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Groundwater Quality Dynamics during Wet and Dry Incidents in Urban West Region of Zanzibar Island

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Abstract: Groundwater is the major source of water by inhabitants of Zanzibar communities. In this study, twenty-one water sources from three districts of Urban West Region of Unguja Island were studied in May to July 2019. Insitu measurements for temperature, pH, Dissolved Oxygen (DO) and Electrical Conductivity (EC) in groundwater sources were taken by Professional Digital Sampling System (ProDSS). Data analysis revealed that parameters undergo dynamics (spatial and temporal). During the wet period, the ranges of pH, DO and EC were: (4.98 – 7.50), (3.51 – 7.51 mg/L), and (156.2 – 2047.6 µS/cm) respectively. During dry period the ranges were: (5.14 – 7.41), (2.71 – 7.20 mg/L), and (223.1 – 1936.8 µS/cm) respectively. temperature and EC had positive relationship. Nevertheless, small change in groundwater temperature led a remarkable change in DO. Strong correlation existed between EC and salinity (R^2 = 0.999). Also, a strong correlation existed between EC (dry period) and EC (wet period) with R^2 = 0.896. During wet period, the mean values recorded for all studied parameters were: 27.87° C, 6.92, 782.85 µS/cm, and 5.44 mg/L for temperature, pH, EC, and DO, respectively. While, during dry period the values were: 27.83° C, 6.97, 743.80 µS/cm, and 5.12 mg/L for temperature, pH, EC, and DO, respectively. Remarkably, during wet period, pH was 4.98 (27.17° C - 28.88° C), while in dry period pH was 5.14 (26.74 - 28.83° C). The present study revealed that even slight change in temperature could cause a remarkable effect on other groundwater parameters specifically dissolved oxygen. If water DO is under pressure it might affect other water quality parameter significantly.

Keywords: DO, Unguja, groundwater, temperature, pH.

INTRODUCTION

There are many chemical constituents present in drinking-water. However, only a few of them are of direct health significance under certain conditions. The priority is given to both monitoring, and remedial actions on chemical contaminants in groundwater, and should be managed to ensure that scarce resources are not unnecessarily directed towards serious health concern.[1] This study attempted to explore the dynamics of groundwater quality during wet and dry episodes in urban west of Zanzibar Island. It specifically, focused on examining the variation of several parameters that are subjected as indicators in determining the water quality within the aquifer.

Groundwater is an invisible component of the hydrosphere, representing a hidden part of the water cycle.[2]Approximately, half of the world's population use groundwater for their everyday consumption. Groundwater is also significant for agriculture and contributes to more than half of the world's population. Changes in climate are suspected to affect the hydrological cycle (either from natural variability or anthropogenic induced changes). Extreme events such as droughts and floods may pose significant impacts on the quantity and quality of water bodies.[3] More importantly, water quality varies from place to place and with the seasons.[4]

Diffuse pollution caused by rainfall events affects water quality. Therefore, thorough investigation and strategies should be taken to improve water quality planning and management recovery.[5]Water temperature is affected by several factors such as air temperature, amount of shade, soil erosion increasing turbidity, natural and anthropogenic thermal pollution.

On the other hand, indirect influences on groundwater temperature processes relate to urbanization and change in the heat balance in the near-surface atmosphere (Source.[6])

Temperature affects physical, and bio-chemical activities in the water systems.[7]In addition, the effects of temperature to water sources include solubility of oxygen (DO), where more gas can be dissolved in cold water compared to warm water.
In the present study, five water quality parameters (DO, salinity, temperature, pH and EC) were investigated. These parameters were quantified during both wet and dry period for the purposes of quantification and quality determination of the sampled water.
Therefore, this study used four physico-chemical parameters to reveal the water quality dynamics during both wet and dry periods. These parameters were; salinity, temperature, pH, DO, and EC. Monitoring the changes of these parameters as function of temperature can give an early warning signal to the water authorities and other stakeholders, so that suitable action can be taken appropriately.

pH

The pH for drinking water generally lies between 6.5 and 8.0 at 25°C. Acid rain can lower the pH of water bodies. Also, the pH level of the water in a stream, river, lake or underground varies depending on factors such as water source, type of soil, bedrock, and types of contaminants the water encounters in its path.[4]Although pH generally has no direct impact on consumers, yet it is one of the most important chemical parameters used in testing water quality. Acidic water can cause toxic heavy metals to be released into the water. For instance, for effective disinfection with chlorine, the preferable pH should be between 5.5 and 7.5.[3, 4]

