Impact of Climate Change on Groundwater Resources: An Example from Cross River State, Southeastern Nigeria

*Edet A., Ukpong A. J. and Ekwere A. S.

Department of Geology, University of Calabar, Calabar, Nigeria

*Corresponding author ; E mail: aniekanedet@yahoo.com,, andyukpong@yahoo.com, zerratta77@yahoo.com

Abstract

This paper presents least square equations for predicting some groundwater physical properties (static water level, total dissolved solids, groundwater temperature) in Cross River State, based on some climatic parameters (rain amount, air temperature). This was to assess the impact of future climate variability on the quantity and quality of groundwater in the study area. The results showed that irrespective of the geologic units and seasons, the static water level (SWL), groundwater temperature (GWT), pH and dissolved oxygen (DO) were in stable state conditions based on low standard deviation (SD) values. Secondly, in all the locations occupied, the amount of rainfall (RA) and air temperature (AT) showed significant correlations with SWL, GWT, pH, electrical conductivity (EC) and total dissolved solids (TDS). Predictive equations using climatic change indicators (RA, AT) and groundwater physical properties (SWL, GWT, TDS) were developed and used as a tool for monitoring the change in groundwater quantity and quality due to climate change. The fluctuations observed in groundwater properties (SWL, GWT) for the study period are attributed to the amount of rainfall and air temperature. The variation in TDS is due more to the influence of seawater and brine intrusion. The effect of geology was more or less insignificant. Hence generally, irrespective of the geology, with known amount of precipitation and air temperature, future changes in SWL, TDS and GWT can be predicted at least for limited management and environmental decisions in the study area.

Keywords Climatic change, temperature, rainfall, static water level, total dissolved solids

Introduction

The economic and social development of any community is influenced by the availability of good quantity and quality of water resources and its seasonal variability for drinking, domestic and agricultural purposes. The most noticeable impacts are generally related to alternation of wet and dry seasons. Several studies have shown that there is a strong relationship between atmospheric processes and the depth to water table and water quality. In Nigeria, studies have shown that the air temperature trend since 1901 shows increasing pattern. The mean air temperature in Nigeria between 1901 and 2005 was 26.6 ^{0}C while the temperature increase for 105 years was 1.1 ^{0}C. This is higher than the global mean temperature increase of 0.74 ^{0}C (Akpodiogaga-a & Odjugo, 2010; Spore 2008; IPCC, 2007). Also, rainfall trend in Nigeria between 1901 and 2005 shows general decline. According to Akpodiogaga-a & Odjugo (2010), within the period (1901-2005), rainfall amount in Nigeria dropped by 81 mm. Moreover, Odjugo (2005, 2007) also observed that the number of rainy days dropped by 53% in northeastern Nigeria and 14% in the Niger Delta coastal areas. Besides the short dry season, August Break is being experienced more in July as against it's normal occurrence in the month of August prior to the 1970s. This was attributed to major disruptions in climate patterns in Nigeria showing evidences of climatic change (Akpodiogaga-a & Odjugo, 2010).

One of the greatest impacts of climatic change is the alteration of hydrological cycle ranging from evaporation through precipitation, runoff and discharge (McGuire et al., 2002). According to Akpodiogaga-a & Odjugo (2010), the global warming and decreasing rainfall produce a minimal recharge of groundwater resources, wells, lakes and rivers in most parts of the world, especially in Africa, thereby creating water crisis. The resulting water crisis will create the tendency for concentrations of users around the limited sources of water. Under such conditions, there is increase possibility of additional contamination of limited resources of water and transmission of water borne diseases.

According to Vadillo (2005), climate change may alter the water quality by four ways: (1) increasing air temperature, (2) alteration of rainfall regime, with its changes in volume and velocity of flows to the aquifers, (3) atmospheric deposition of acid substances with an anthropic origin and (4) increase of CO_2 concentration of the air. Each one of these factors, and theirs interrelation, could vary in a drastic way the quantity and quality of the water resources. The increase of temperature of the air, even without changes of the rainfall, may increase the temperature of the water, and hence, a decrease in the concentration of dissolved O_2 and CO_2 (Gleick, 1987). In case of CO_2, this process could be masked by the increase of its concentration in the atmosphere. The decreasing concentration of O_2 has a direct consequence in the oxidation processes of contaminants. In regions with higher air temperatures, the natural biomass production (organic matter) will be enhanced. In a similar way with contamination episode with organic matter (landfill or sewage system leakage), this "extra" organic matter will need more oxygen to be degraded, so the net result will be less concentration of dissolved oxygen and a lost in the self cleaning capacity of the aquifers. Temperature is a master variable in all the chemical reactions, so any process in the soil will be affected if temperature increases, and this will have an associated change in the concentration of species and ions in water and an alteration of the hydrogen ions concentration (pH) in soil and water. Changes in volume and velocity of flows to the aquifers also have consequences in the quality of the water (Panagoulia and Dimou, 1996).

Stakeholders in Nigeria recently, have noted that climatic change will affect urban and rural water through unpredictable rainfall leading to inadequate recharge of aquifers and surface water, while quality and quantity of water resources will be impaired. As a prelude to management, they suggested the promotion of water reuse and recycling and efficient utilization of grey water (among others), in addition to incorporation of information about current climate variability into water related management (Omotosho, 2011). Further, the Nigerian Meteorological Agency (NIMET), in its presentation of the 2011 seasonal rainfall prediction, predicted longer and early rainfall compared to 2010 and noted that the above normal rainfall predicted for 2011 would impact positively on the water resources of the various hydrological areas and its water related socio-economic activities (Igbokwe, 2011).

Short term climate variability or climatic fluctuations have been of great interest for a few years (Ropelewski & Jones, 1987; Lau & Shew, 1988; Moura, 1994). The importance lies in the applicability of the variability to agriculture, water resources and other social and economic activities. The present work is to develop statistical methodology to predict the future fluctuation of water quantity and quality of groundwater in Cross River State using available climatic data as input parameters. This is expected to guide the future impact of climate variability in the area, for at least, limited management of the resource.

Overview of Cross River State

Cross River State is very extensive, covering an area of approximately 23, 000 km^2. It has a population of 2.89 million people (2006 Population Census) and spans latitudes 4^o 49'-6^o 56' North and longitudes 7^o 49'-9^o 28 East (Figure 1). The mean annual rainfall varies from more than 3063 mm at Calabar in the south through 2018 mm at Ikom in the central part of the area to less than 1800 mm at Ogoja in the north (Edet et al., 1998). The rainfall patterns consist of alternating wet (April-October) and dry (November-March) periods. Temperatures are relatively high with mean annual temperature in the range of 30.1 ^{0}C at Ogoja to 22.4 ^{0}C at Calabar.

