14	0.14 – 0.17	0.16	0.17	0.10	0.10 – 0.17	0.21	-	-	4.5 – 8.0
Alkalinity (mg/l)	2.50	3.00	1.50	1.50 – 3.00	1.80	2.50	2.13	1.80 – 2.50	2.25	1.77	3.00	1.77 – 3.00	2.50	-	-	200
Chloride(mg/l)	13.45	17.00	13.00	13.00 – 17.00	12.80	15.60	14.94	12.80 – 15.60	11.35	10.93	12.00	10.93 – 12.00	11.60	-	-	250
Nitrate (mg/l)	0.15	0.10	0.10	0.10 – 0.15	0.20	0.19	0.15	0.15 – 0.20	0.11	0.11	0.20	0.11 – 0.20	0.10	-	-	50
Nitrite (mg/l)	0.02	0.03	0.02	0.02 – 0.03	0.01	0.02	0.08	0.01 – 0.08	0.02	0.02	0.02	0	0.02	-	-	<3.0
Manganese (mg/l)	0.01	0.1600	0.0070	0.007 -0.01	0.095	0.02	0.08	0.02 – 0.095	0.16	0.30	0.070	0.07 – 0.30	0.163	-	-	0.1
Potassium (mg/l)	0.15	0.10	0.10	0.10 – 0.15	0.20	0.10	0.26	0.10 – 0.26	0.25	0.23	0.10	0.10 – 0.25	0.10	-	-	250
Sodium (mg/l)	1.65	2.20	2.10	1.65 – 2.20	1.00	1.10	1.86	1.00 – 1.86	1.50	2.07	1.80	1.80 – 2.07	1.80	-	-	<200
Iron (mg/l)	0.40	1.249	0.352	0.352 – 1.249	0.151	0.96	2.98	0.151 – 2.98	9.21	5.02	0.591	0.59 – 9.21	10.623	-	-	0.3

CZ = central zone; SZ = southern zone; NZ = northern zone; WHO = World Health Organisation (2011a).

Table 2. Total coliform in river, stream, borehole and well water samples from Uruan

Water sources	CZ	SZ	NZ	WHO
River	5.73E+02	4.90E+02	9.85E+02	200 MPN/100ml
Stream	8.10E+02	7.36E+04	2.37E+03	200 MPN/100ml
Borehole	2.57E+03	1.56E+03	8.00E+02	0.00 MPN/100ml
Well	2.10E+02	NS	NS	0.00 MPN/100ml

NS= no sample, MPN = most probable number, CZ = central zone, SZ = southern zone, NZ = northern zone.

Table 3. Pearson correlation among determinands in river water from Uruan Local Government.

	pH	Temp	Colour	EC	Turbidity	NH_3	DO	TDS	TSS	BOD5	TH	Salinty	CO_2	Acidity	Alk	Cl	NO_3	NO_2	Mn	K	Na	Fe
pH	1																					
Temp	.489	1																				
Colour	.923	.333	1																			
EC	-.511	**-.966***	-.452	1																		
Turbidity	.475	-.439	.389	.497	1																	
NH_3	.054	.333	-.333	-.079	.154	1																
DO	.923	.333	**1.000****	-.452	.389	-.333	1															
TDS	-.492	**-1.000****	-.344	**.971***	.445	-.314	-.344	1														
TSS	.552	-.139	.325	.278	.917	.510	.325	.150	1													
BOD5	-.645	-.619	-.793	.788	.252	.479	-.793	.634	.277	1												
TH	-.478	**-.997****	-.294	.942	.412	-.408	-.294	**.995****	.091	.558	1											
Salinity	-.904	-.799	-.825	.830	-.060	-.074	-.825	.803	-.219	.811	.780	1										
CO_2	-.766	-.870	-.522	.782	-.054	-.522	-.522	.866	-.363	.487	.887	.886	1									
Acidity	.935	.647	.734	-.586	.396	.388	.734	-.644	.606	-.489	-.660	-.899	-.924	1								
Alk	-.597	-.556	-.778	.742	.265	.556	-.778	.572	.325	**.996****	.490	.758	.406	-.417	1							
Cl	-.653	-.944	-.417	.859	.136	-.519	-.417	.939	-.195	.501	**.958***	.851	**.981***	-.835	.422	1						
NO_3	.054	.333	-.333	-.079	.154	**1.000****	-.333	-.314	.510	.479	-.408	-.074	-.522	.388	.556	-.519	1					
NO_2	-.333	-.816	.000	.640	.175	-.816	.000	.804	-.227	.086	.860	.534	.853	-.634	.000	.896	-.816	1				
Mn	-.535	**-.997****	-.359	**.950***	.369	-.381	-.359	**.996****	.059	.598	**.998****	.821	.907	-.701	.530	**.967***	-.381	.844	1			
K	-.489	.333	-.333	-.435	**-.982***	-.333	-.333	-.342	**-.974***	-.305	-.294	.100	.174	-.475	-.333	-.009	-.333	.000	-.257	1		
Na	.103	-.632	.422	.434	.390	-.843	.422	.618	.000	-.212	.684	.149	.550	-.246	-.281	.645	-.843	.904	.641	-.211	1	
Fe	-.617	-.921	-.352	.813	.109	-.600	-.352	.915	-.241	.414	.943	.805	**.978***	-.826	.331	**.995****	-.600	.932	.949	.030	.701	1