Dissolved oxygen

DO refer to the level of free, non-compound oxygen present in water. Non-compound oxygen, or free oxygen (O_2), refers to oxygen that is not bonded to any other element; its presence is free O_2 molecules within the water. The attached one in water (H_2O) is in a compound and therefore, does not account for DO.[8]The fundamental point about the solubility of oxygen in water is that it has an inverse relationship with temperature.[9]
DO is an important parameter in evaluating water quality. Respiration by aquatic animals, decomposition, and various chemical reactions consume oxygen. If the rate of consumption of DO exceeds its rate of production, there will a DO decline. When, DO level is too high or too low it could cause harm to aquatic life,and might affect water quality.[10]
To ensure water bodies are healthy, the Washington State Department of Ecology, [11]adopted standards for DO and other parameters (Table 1).

Table 1: DO Standards in Washington (The Washington State Department of Ecology

DO Standards in Washington State	
Class AA – Extraordinary	> 9.5 mg/L
Class A - excellent	> 8.0 mg/L
Class B – good	> 6.5 mg/L
Class C – Fair	>4.0 mg/L
Class Lakes and reservoirs	No change from natural conditions

Electrical conductivity (EC)

EC is an important parameter in groundwater quality assessments for drinking and for other utilities.[12]The EC estimates saltiness of the water and the total amount of dissolved solids in water.
Besides the EC of the water depends on its temperature, the higher the temperature, the higher the EC. The EC of water increases by 2-3% for an increase of 1 degree Celsius of water temperature.[13]

General objectives

The main objective of this study is to assess the groundwater quality dynamics in the urban West region of Zanzibar Island during wet and dry periods. Specifically, the present study aimed at the following objectives:

i. To assess the state of groundwater variation in terms of DO during wet and dry episodes
ii. To assess the variation of temperature with DO
iii. To investigate the relationship between some of the analyzed parameters

Water Quality Standard

Access to safe drinking water is an important aspect for the health and development issue at a national, regional and local level.[14] WHO produces international standards on water quality and human health in the third edition[14] and fourth addition[15] in form of guidelines to be used as the basis for regulation and standard-setting for the countries of the World. Some of these guidelines are depicted on Table 2.

Parallel to this, Tanzania has prepared temporary standards of quality for domestic water. The Standards are classified into three subsections:

i. Toxic substances
ii. Substances that affect human health, which would result in chronic states if ingested in large quantities over a long period
iii. Substances which affect the palatability of drinking water or affect the suitability of water for general domestic purposes

Table 2: WHO and Tanzania standards on some parameters (source.[16])

Parameters	Unit	WHO standards		Tanzania
		Accept	Allow	STD
TDS	mg/L	500	1,500	1000
Turbidity	NTU	5	25	5
pH		7.5-8.5	6.5-9.2	6.5-8.5
DO	mg/L	NA	NA	NA
EC	µS/cm	NA	NA	NA
Temp	^{o}C	NA	NA	NA

Zanzibar as part of Tanzania also relies on the temporary standards as shown in table 2.

MATERIAL AND METHODS

The study Area

The study was conducted in Unguja Island at Urban West region of Zanzibar; it involved all three districts (Urban, West A, and West B districts). The area was selected because almost 43% [17] of all groundwater sources recently existing in Unguja (Figure 1).

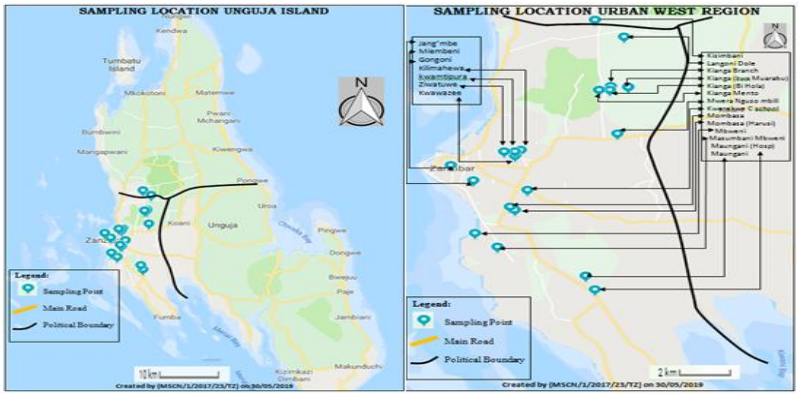


Figure 1: Location of the Study Area

Water sampling

From each district (Urban, West A, and West B), 7 groundwater sources were included in water sampling and analysis to make a total of 21 water sources. The sources included in the sampling were Bore Holes (BH) and Wide Diameter Wells (WDW).
The measurements were conducted repeatedly from May to August 2019 which included both wet and dry periods.