The main physical features of the area include highlands with elevations in excess of 400 m above sea level. These include the Obudu and the Oban massifs (Figure 1). By contrast, the low lands have elevations up to 350 m, decreasing southwards to a few meters near the coast: Cross River Plains and the Calabar Coastal Plains. From geological point of view, the area consists of Precambrian crystalline basement (Obudu plateau and Oban massif) and a sedimentary cover ranging in age from Cretaceous to Tertiary. The basement complexes consist predominantly of gneisses, schists, amphibolites, pegmatites, granites, granodiorites, diorites, tonalities etc. Cross River State is underlain by three sedimentary basins viz: Calabar Flank, Ikom-Mamfe Embayment and southern Benue Trough. The sedimentary Formations consists mostly of conglomerates, sandstones, shale, limestones, marls, clays, sands and silts. The hydrogeology is largely dependent on the lithology of the area. The major hydrogeological units are the crystalline basement; sandstone-siltstone-limestone-intrusive; shale-intrusive; shale; coastal plain sand and alluvium (Edet, 1993; Okereke et al., 1998).

Data Acquisition and Methods

Air temperature (AT), relative humidity (RH) and rainfall amount (RA) data from Calabar Airport, Ikom and Ogoja Meteorological Stations (Figure 1) were used. The stations are managed by the Nigerian Meteorological Agency (NIMET) and the data covered the period of study (January 2009-June 2010). A monitoring network of wells (Figure 2) meant to observe groundwater level and quality fluctuations was set up and implemented in 12 locations spanning different geologic units within the study area. However, only 4 locations were used in this study due to nearness to the meteorological stations and geologic consideration. The monitored properties included groundwater level (SWL), electrical conductivity (EC), total dissolved solids (TDS), groundwater temperature (GWT), pH, Eh and dissolved oxygen (DO). A water level meter, a Hanna microprocessor EC/TDS meter model HI 8314, Hanna membrane pH meter model HI 8314, and Hanna DO meter model HI 9142, were used to measure the parameters.

Several statistical computations were made in order to determine the possibility of predicting groundwater physical properties (SWL, GWT, EC, TDS, pH, Eh, DO) from climatic properties (RA, AT). All the statistical analyses were made using software called STATISTICA (Pilz, 1993) and excel spread sheet. First a descriptive statistics (maximum, minimum, mean, median, standard deviation) for the climatic and water properties was made for all the locations and on the basis of the different lithologic units. To determine the background/threshold values, the cumulative frequency plots of the variables were made. This is expected to guide any further change in the water properties measured in the area.

To define the strength of the relationships, the correlation coefficient (r) between the climatic and groundwater physical properties was computed. The r measures the strength of relations between variables. A value of r close to ±1 means that the variables are strongly correlated, thus if the value of one variable is known, the value of the other variable can be predicted (Tanco & Kruse, 2001). A value of r that is very close to 0 means that the values are not linearly related. This method provides an estimate of the predictability of seasonal changes in groundwater physical properties. The computation of coefficient of correlation and linear regression are well documented (Wellmer, 1998).

To measure the relationship between the field and predicted data, the difference between the former and the later was computed and the 25% quartile, mean and 75% quartile determined. Using the two quartiles as a criterion, the data was divided into three parts. All the data in the first part correspond to below expected predicted values. The second part is within the expected predicted value and the last part corresponds to above the expected predicted values.

Results and Discussion

Climatic Framework of the Area

Monthly precipitation for the study period varied from 0.0 mm for the three meteorological stations to 611.30 mm at Calabar. The highest rainfall amount was recorded during the wet season. The air temperature ranged between 28.1^{0}C at Calabar in the south and 37.50^{0}C at Ogoja in the north. The relative humidity varied between 53% at Ogoja in the north and 92% at Calabar in the south. A summary of the climatic data for the 3 meteorological stations is presented in Table 2. The average annual precipitation for the period 1990-1995 (Fig. 2) shows that the rainfall amount decreases from Calabar in the south to Ogoja in the north, showing the normal precipitation pattern for the area. However, the reverse is the case for this study due to its short duration (see Table 2). A correlation analysis for the climatic data for the study period (Jan 2009-June 2010) indicates a decrease in amount of precipitation with increase in air temperature, with correlation coefficient of -0.824, -0.719 and -0.833 for Calabar, Ikom and Ogoja respectively.

For the present work however, consideration is given to data obtained in August, September, October, December 2009 and February, March 2010. The air temperature and rain amount distribution for this period is presented in Figure 3. The climatic data showed that the temperature increased gradually from August 2009 (wet season), reaching a maximum in January 2010 (dry season) before decreasing again. The reverse was the case for the precipitation. The data showed that the temperature is fairly constant with standard deviation (SD) of 2.10 while the amount of precipitation is highly variable (SD = 205.74).

Threshold Values for Groundwater Properties

Cumulative frequency plots of constituents are useful to discriminate between background and affected values by certain factors such as seawater and anthropogenic contamination (Park et al., 2005; Lee and Song 2007). The physical properties of groundwater in the area generally showed abrupt increasing trends (Figure 5). The average of the lower and upper values at the point of break is considered as the threshold value for the parameter. Among the properties, some of them showed increasing value without any break. The threshold values are 3.94 m, 29.01^{0}C, 248.60μS/cm, 99.20ppm, 5.90, 99.77mV and 2.40mg/l for SWL, GWT, EC, TDS, pH, Eh and DO respectively.

Physical Properties of groundwater

Groundwater temperature

Figure 5 shows that throughout the study period, there was little variation in both air and water temperatures. The air temperature for the period under consideration varied between 28.10 ^{0}C at Calabar in the south to 36.0 ^{0}C at Ogoja in the north. The groundwater temperature varied from 27.8 ^{0}C at Ugep in the central part of the study area to 30.9 ^{0}C at Okpoma in the north near Ogoja. The maximum air temperature fluctuation is 7.9 ^{0}C, while for groundwater, the variation is 3.1^{0}C indicating lower fluctuations. The mean groundwater temperatures for the different monitored wells varied between 28.71 ^{0}C at Uyanga and 29.36 ^{0}C at Anantigha (Table 3) with higher values in the dry season (Table 4). The average air temperature (31.87±2.11^{0}C) is very close to the average groundwater temperature (29.21±0.75 ^{0}C). Such a similarity shows that the groundwater temperature is a reflection of the air temperature (Kazemi, 2004). For the entire study, the air and water temperatures were positively correlated with correlation coefficient of 0.442. The difference between these averages may be attributed to (i) the air temperature were not measured by the authors, and hence, there was no quality control and (ii) the meteorological stations were not very close to the groundwater monitoring wells (Figure 1).