Bold face implies: *correlation is significant at the 0.05 level (2-tailed), **correlation is significant at the 0.01 level (2-tailed).

Table 4. Pearson correlation among determinands in stream water from Uruan Local Government.

	pH	Temp	Colour	EC	Turbidity	NH_3	DO	TDS	TSS	BOD5	TH	Salinity	CO_2	Acidity	Alk	Cl	NO_3	NO_2	Mn	K	Na	Fe
pH	1																					
Temp	.212	1																				
Colour	-.397	.533	1																			
EC	-.409	-.632	-.164	1																		
Turbidity	-.114	-.037	.158	.247	1																	
NH_3	-.232	.325	.247	-.214	**.681***	1																
DO	-.276	-.237	.555	.383	.299	-.087	1															
TDS	-.481	-.551	.004	**.986****	.277	-.176	.483	1														
TSS	.005	.003	.104	-.121	.537	.449	-.034	-.104	1													
BOD5	-.029	.361	.344	.000	.226	.300	-.034	.058	-.210	1												
TH	.463	.031	-.190	.100	-.513	-.536	-.062	.069	**-.685***	.413	1											
Salinity	.234	-.319	-.300	.389	.518	.227	-.075	.343	.570	.223	.020	1										
CO_2	-.319	-.538	-.287	-.043	-.519	-.268	-.159	-.092	-.267	-.122	.080	-.233	1									
Acidity	.127	.239	-.046	.222	.179	.220	-.025	.217	.200	-.295	-.089	.213	**-.672***	1								
Alk	.339	.264	-.316	.153	.502	.311	-.344	.102	.169	.074	-.079	.372	**-.743***	.610	1							
Cl	.202	-.354	-.639	.467	-.061	-.051	-.407	.365	-.034	.117	.429	.661	.054	.361	.342	1						
NO_3	**-.725***	-.529	.255	.541	.029	-.077	**.688***	.592	-.326	-.118	-.123	-.296	.398	-.192	-.520	-.202	1					
NO_2	.621	.072	-.170	-.248	.160	-.293	-.139	-.279	.362	-.041	-.008	.282	-.297	-.231	.269	-.172	-.621	1				
Mn	-.311	.551	**.990****	-.227	.091	.188	.539	-.062	.053	.395	-.089	-.310	-.247	-.123	-.369	-.641	.212	-.120	1			
K	.099	.480	.000	-.589	**-.701***	-.202	-.624	-.598	.000	-.256	.000	-.423	.172	.069	-.152	-.094	-.865	.013	.020	1		
Na	.367	.171	-.401	**-.731***	-.583	-.081	-.657	**-.809****	-.262	-.117	.184	-.394	.520	-.355	-.231	-.031	-.377	.033	-.327	.601	1	
Fe	.563	-.255	-.387	-.230	-.379	-.599	-.189	-.298	-.179	.089	.4966	.092	.404	-.662	-.292	.050	-.303	.629	-.270	.058	.452	1

Bold face implies: *correlation is significant at the 0.05 level (2-tailed), **correlation is significant at the 0.01 level (2-tailed).