Sampling procedures

This study used purposive sampling to get the groundwater sources that meet the study requirements. The condition for a source to be included in this study was that, it should enable a researcher to get sample direct from the exact source. The list of selected sampling sites involved in this study is shown in table 3.

Table 3: Selected groundwater sources involved in the study

URBAN WEST GROUNDWATER SOURCES SAMPLING SITES		
WEST A	**WEST B**	**URBAN**
Nguzo 2 mwera	KwerekweC school	Jang'ombe
Langoni	Maungani	K/hewataifa
Kianga branch	Mombasa (harusi)	K/pura school
Kianga (muarabu)	Maungani hospital	Miembeni (bitaifa)
Kiangabihola	Bwenikwarais	Gongoni
Kiangamento	Masumbani	Ziwatuwe
Kizimbani	Mombasa	Kwawazee

Data collection

This study employed quantitative research method during sample collection. For every sample, the levels of salinity, DO, pH, EC, and temperature were quantified insitu(Figure 2a,b) using Professional Digital Sampling System (ProDSS). In order to minimize instrumental and human errors, the sample was measured in three trials to acquire the mean value each parameter necessary for further statistical analysis.

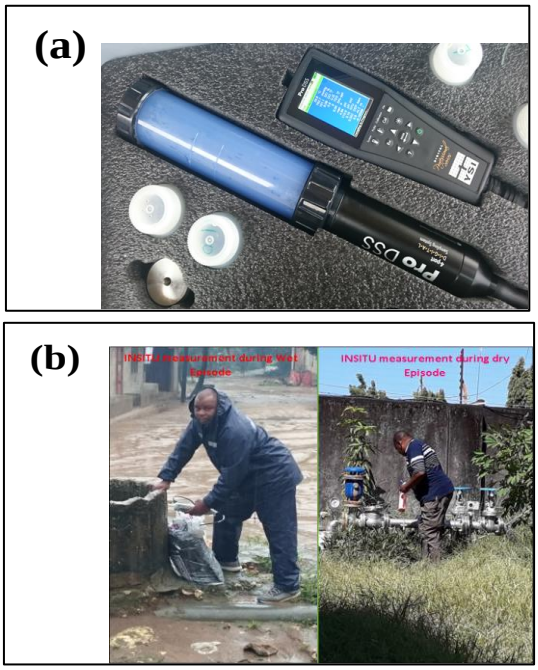


Figure2: (a) Instrument used during INSITU measurement (b) INSITU measurement during Dry and Wet Period (Source: Pictures taken 2019)

RESULTS AND DISCUSSION

The results from this study showed that the groundwater quality's parameters were not stable; continuous variations were witnessed from all measured parameters based on day to day, source to source, season to season, and even from time to time.

Variations of measured water quality parameters

Temperature variations

Temperature variations from source to source, from day to day as well as from season to season were observed during data collection this underlines that water temperature as well as other water quality parameters are under dynmic situations.

Temperature variations during Wet and Dry period in West A district

Wet period

The results revealed temperature dynamics of groundwater sources of West A district as shown in figure 3a, the lowest temperature of 26.30° C was recorded in day 1 at KiangaBiloha, and in day 5 at the same source the temperature increased to 27.70° C (range = 1.4° C). Where the highest temperature of 28.60° C was recorded in day 5 at Kianga Branch, and its minimum value of 27.43° C was recorded in day 1 (range =1.17° C). This variation in temperature has some effect in other parameters in water system. For example, DO in water, generally decrease with increase in temperature.

Dry Period

The results showed fluctuation in temperature measurements. in the wet episode was relatively lower compared to that of the wet period. However, in general temperature measurements were found to increase slightly during the dry period. The highest temperature recorded was 28.30° C in day 2 (at Kianga Branch), where in day 5 (Figure 3b) at the same site the lowest value of 25.90° C was observed (range = 2.4° C).

