Open Journal of Applied Sciences, 2023, 13, 2198-2209
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Seasonal Effect of Weather Elements on Water Table Fluctuation in Potable Wells in Kono District, Eastern Sierra Leone

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How to cite this paper: Simbo, R.T., Gogra, A.B., Kawa, Y.K. and Moiwo, P.J. (2023) Seasonal Effect of Weather Elements on Water Table Fluctuation in Potable Wells in Kono District, Eastern Sierra Leone. *Open Journal of Applied Sciences*, **13**, 2198-2209.
https://doi.org/10.4236/ojapps.2023.1311171

Received: October 7, 2023
Accepted: November 27, 2023
Published: November 30, 2023

Abstract

The study investigated the seasonal effects of weather elements on water table fluctuations in drinking wells in Nimikoro and Tankoro Chiefdoms in Kono District, Eastern Sierra Leone. The study specifically determined the trends in precipitation, air temperature and relative humidity relative to water table depth and water volume in both manually dug and mechanically drilled water wells in the chiefdoms. The key objective was to provide a clear guide on sustainable well development and operation in the study area and beyond. To do so, the depth of each well was taken and the water table measured. Also, data on key weather elements such as precipitation, air temperature and relative humidity were collected on the 15th of every month for a period of one year. The data were analyzed on Excel, SPSS and ArcGIS platforms for monthly and seasonal trends in the time-space fabric. The results showed that the depth to water table was high in the dries (small well water volume) and low in the rains (large well water volume) for both manually dug and mechanically drilled wells. Well water temperature increased as temperature increased during the dry season but decreased as temperature decreased during the rainy season. The study showed that weather elements such as precipitation and temperature had direct impact on groundwater availability. This is critical for groundwater development and management in the study area and in Sierra Leone at large.

Keywords

Groundwater, Water Table, Relative Humidity, Precipitation, Temperature

1. Introduction

Water is so much so useful for nearly everything, including domestic, agricultural, industrial and ecological purposes. It is the third most abundant molecule in the universe, trailing behind only hydrogen and carbon monoxide [1]. Only 2.5% of the water on earth is fresh and nearly all of it (98.8%) occurs as ice/glacier or groundwater. Groundwater accounts for 99% of the freshwater on earth. It is key for food production, industrial growth and national wealth [2] [3].

The primary sources of water are groundwater and surface water [4]. If collected and stored, precipitation can be a good source of water too. Surface water (such as lake, reservoir, stream and river) is the source of drinking water for some 50% of the population in Sierra Leone. This source of water is generally poor in quality and therefore requires treatment. Groundwater, the source of water for another 30% of the population, is relatively of better quality.

Water wells are variously used to harness groundwater for drinking and other purposes. When hand dug, water well can be less than 15 m deep. If, however, machine drilled, water well can be over 30 m deep. Water wells driven in alluvial or glacial sediments are typically 30 m deep. About 97% of the available freshwater in the world is from the ground, providing water for individual, community, national needs. Some wells are drilled for heating or cooling purposes. Wells dug for water scientific studies are called monitoring wells [5]. Wood-lined wells are known from the early Neolithic Linear Pottery Culture, as found in Kückhoven (dated 5090 BC), in Eythra (dated 5200 BC) in Schletz and in Austria [6].

Climate change is posing a considerable threat to the ecological environment we live in today. It has changed the normal patterns of temperature, rainfall, sea level rise, etc. Temperature is reported to have increased by 2˚C - 4.8˚C in this century alone [7]. There is also evidence of increasing frequency and intensity of extreme heat and precipitation events. While precipitation is increasing in high latitude zones, it is decreasing in subtropical regions [7]. Groundwater is mainly infiltration, percolation and storage of water into the ground following precipitation or snowmelt [8].

The amount of water that seeps through the soil is a function of the land surface characteristics. In coarse materials such as sand or gravel, as much as 40% - 50% of rainwater and snowmelt can seep into the ground. For fine materials such as clay, water seepage can be as low as 5%. The rest of the rainwater flows in streams as runoff or returns to the atmosphere as water vapor via evaporation. Water is mostly lost to evapotranspiration during warm periods and to runoff during cold periods. Rainwater or snowmelt seeps into the ground and flows down under gravity until saturation point is reached. The saturated zone is called aquifer, on top of which seats the water table. The water table rises/falls in response to water recharge or discharge [9]. Increase in temperature could also increase the water table during winter period [10], suggesting that water table fluctuation is also driven by climatic factors. Important among these are the intensity of precipitation, air temperature, evapotranspiration and runoff. Hydrology and relief also influence water table fluctuations in a given area [11]. Thus, groundwater regimes can be driven by precipitation, temperature and lithology of an area [12].