Table 5. Pearson correlation determinands in borehole water from Uruan Local Government.

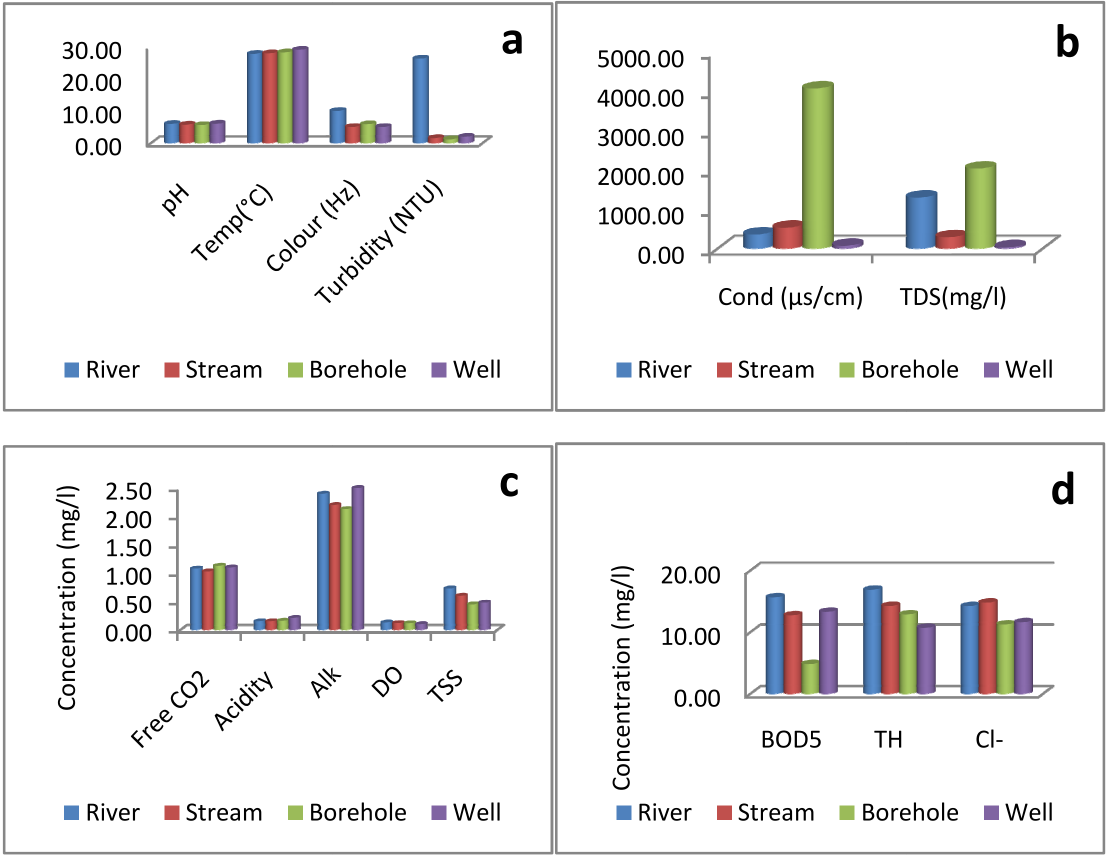
	pH	Temp	Colour	EC	Turbidity	NH_3	DO	TDS	TSS	BOD5	TH	Salinity	CO_2	Acidity	Alk	Cl	NO_3	NO_2	Mn	K	Na	Fe
pH	1																					
Temp	-.266	1																				
Colour	**.797***	-.113	1																			
EC	-.492	-.175	-.360	1																		
Turbidty	**.938****	.032	**.857***	-.542	1																	
NH_3	-.180	.519	.000	.066	-.022	1																
DO	-.392	.679	-.167	.178	-.246	**.764***	1															
TDS	-.454	-.612	-.467	.547	-.687	.058	.006	1														
TSS	**.866***	.067	**.950****	-.533	**.959****	.078	-.119	-.645	1													
BOD5	.474	.349	.029	-..545	.534	.039	-.138	-.618	.324	1												
TH	.455	-.390	.642	.036	.338	.187	.184	.248	.487	-.425	1											
Salinty	.435	-.006	**.823***	.162	.530	.251	.183	-.212	.686	-.328	.719	1										
CO_2	-.571	.570	-.256	-.019	-.297	.261	.142	-.247	-.223	-.050	-.630	-.156	1									
Acidity	-.235	-.229	-.439	.519	-.277	.089	-.303	.367	-.427	.127	-.440	-.287	.200	1								
Alk	.587	.244	.707	-.386	**.787***	.284	-.161	-.639	**.795***	.418	.063	.524	.271	.058	1							
Cl	.256	.000	.368	.192	.402	-.034	-.421	.352	.352	.156	-.213	.392	.368	.527	.732	1						
NO_3	.662	-.264	**.912****	-.023	.710	.000	-.270	-.264	**.795***	-.142	.594	**.880****	-.173	-.103	.706	.618	1					
NO_2	.255	-.085	.167	.580	.230	.382	.167	.133	.158	.089	.302	.457	-.341	.508	.248	.421	.389	1				
Mn	-.234	-.369	-.295	**.915****	-.342	-.043	-.110	.518	-.422	-.294	-.012	.091	-.167	.736	-.234	.365	.072	.720	1			
K	-.479	.000	-.382	-.223	-.550	.250	.382	.492	-.415	-.363	.131	-.377	.065	-.358	-.540	**-.809***	-.542	-.573	-.432	1		
Na	.145	-.272	-.011	-.524	-.007	.255	.067	.370	.034	.053	.348	-.261	-.309	-.239	-.150	-.617	-.207	-.300	-.477	.738	1	
Fe	-.557	.708	-.686	.030	-.390	.104	.292	-.301	-.498	.414	**-.872***	-.620	.572	.219	-.178	-.043	-.722	-.201	-.051	.001	-.340	1