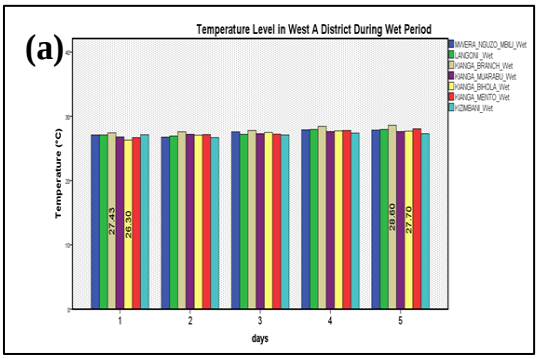
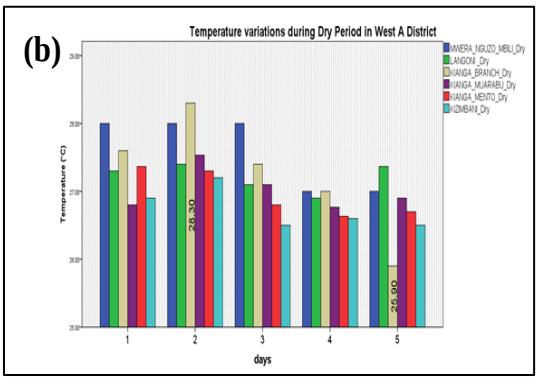


Figure 3: Temperature variations during (a) Wet (b) Dry period in West A District



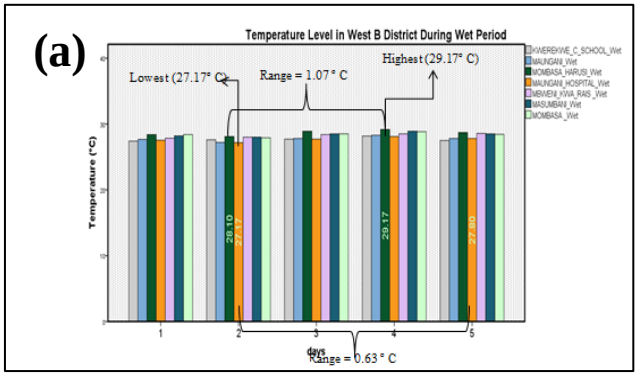
.**Temperature variations during Wet and Dry period in West B District**

Wet period

As depicted on figure 4a, the lowest temperature of 27.17° C was recorded in day 2 at Maungani Hospital, where in day 5 it increased to 27.80° C (range = 0.63 ° C). On the side of the highest temperature in day 4 at Mombasa (Harusi) reported 29.17° C and minimum value of 28.10° C was recorded in day 2 (range = 1.07° C).

Dry period

During the dry period, the highest temperature recorded was 29.0° C in day 3 (at MbwenikwaRais), at the same the minimum temperature was 28.10 ° C in day 4, hence the temperature range was 0.9 ° C (Figure 4a&b).



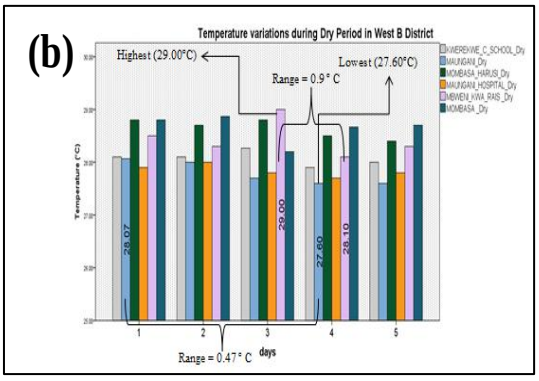


Figure 4: Temperature variations during (a) Wet and (b) Dry Period in West B District

Dissolved Oxygen variations with Temperature during Wet and Dry period in West A district

Wet period

As a rule of thumb, the present study revealed an inverse relationship between DO and temperature in many water sources. Besides, few of them showed abnormality by rejecting inverse relationship, this could be due to attributed by other complicated biochemical processes taking place in a given water source. For example, during wet period the site of Kianga Branch in day 5, DO value was the highest by 6.23 mg/L, meanwhile, its temperature was also highest by 28.60^{o} C. (Unpredictably, in day 1 temperature decreased to 27.43^{o} C and DO decreased to 6.03 mg/L). Although in day 2 when temperature was 27.80^{o} C, consistently DO decreased to 6.10 mg/L.

Besides, inverse relationship was further observed in several sites, for instance, in day 1 (at KiangaBihola), the lowest temperature value of 26.30^{o} C was recorded meanwhile DO level was 6.1 mg/L. In day 5, when the temperature was 27.70^{o} C, DO dropped to 5.8 mg/L. This decrease of 1.4^{o} C in temperature led to increase in DO by 4.95% (Figure 5a).