Rainwater is the main source of groundwater and the variability of rainfall particularly influences groundwater storage [13] [14]. The seasonality of rainfall affects the amount of water stored in an aquifer [15] [16]. Variations in rainfall in time-space fabric affect surface water and groundwater storage. Aquifers rich in groundwater are a reliable source of water for domestic use [17] [18]. Baseflow from groundwater discharge also sustains streamflow in the dry season [19] [20]. The combined use of surface water and groundwater is good ecological sustainability [8] [21]. High evapotranspiration accelerates groundwater depletion in the dry season in arid/semi-arid regions [22], negatively affecting well productivity [23] [24] [25].

The purpose of this study was to investigate the influence of the weather elements of precipitation, temperature and relative humidity on water table fluctuation in portable wells in Kono District, Eastern Sierra Leone. The objectives were to: 1) determine the trends in precipitation, temperature and relative humidity in 2011-2021; and 2) relate these trends to those in depth to water table and water volume in manually dug and mechanically drilled wells in the study area. This study is critical for efficient management of portable wells in the study area and beyond.

2. Methods and Materials

2.1. Study Area

Kono District is in the Eastern Province of Sierra Leone and it lies within latitude 8˚44'02.44'' and longitude 10˚58'48.00''. There are 14 chiefdoms in this district, two of which were covered in this study. The two chiefdoms (Nimikoro and Tankoro) are the main agricultural zones, cultivating various crops and equally so rearing various animals. These chiefdoms have also been the main source of diamonds since the 1900s. The diamond mine has over the decades attracted countless number of youths into the chiefdoms, engaged in primarily in artisanal small-scale mining of the highly precious diamond and gold minerals.

Kono District, with Koidu as the district headquarter town, borders with the Republic of Guinea [26]. Diamonds were first discovered in Yengema (which is in Jaiama Nimikoro) in the 1930s. This was the start of both artisanal and small-scale mining of the so-called alluvial diamond in Jaiama Nimikoro Chiefdom. This later expanded to include Tankoro Chiefdom.

The climate in the study area is humid with unimodal precipitation [26]. The annual average temperature, precipitation and relative humidity are respectively 24.4˚C, 1694 mm and 87.3% [27].

In Nimikoro Chiefdom, the mechanically-drilled hand-pumped well investigated was located at 8˚26'38.409''W and 11˚1'21.021''N. Then the manually-dug hand-drawn well was located at 8˚36'38.739''W and 11˚1'22.669''N. In the contiguous Tankoro Chiefdom, the mechanically-drilled hand-pumped well lied at 8˚37'53.500''W and 10˚59'24.200''N, and the manually-dug hand-drawn well at 8˚37'56.000''W and 10˚59'28.400''N in **Figure 1**.