Bold face implies: *correlation is significant at the 0.05 level (2-tailed), **correlation is significant at the 0.01 level (2-tailed).

Table 6. Organic pollution index of river, stream, borehole and well water samples from Uruan using $BOD_5:NO_3^-$ ratio.

Water sources	CZ	SZ	NZ
River	104	187	103
Stream	71.8	66.2	83.2
Borehole	44.6	39.1	31.2
Well	133	NS	NS

NS- No sample, CZ = central zone, SZ = southern zone, NZ = northern zone.



Figuures 2a-d. Physicochemical characteristics of different water sources in Uruan.

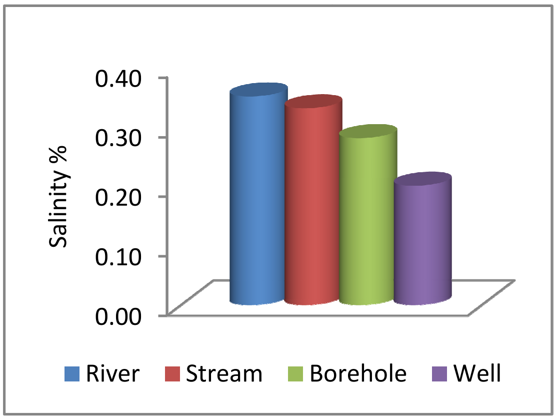


Figure 3. Salinity of Different Water Sources in Uruan.