Static water level

The SWL with respect to the ground surface for the chosen monitored wells, varied from 1.30 m at Okpoma in the wet season to a maximum of 5.85 m at the same location in the dry season (Table 4). The difference between the SWL for the dry and wet seasons were 1.37 m (Anantigha), 2.35 m (Uyanga), 1.75 m (Ugep), 0.75 m (Obubra) and 4.55 m (Okpoma). The standard deviations for the sampled periods were 0.46, 0.91, 0.66, 0.29 and 1.92 respectively for the same locations, indicating low variability between different sample periods irrespective of the lithologic units.

Electrical conductivity (EC) and Total Dissolved Solids (TDS)

The EC for the groundwater samples varied between 53.8 and 872 µS/cm (mean 161.50±153.60 µS/cm) with higher value for the dry season relative to the wet season. The mean values for the different monitored locations varied from 89.06 µS/cm at Ugep in the central area to 314.04 µS/cm at Anantigha in the south. The high value at Anantigha is attributed to the influence of sea water. The TDS followed the same trend as the EC with mean values in the range of 44.47 ppm (Ugep) to 157.59 ppm (Anantigha). The correlation of EC and TDS was statistically significant at 95% confidence limit.

Hydrogen ion (pH) and redox potential (Eh)

The pH values ranged from 4.71 to 7.57 (mean 5.99±0.57), indicating insignificant variations throughout the entire period of study. The median value is 6.07. This may represent the dominant effect of humic acid from decomposing vegetation. The mean values for the different monitored wells ranged between 5.32 and 6.49 (Table 4). Seasonally, the pH values were higher in the dry season relative to the wet season

The Eh values ranged from 11–149 mV. The Eh values and characteristics showed inverse relationships compared to the pH. Lower values of Eh were recorded in the dry season and higher values in the wet season. According to Scheytt (1977), the redox potential is a potential that is caused by various redox reactions in groundwater. High Eh in wet season is attributed to the fact that infiltration water has a higher potential and more oxygen is dissolved in groundwater hence oxidation processes prevail leading to an increase of Eh in groundwater.

Dissolved Oxygen Contents (DO)

The oxygen content varied from 2.10 to 3.60 mg/l (Table 4) with higher values in the dry season (Tables 4). The oxygen contents results from oxygen usage and supply. The oxidation of organic substances and reduced inorganic substances leads to lower oxygen content in groundwater. A high content of oxygen infiltration water enriches the groundwater with oxygen (Matthess, 1994). Because most of the groundwater recharge takes place in the wet season and because the solubility of oxygen in warm water is lower than in cold water, higher contents of oxygen are measured in wet season (Scheyett, 1997; Joshi & Kocthyari, 2003). In this work, the reverse was obtained. This is attributed to high rate of reactions as noted in the Eh values (Edet & Worden, 2009).

Relationship between Lithology and Physical Properties of Groundwater

The SWL, GWT, pH, Eh and DO showed low variability for all the locations underlain by different lithologic units and all seasons based on low standard deviation values (Table 3). This indicates steady state conditions. The EC, TDS and Eh showed high variability for the different locations considering the different sample periods. The variation in EC and TDS is attributed to seawater influence during different seasons and tidal periods at Anantigha (Edet & Worden, 2009) and brines at Okpoma (Tijani et al., 1996; Uma, 1998). The differences in SWL, oxygen supply and reaction rates are responsible for the variation in Eh.

Correlation between Climatic Parameters and Groundwater Properties

The correlation matrix for the different variables for different geologic locations is shown in Table 5. The data illustrate that for all the locations, correlation between RA and AT is statistically significant at 95% confidence level with r in the range -0.784 to -0.817. The correlation between RA and SWL was statistically high for three locations (Anantigha, Uyanga and Ugep) with r varying between -0.620 and -0.680. For the Okpoma location, the r was -0.399. The low r value is attributed to the fact that in the dry season, the monitored well was almost dry. The correlation between RA and GWT; EC and TDS were not statistically significant for all the locations. The AT was statistically highly correlated with SWL and GWT in all the locations. The correlation of AT and GWT was not significant at Okpoma. The correlation between AT with EC and TDS was statistically significantly correlated only at Ugep and Okpoma. Rain amount (RA) was correlated with pH (Anantigha, Okpoma) and AT correlated with pH (Ugep, Okpoma), Eh and DO (Okpoma). The variability in correlation is attributed mainly to the fact that the meteorological stations are not very close to the monitored wells as stated earlier (Fig 1).

Development of Predictive Least Square Equations

In developing predictive equation, least square equations in the form y = mx + c (where y is the required groundwater property; x the input climatic parameter; m slope relating the groundwater property and the climatic parameter; c the intercept on the groundwater property or climate parameter of a line relating the two parameters) for the physical properties of groundwater from climatic parameters, three parameters were used as follows: static water level (SWL) based on statistically significant high positive correlation with rain amount (RA) and air temperature (AT); total Dissolved Solids (TDS) due to high variability at different geologic locations and seasons; and groundwater temperature (GWT) as an indicator of slight changes in climatic parameters

The predictive least square equations alongside the coefficients of variability and correlation are presented in Table 6. Using the prediction equations, the fluctuations in SWL, TDS and GWT were estimated for the different locations. Figure 7 shows the predicted and observed values for SWL, TDS and GWT fluctuations with RA and AT. A classification of the difference between the observed and predicted values (Fig. 8) showed that, based on a scheme (Table 7), at least 50% of the data generated was within expected predicted value. The difference between observed and predicted values showed high variability in respect of TDS compared to SWL and GWT (Table 8).

Conclusion

A simple model based on the least square equation was developed to predict the variations in static water level (SWL), total dissolved solids (TDS) and groundwater temperature (GWT) due to the variability of some climatic parameters. First, the correlation between the rain amount

(RA) and air temperature (AT) were established. The highest statistically significant correlation were found to be between the climatic parameters (RA, AT) and SWL, GWT and TDS.

The climatic parameters (RA, AT) were then used to estimate the variation of SWL, GWT and TDS. Good results were achieved when estimating SWL and GWT, but high variability was observed in the case of TDS.