Dry period

In day 2, at Kianga branch the highest temperature of 28.30^{o} C and DO of 5.9 mg/L were recorded. In day 5 temperature decreased to 25.90^{o} C, while DO increased to 6.4 mg/L. It was further noted that increase in temperature by 2.4^{o} C, caused DO to decrease by almost 8%. Similar observation was noticed in day 1 (at MweraNguzoMbili), when temperature was 28.00^{o} C, DO was 4.7 mg/L. At the same area but in day 5 when temperature was 27.00^{o} C, DO increased by 5% (Figure 5b).

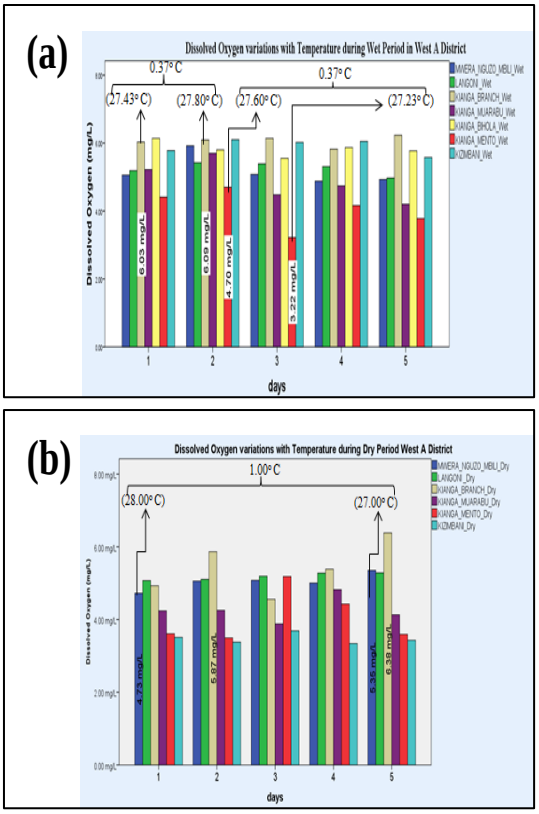


Figure 5: DO variations during (a) Wet and (b) Dry Period in West A District

Dissolved oxygen variations with Temperature during Wet and Dry period in West B district

Wet period

In day 4, (at Mombasa, bi Harusi) the highest temperature was 29.17^{o}C, and DO level was 5.51 mg/L, while at same site but in day 2, temperature was 28.10^{o}C and DO (figure 6a) increased to 5.91 mg/L (3.03%).

In day 1 (at Kwerekwe C school), temperature and DO were recorded as 27.40^{o}C and 6.76 mg/L respectively. Meanwhile in day 3 (same site) temperature raised to 27.70^{o}C, while DO level decreased to 5.73 mg/L (16.1%).

Dry Period

In day 3, at MbwenikwaRaisi the highest temperature of 29.00^{o}C was recorded and its DO level was 6.9 mg/L. In day 4 temperature decreased by 0.9^{o}C leading to increased DO level by 2.8%. At Maungani in day 4 (figure 6b) when temperature was 27.60^{o}C, DO was 5.8 mg/L. In day 3 (at the same site) temperature was 27.70^{o}C, while DO decreased to 5.7 mg/L (1.72% increase in DO).

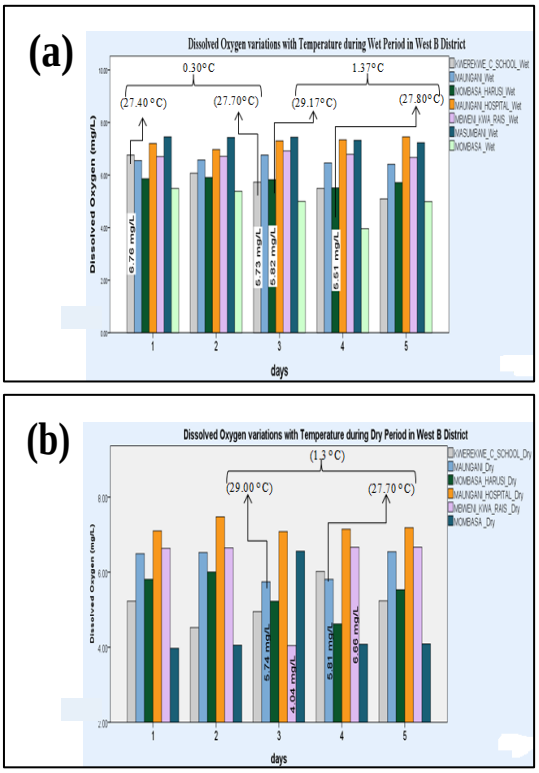


Figure 6: DO variations during (a) Wet and (b) Dry Period in the West B District

pH correlation between wet and dry period

Although there was pH variations (both spatial and temporal) in groundwater samples, yet strong correlation (R^2 = 0.935) existed between pH (dry period) and pH (wet period) indicating that pH data originated from the same sources (Figure 7).