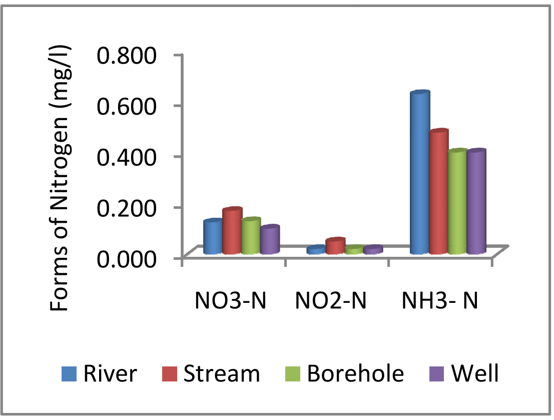
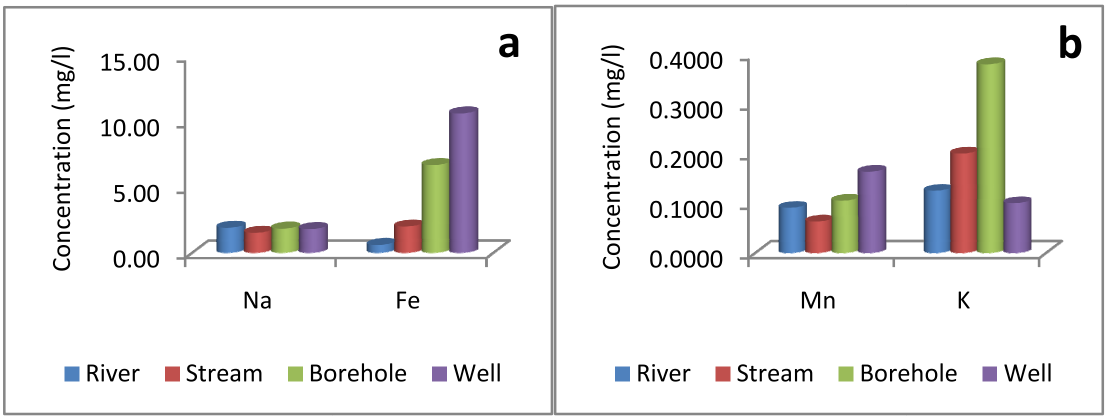


Figure 4. Nitrogen Levels of Different Water Sources in Uruan.



Figs. 5a-b. Metal Concentrations of Different Water Sources in Uruan.

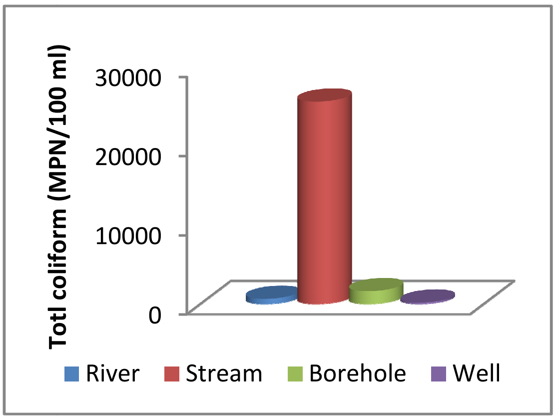


Figure 6. Total Coliform Content of Different Water Sources in Uruan

Table 7. Total variance explained by PCA for river, stream and ground water with eigenvalues greater than one.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
River water									
1	11.968	54.401	54.401	11.968	54.401	54.401	10.853	49.333	49.333
2	5.361	24.370	78.771	5.361	24.370	78.771	6.440	29.273	78.606
3	4.670	21.229	100.000	4.670	21.229	100.000	4.707	21.394	100.000
Stream water									
1	5.475	24.886	24.886	5.475	24.886	24.886	4.766	21.664	21.664
2	4.353	19.786	44.672	4.353	19.786	44.672	3.927	17.849	39.512
3	4.220	19.182	63.854	4.220	19.182	63.854	3.392	15.418	54.930
4	2.404	10.925	74.779	2.404	10.925	74.779	3.164	14.381	69.311
5	2.203	10.014	84.794	2.203	10.014	84.794	3.069	13.948	83.259
6	1.658	7.537	92.331	1.658	7.537	92.331	1.996	9.072	92.331
Ground water									
1	7.559	34.360	34.360	7.559	34.360	34.360	6.858	31.174	31.174
2	4.448	20.219	54.579	4.448	20.219	54.579	3.821	17.367	48.541
3	4.225	19.206	73.785	4.225	19.206	73.785	3.591	16.322	64.863
4	2.797	12.713	86.498	2.797	12.713	86.498	2.873	13.060	77.923
5	1.683	7.648	94.146	1.683	7.648	94.146	2.453	11.148	89.071
6	1.288	5.854	100.000	1.288	5.854	100.000	2.404	10.929	100.000

Extraction Method: Principal Component Analysis.