In order to improve the ability of the equation as a better predictive tool, some other climatic parameters, such as relative humidity, evapotranspiration are recommended for inclusion, in addition to the fact that the meteorological stations should be as close as possible to the monitored wells.

Finally, the effect of geology was more or less insignificant. Hence, generally, irrespective of the geology, with known amount of precipitation and air temperature, future changes in SWL, TDS and GWT can be predicted at least for limited management and environmental decisions.

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Table 1: Location of monitored wells and meteorological stations including geological setting of Cross River State

Age	Basin	Formation	Hydrogeologic unit[a]	Location	Coordinates N	Coordinates E	Lithology	Remarks
Quaternary-Pliocene	Niger Delta	Benin	Coastal Plain Sands	Anantigha	4°55.088	8°18.945	Sand, clay	Monitored well
				Calabar Airport	4°58.433	8°21.067		Meteorological station
Campanian-Turonian	SE Benue Trough	Nkporo Shale	Shale					
Coniancian-Turonian	and	Amaseri Sandstone	Sandstone-Shale-intrusive	Ugep	5°47.750	8°04.447	Sandstone	Monitored well
Turonian-Cenomanian	Ikom-Mamfe Embayment	Ezillo Formation	Shale-Sandstone-Intrusives	Okpoma	6°35.971	8°38.486	Shale, basic intrusive	Monitored well
				Ogoja	6°38.699	8°46.661		Meteorological station
Cenomanian-Albian		Mamfe	Sandstone, arkosic, conglomeritic	Ikom	5°56.395	8°42.603		Meteorological station
Precambrian	Basement Complex	Oban massif	Basement	Uyanga	5°22.994	8°15.657	Granodiorite	Monitored well

[a] Edet (1993)

Table 2: Summary of climatic data for the study period from three meteorological stations at Calabar, Ikom and Ogoja

Year	Month	Location								
			AT °C			RA mm			RH %	
		Calabar	Ikom	Ogoja	Calabar	Ikom	Ogoja	Calabar	Ikom	Ogoja
2009	Aug	28.1	29.7	31.4	507.3	558.1	349.1	92.0	89.0	87.0
	Sept	29.7	30.2	31.5	273.9	283.3	336.9	89.0	87.0	85.0
	Oct	30.0	31.1	31.8	148.1	294.8	398.3	87.0	85.0	83.0
	Dec	33.0	33.7	35.9	0.0	0.0	0.0	84.0	78.0	76.0
2010	Feb	33.1	35.9	36.0	88.2	20.2	11.8	85.0	75.0	60.0
	Apr	33.1	34.9	34.4	130.4	166.0	411.6	83.0	77.0	75.0
	Jun	29.8	31.2	31.9	611.3	595.8	434.6	88.0	85.0	83.0
Statistics	Mean	30.97	32.39	33.27	251.31	274.03	277.47	86.86	82.29	78.43
	Median	30.00	31.20	31.90	148.10	283.30	349.10	87.00	85.00	83.00
	Min	28.10	29.70	31.40	0.00	0.00	0.00	83.00	75.00	60.00
	Max	33.10	35.90	36.00	611.30	595.80	434.60	92.00	89.00	87.00
	SD	2.06	2.43	2.09	227.55	236.62	188.64	3.13	5.50	9.27

Rain amount (RA), air temperature (AT) and relative humidity.

Table 3: Descriptive of groundwater physical properties

Area	Location	Geology	Statistics	SWL m	GWT ^{o}C	EC µS/cm	TDS ppm	pH	Eh mV	DO mg/l
South	Anantigha		Mean	4.026	29.357	314.043	157.586	5.316	112.429	3.043
		Benin Formation	Med	4.150	29.400	221.500	110.800	5.320	107.000	3.000
		Niger Delta	Min	3.230	28.700	205.100	102.600	4.710	77.000	2.600
		Gravel, sand, silt, clay	Max	4.600	30.800	872.000	440.000	5.920	149.000	3.600
			SD	0.461	0.766	246.543	124.781	0.424	28.401	0.341
	Uyanga		Mean	3.479	28.914	110.369	55.243	6.126	87.857	2.900
		Oban massif	Med	3.200	28.700	97.780	48.900	6.160	103.000	3.000
		Precambrian Basement	Min	2.300	28.200	81.400	40.600	5.180	48.000	2.300
		Granite, granodiorite, gneiss	Max	4.650	29.700	213.000	106.500	6.660	135.000	3.200
		schist	SD	0.508	45.815	22.896	0.460	31.793	0.327	2.700
Central	Ugep		Mean	3.214	28.714	89.057	44.471	5.851	97.857	2.743
		Amaseri Sandstone	Med	2.950	28.600	98.300	49.100	5.680	118.000	2.800
		Ikom-Mamfe Embayment	Min	2.300	27.800	53.800	26.800	5.600	66.000	2.100
		Sandstone, shale, intrusives	Max	4.050	29.500	111.200	55.600	6.200	121.000	3.200
			SD	0.664	0.593	21.772	10.947	0.258	27.052	0.450
North	Okpoma		Mean	3.143	29.243	188.343	94.186	6.493	74.571	2.907
		Southern Benue Trough	Med	2.250	28.800	91.400	45.700	6.170	78.000	2.900
		Nkporo Shale	Min	1.300	28.100	70.800	35.400	5.940	11.000	2.600
		Shale, intrusives	Max	5.850	30.900	507.000	254.000	7.570	110.000	3.300
			SD	1.917	0.983	171.315	85.731	0.595	36.864	0.259

Rain amount (RA), air temperature (AT), static water level (SWL), groundwater temperature (GWT), electrical conductivity (EC), total dissolved solids (TDS), pH, redox potential (Eh) and dissolved oxygen (DO).