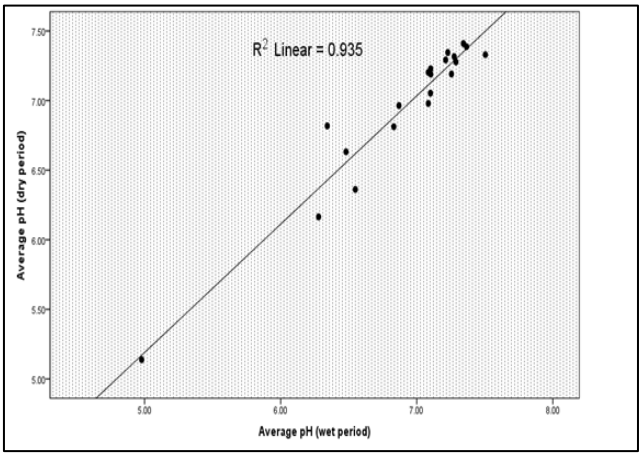


Figure 7: Correlation of pH between the dry and wet season

However; based on Tanzania Standards as derrived from WHO standards on level of pH in water as illustrated in table 2
Almost 90% of mesured sources meet the accepted standard of pH. The pH of only two sites (Kianga Muarabu and Kianga Branch) were below the WHO recommended pH range (Figure 8).

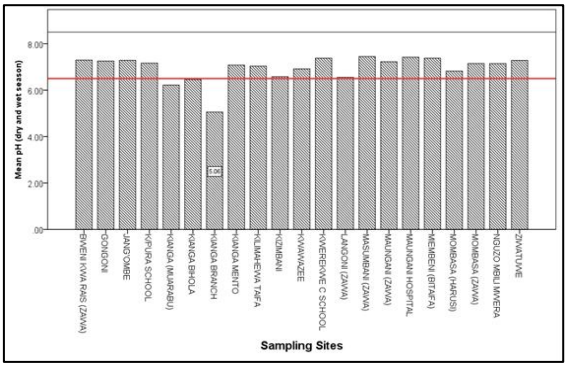


Figure 8: pH level based on WHO and Tanzania standards

EC and Salinity correlation in water samples

As expected, strong correlation (R^2 = 0.999) was observed between EC and salinity. (Figure 9). As an example, about 71% of analyzed samples at Urban West Region had EC falling on the range of 0-800 µS/cm, while 29% were within 800-2500 µS/cm category according to MRCCC.[18]

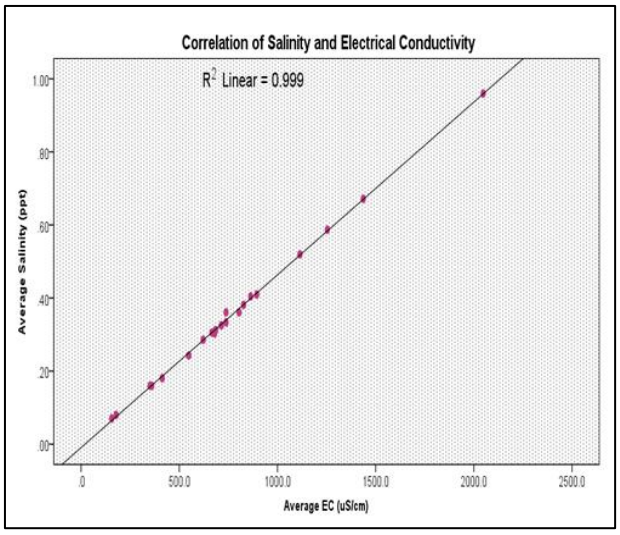


Figure 9: **Correlation between salinity and EC**

CONCLUSION

The present study revealed that even slight change in temperature could cause a remarkable effect on other groundwater specifically dissolved oxygen. If dissolved oxygen is under pressure it might affect other water quality parameters significantly.

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