Table 8. Rotated component matrix[a] of river water of water quality model.

Parameter	Component		
	1	2	3
pH	-.442	-.714	.543
Temperature	**-.933**	-.279	-.226
Colour	-.168	**-.920**	.354
EC	**.810**	.476	.343
Turbidity	.270	-.104	**.957**
NH_3	-.649	.640	.413
DO	-.168	**-.920**	.354
TDS	**.926**	.296	.236
TSS	-.106	.049	**.993**
BOD_5	.327	**.906**	.269
Total Hardness	**.959**	.216	.184
Salinity	.690	.701	-.181
CO_2	**.914**	.292	-.282
Acidity	-.693	-.456	.559
Alkalinity	.246	**.919**	.308
Cl	**.966**	.236	-.105
NO_3	-.649	.640	.413
NO_2	**.969**	-.221	-.114
Mn	**.951**	.273	.147
K	-.117	.001	**-.993**
Na	**.818**	-.563	.115
Fe	**.978**	.148	-.145

Extraction Method: Principal Component Analysis.
Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.

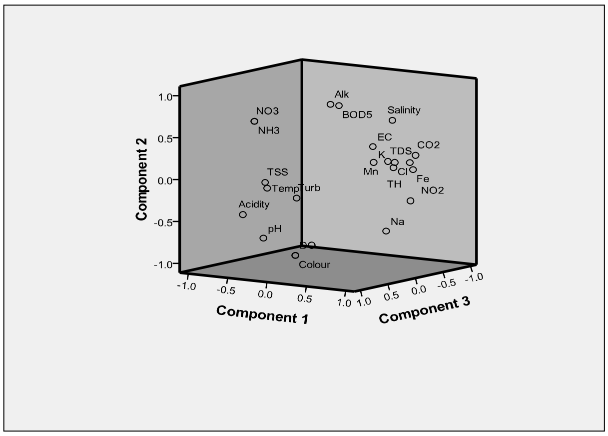


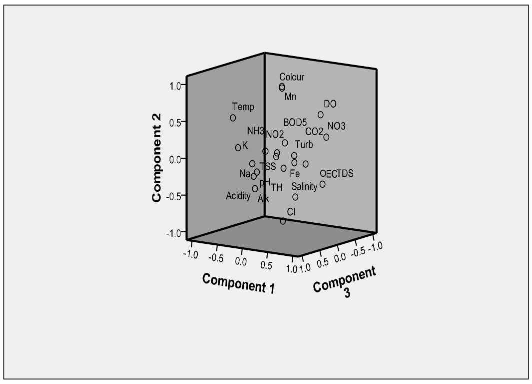
Figure 7. Component Plot on Rotated Space for River Water

Table 9. Rotated component matrix[a] (stream water) and matrix[b] (ground water) quality models.