Table 4**:** Seasonal variation of climatic parameters and physical properties of groundwater

Season	Statistics	RA mm	AT ^{o}C	SWL m	GWT ^{o}C	EC µS/cm	TDS ppm	pH	Eh mV	DO mg/l
Dry	Mean	20.03	34.23	4.34	29.39	166.11	83.19	6.10	86.50	2.96
	Median	5.90	33.70	4.28	29.60	102.85	51.70	6.08	91.50	3.05
	Min	0.00	33.00	3.15	27.80	53.80	26.80	4.91	11.00	2.30
	Max	88.20	36.00	5.80	30.80	507.00	254.00	7.57	143.00	3.60
	SD	34.40	1.36	0.77	1.02	133.31	66.74	0.77	37.54	0.43
Wet	Mean	366.63	31.25	3.50	29.13	159.66	79.94	5.95	94.08	2.88
	Median	349.10	31.20	3.23	29.20	100.80	50.40	5.94	103.00	2.90
	Min	130.40	28.10	1.30	28.20	62.40	31.00	4.71	45.00	2.10
	Max	611.30	34.90	5.85	30.90	872.00	440.00	6.71	149.00	3.30
	SD	156.34	1.83	1.21	0.63	163.55	82.49	0.48	28.54	0.29

Explanations as in Table 3

Table 5: Correlation matrix between climatic parameters and groundwater properties for the different monitored locations

		RA	AT	SWL	GWT	EC	TDS	pH	Eh	DO
Ananthiga	RA	1.000								
	AT	-0.784	1.000							
	SWL	-0.664	0.865	1.000						
	GWT	-0.237	0.528	0.426	1.000					
	EC	-0.274	0.471	0.575	0.168	1.000				
	TDS	-0.273	0.471	0.574	0.169	1.000	1.000			
	pH	0.674	-0.242	-0.236	-0.022	0.169	0.169	1.000		
	Eh	-0.439	-0.012	0.003	-0.257	-0.258	-0.259	-0.934	1.000	
	DO	-0.084	-0.034	-0.311	0.570	-0.088	-0.087	-0.191	0.070	1.000
Uyanga	RA	1.000								
	AT	-0.784	1.000							
	SWL	-0.620	0.953	1.000						
	GWT	-0.547	0.497	0.572	1.000					
	EC	0.097	-0.363	-0.363	0.330	1.000				
	TDS	0.095	-0.361	-0.361	0.334	1.000	1.000			
	pH	-0.007	0.382	0.475	-0.186	-0.934	-0.934	1.000		
	Eh	-0.053	-0.483	-0.664	-0.047	0.698	0.697	-0.880	1.000	
	DO	0.229	-0.057	-0.137	-0.593	-0.234	-0.240	0.207	-0.053	1.000
Ugep	RA	1.000								
	AT	-0.787	1.000							
	SWL	-0.680	0.938	1.000						
	GWT	0.057	0.199	0.315	1.000					
	EC	0.635	-0.841	-0.833	-0.652	1.000				
	TDS	0.634	-0.841	-0.833	-0.652	1.000	1.000			
	pH	-0.028	0.602	0.561	0.419	-0.612	-0.613	1.000		
	Eh	0.056	-0.626	-0.559	-0.369	0.592	0.593	-0.993	1.000	
	DO	-0.146	0.154	0.374	-0.271	0.021	0.020	-0.069	0.120	1.000
Okpoma	RA	1.000								
	AT	-0.817	1.000							
	SWL	-0.399	0.795	1.000						
	GWT	0.221	-0.135	0.049	1.000					
	EC	-0.519	0.789	0.946	0.183	1.000				
	TDS	-0.520	0.789	0.945	0.184	1.000	1.000			
	pH	-0.793	0.946	0.839	0.080	0.911	0.911	1.000		
	Eh	0.452	-0.765	-0.872	-0.410	-0.937	-0.937	-0.883	1.000	
	DO	-0.852	0.588	0.232	-0.018	0.396	0.399	0.652	-0.318	1.000

Explanations as in Table 3

Table 6: Predictive least square equations for groundwater physical properties

Location	y	m	x	c	r^2	r
Anantigha	SWL	-0.001	RA	3.894	0.423	0.650
	GWT	-0.003		30.065	0.482	0.694
	TDS	-0.060		109.260	0.587	0.766
	SWL	0.148	AT	-0.927	0.842	0.918
	GWT	0.399		16.958	0.684	0.827
	TDS	37.007		-1005.100	0.799	0.894
Uyanga	SWL	0.014	RA	2.831	0.795	0.892
	GWT	-0.002		29.729	0.885	0.941
	TDS	0.097		39.981	0.787	0.887
	SWL	0.740	AT	-18.647	0.576	0.759
	GWT	0.195		22.845	0.581	0.762
	TDS	23.398		-630.910	0.662	0.814
Ugep	SWL	-0.003	RA	3.824	0.422	0.650
	GWT	-0.003		30.419	0.435	0.659
	TDS	-0.633		404.730	0.508	0.713
	SWL	0.663	AT	-18.259	0.587	0.766
	GWT	0.438		15.469	0.737	0.858
	TDS	66.862		-1985.400	0.700	0.837
Okpoma	SWL	-0.009	RA	5.601	0.726	0.852
	GWT	-0.004		30.487	0.781	0.883
	TDS	-0.455		242.720	0.718	0.847
	SWL	0.434	AT	-9.879	0.519	0.721
	GWT	0.313		19.462	0.678	0.823
	TDS	26.623		-702.300	0.538	0.733

Table 7: Evaluation scale for the predicted values

SWL	TDS	GWT	Remarks
< -0.34	< -7.6	< -0.66	Below expected
- 0.34 to 0.49	- 7.60 to 5.33	- 0.66 to 0.22	Expected
> 0.49	> 5.33	> 0.22	Above expected

Table 8: Descriptive statistics for the difference between observed and predicted values of SWL, TDS and GWT

Statistics	ΔSWL	ΔTDS	ΔGWT
Mean	0.141	2.051	-0.370
Median	0.040	-0.519	-0.299
Minimum	-1.606	-146.570	-4.400
Maximum	3.247	166.841	2.204
Lower Quartile	-0.335	-7.603	-0.660
Upper Quartile	0.448	5.330	0.220
Range	0.783	12.934	0.879
Std.Dev.	0.767	41.300	1.282