Parameter	Component for stream water						Component for ground water					
	1	2	3	4	5	6	1	2	3	4	5	6
pH	-.302	-.230	.267	-.194	**.773**	.071	.704	-.032	.580	-.275	.054	-.296
Temperature	-.607	.513	.510	-.035	.017	.315	-.175	-.276	.289	**.761**	-.372	.303
Colour	.065	**.922**	.077	.087	-.199	.201	**.967**	-.182	.147	-.064	-.063	-.035
EC	**.887**	-.297	.104	-.122	-.228	-.040	-.166	.724	-.578	.101	-.307	-.095
Turb	.431	.067	.254	**.764**	.070	.288	**.756**	-.108	.630	-.081	-.092	-.065
NH_3	-.173	.058	.210	.731	-.389	.423	.124	.216	.040	**.868**	.369	.218
DO	.710	.600	-.093	-.014	-.025	-.117	-.102	-.076	-.175	**.964**	-.009	-.153
TDS	**.911**	-.145	.118	-.109	-.263	-.006	-.293	.403	-.631	-.136	.537	-.217
TSS	-.008	-.007	.139	**.848**	.218	-.143	**.873**	-.221	.430	.027	-.054	-.017
BOD_5	.050	.161	-.025	-.088	.011	**.967**	-.121	-.004	**.991**	.027	-.034	.022
TH	.050	-.178	.013	**-.845**	.243	.401	.721	.000	-.322	.130	.301	-.519
Salinity	.400	-.508	.181	.412	.316	.341	**.908**	.115	-.233	.244	-.215	-.043
CO_2	-.139	-.269	**-.884**	-.180	-.265	-.113	-.241	-.162	-.113	.230	-.179	**.904**
Acidity	.076	-.158	**.897**	.042	-.226	-.217	-.303	**.842**	.095	-.202	.097	.374
Alk	.022	-.346	**.782**	.232	.176	.145	.688	.054	.490	.081	-.048	.524
Cl	.187	**-.849**	.228	-.175	-.072	.252	.424	.472	.190	-.226	-.365	.614
NO_3	.601	.237	-.414	-.118	-.573	-.186	**.963**	.156	-.028	-.155	-.111	.107
NO_2	-.069	.020	.027	.184	**.944**	-.078	.321	**.871**	.127	.265	-.098	-.207
Mn	.024	**.930**	.022	.017	-.120	.252	-.114	**.905**	-.308	-.129	-.213	-.101
K	**-.810**	.022	.079	-.232	-.082	-.294	-.373	-.487	-.396	.237	.633	-.099
Na	**-.838**	-.261	-.369	-.201	.061	-.034	-.028	-.305	.085	.032	**.922**	-.218
Fe	-.122	-.200	-.541	-.315	.739	.075	**-.758**	-.061	.296	.315	-.378	.301

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 7 iterations.
b. Rotation converged in 10 iterations.



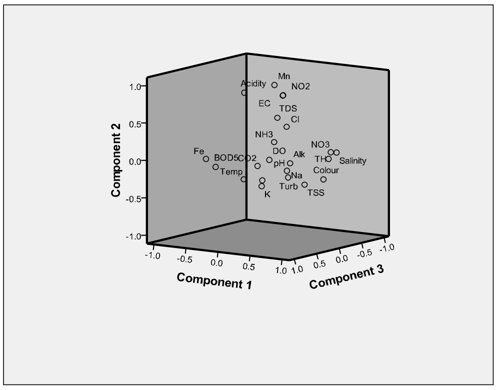


Figure 8. Component plot on rotated space for stream water Figure 9. Component plot on rotated space for ground water

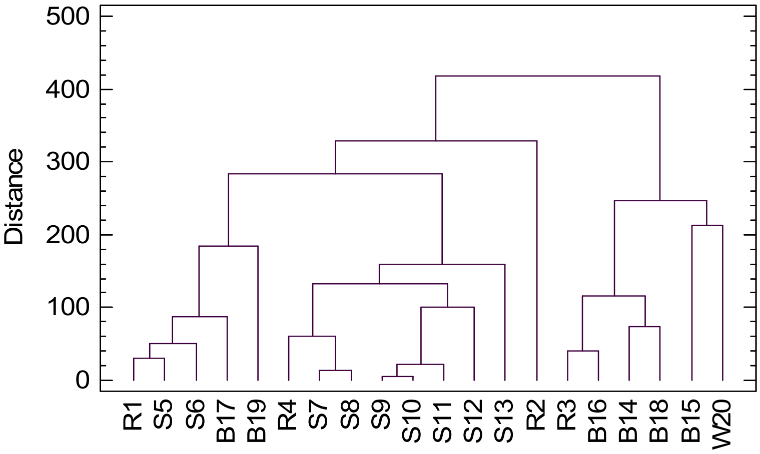


Figure 10. Dendrogram for Component Analysis of Water Sampling Stations using Ward's Method, Square Euclidean Distance (R=River, S=Stream, B=Borehole, W=Well)