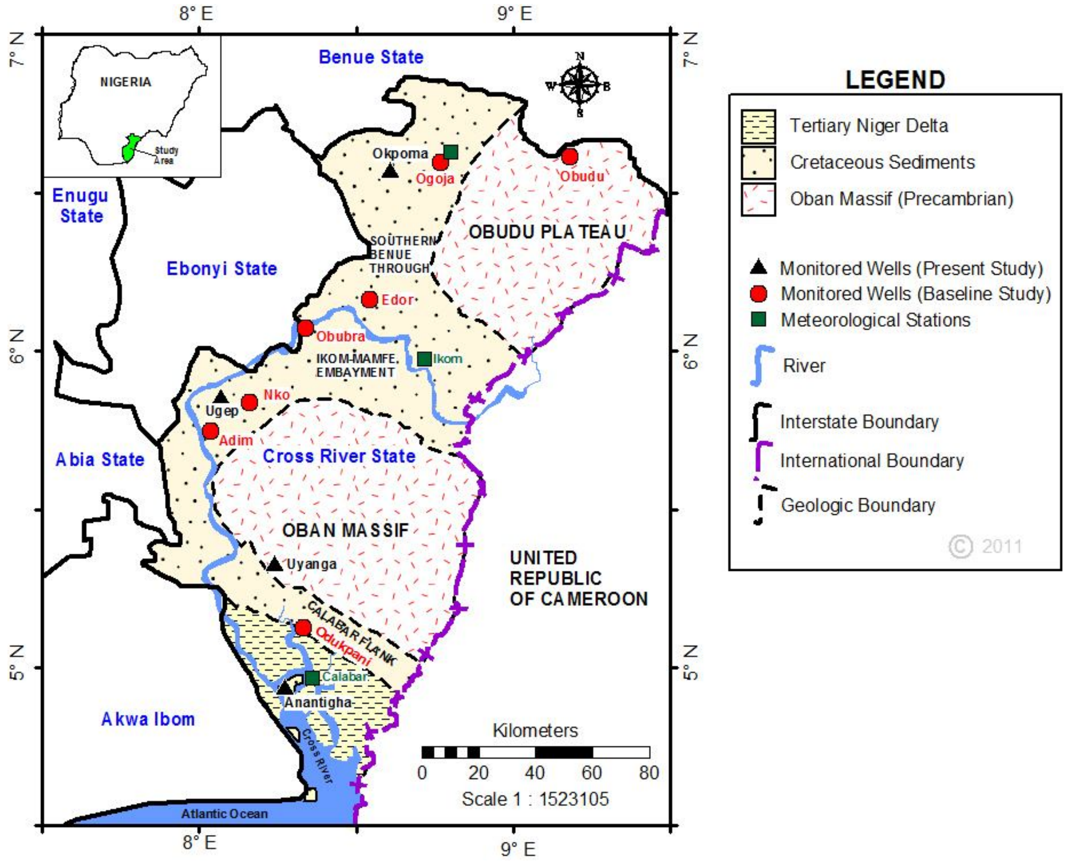


Fig. 1**:** Location of Monitored wells and Meteorological stations

Fig. 2: Typical monitored well at Ugep

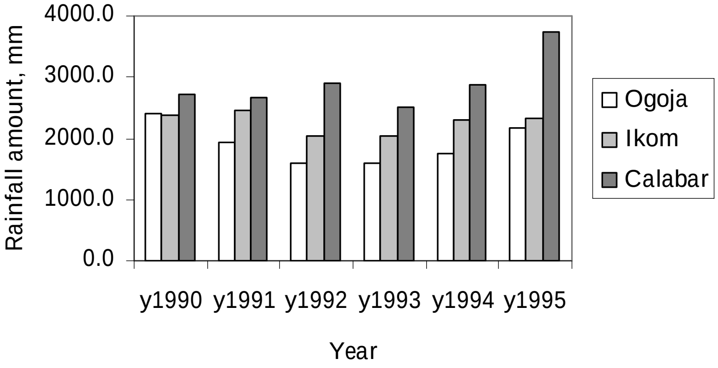
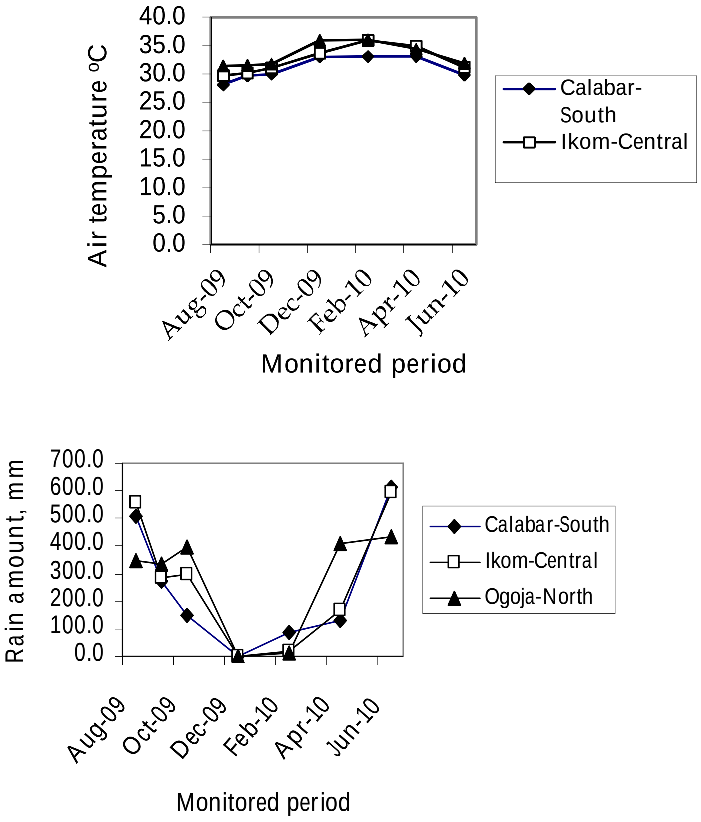
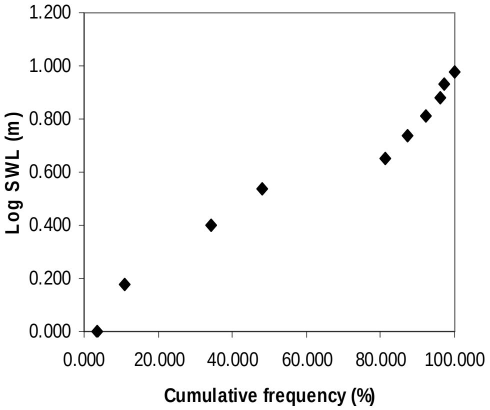


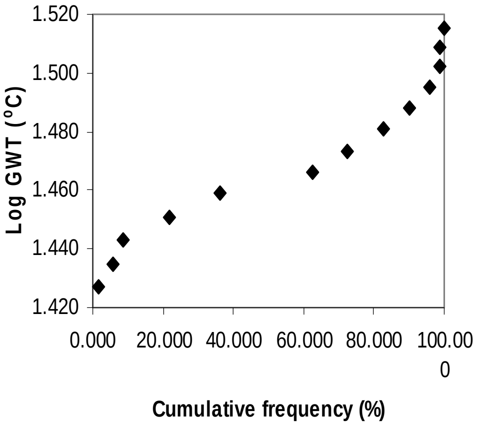
Fig. 3: Average annual rainfall for Calabar, Ikom and Ogoja for the year 1990-1995.

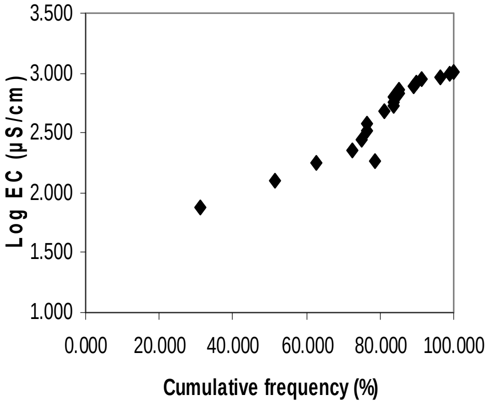


(A) (B)

Fig. 4: Variation of air temperature and rainfall amount for the study period


1.200
1.000
0.800
0.600
0.400
0.200
0.000
Log SWL (m)
0.000
20.000
40.000
60.000
80.000
100.000
Cumulative frequency (%)


1.520
1.500
1.480
1.460
1.440
1.420
Log GWT (°C)
0.000
20.000
40.000
60.000
80.000
100.000
Cumulative frequency (%)


3.500
3.000
2.500
2.000
1.500
1.000
Log EC (µS/cm)
0.000
20.000
40.000
60.000
80.000
100.000
Cumulative frequency (%)

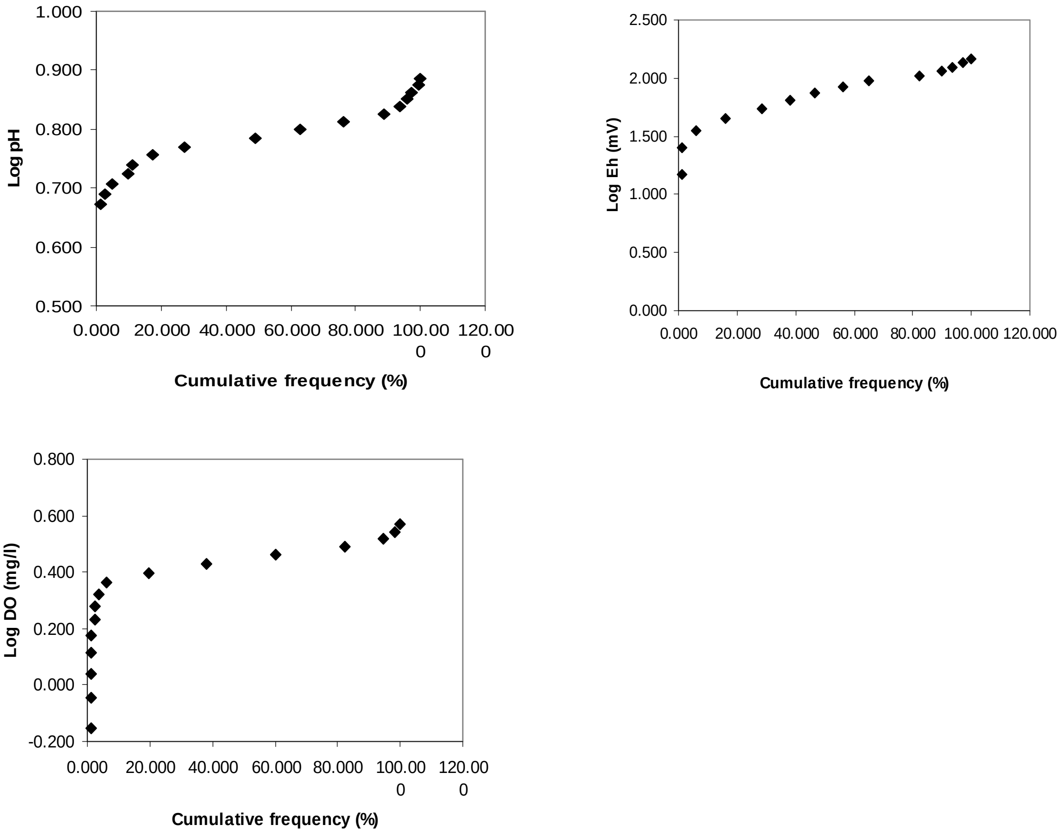


Fig. 5: Cumulative frequency plots for some physical parameters of groundwater.

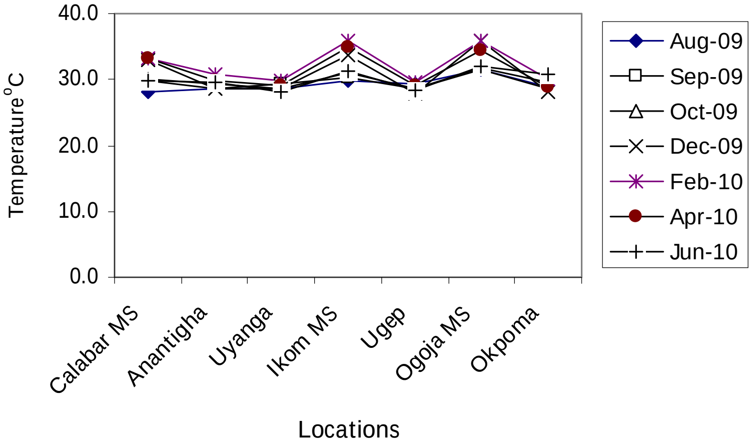
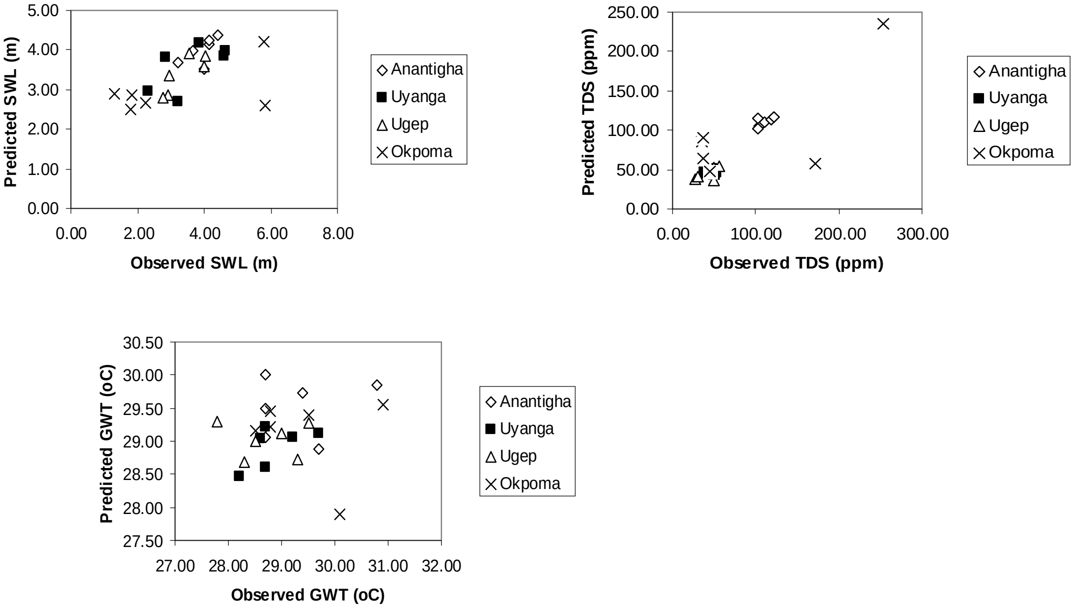


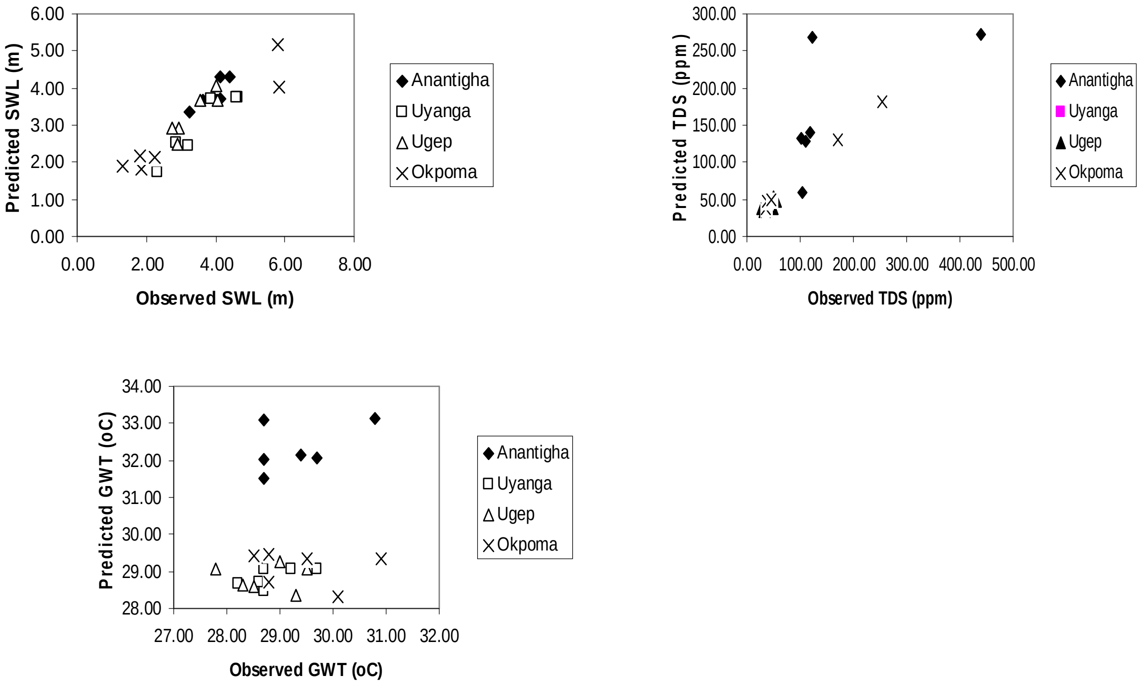
Fig. 6: Comparison of air and groundwater temperatures (MS-Meteorological stations)



(A) (B)

(C)

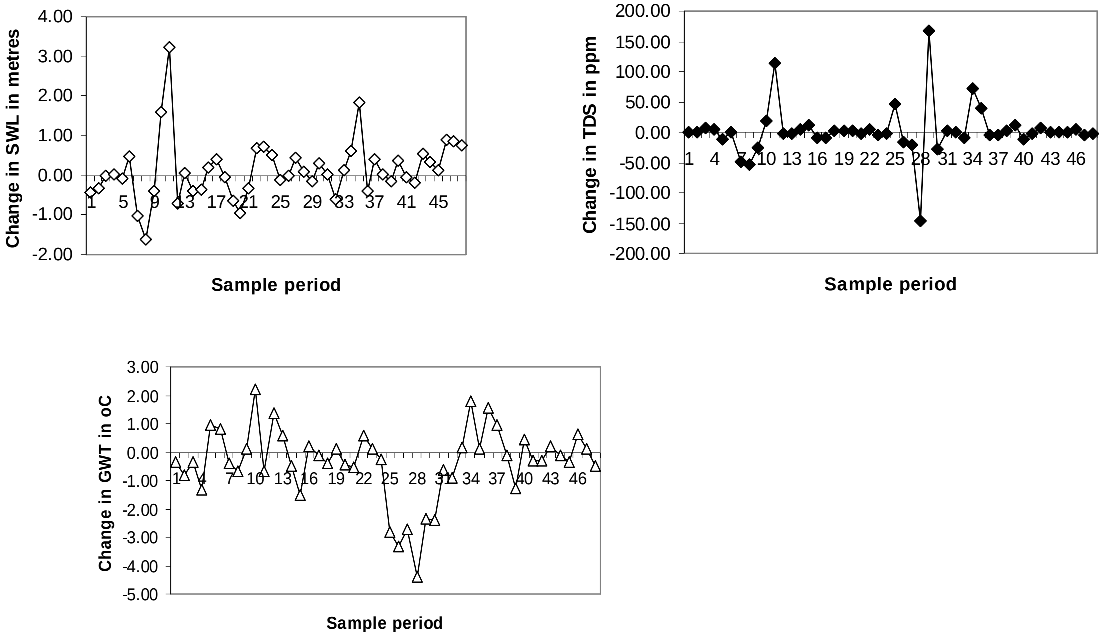
Fig. 7a: The Plot of observed and predicted values for (A) static water levels (B) TDS and (C) Groundwater temperature, GWT for the different sample periods based on correlation with rain amount. The sample periods were August, September, October, December 2009 and February, March 2010.



(A) (B)

(C)

Fig 7b: The Plot of observed and predicted values for (A) static water levels (B) TDS and (C) Groundwater temperature, GWT for the different sample periods based on correlation with air temperature. The sample periods were August, September, October, December 2009 and February, March 2010.



(A) (B)

(C)

Fig. 8: Computed differences between the observed and predicted values of groundwater properties for (A) Static water level (B) Total dissolved solids and (C) Groundwater temperature