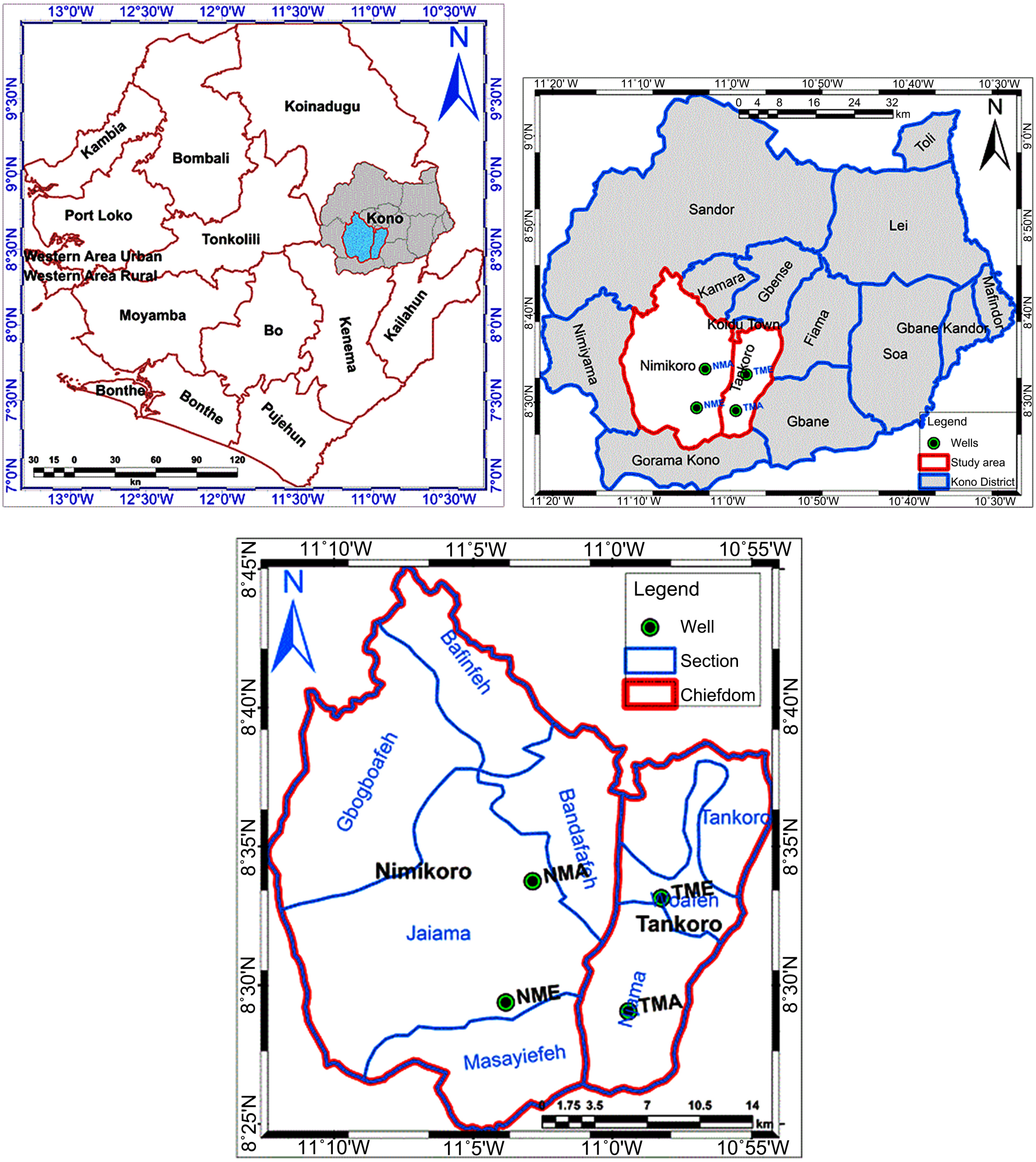

Figure 1. A map of Sierra Leone showing Kono District and the Nimikoro and Tankoro Chiefdoms. NMA = manually dug and operated well in Nimikoro Chiefdom; NME = mechanically drilled and operated well in Nimikoro Chiefdom; TMA = manually dug and operated well in Tankoro Chiefdom; and TME = mechanically drilled and operated well in Tankoro Chiefdom.

2.2. Depth to Water Table and Well Water Volume

Before collecting water samples, well diameter, well depth and depth to water table of each well were measured. The well diameter was measured using the simple measuring tape. The well depth was measured using the tape measure and weight method. Here, a 1.0 kg lead ball was tied to a long tape measure and then sank into the well until there was no more tension in the tape measure. The point at which there was a loss of tension suggested that lead ball has rested at the bottom of the well and the measurement therefore taken at that point. For the depth to water table, also the same tape measure and weight method was used. Here, however, the weight was replaced with fishing float. The measure of depth to water table was done every month for the 12 months in 2021. Note that this measurement was done before purging the water well.

2.3. Well Water Sampling

To determine well water temperature, water samples were collected from four wells in the study area, two manually dug and operated wells and two mechanically drilled and operated wells. The well water samples were collected on the 5th of every month in 2021. A set of water samples was collected at a time, one before and another after purging [28]. The well water temperature was measured *in situ* using two mercury thermometers for comparison. This was repeated three times at each well site and the average reading recorded.

2.4. Climatic Data

Data for precipitation (mm), temperature (˚C) and relative humidity (%) for the period 2011-2021 were obtained from the Sierra Leone Meteorological and Climate Agency [27].

2.5. Data Analysis

The collected data, including that SLMCA data, were screened for outliers and analyzed in Microsoft Excel, Statistical Package for Social Sciences (SPSS) and Geographic Information System (GIS) ArcMap.

The Coefficient of Determinant (r^2) was used to determine the interdependence of the variables, Coefficient of Variation (CV) to assess the variability in the data, and T-test to determine the significance correlation at $p < 0.05$. The results were plotted in time-series and spatial distributions.

3. Results

3.1. Climatic Variables

The dynamics of the climatic variables of precipitation, temperature and relative humidity are plotted in time-series in **Figure 2**. The time-series plot of the precipitation averaged for 2011-2021 (green line) peaked in July followed by August. That for the 2021 was peaked in August, followed by September. Given the months before and after the peak precipitations of the 2011-2021 average and for

2021, it was clear that the period of high rains in the study area was June, July and August. Equally so, the period of low rains was December, January and February.

The period of high air temperatures is March, April and May and that of low temperatures was December, January and February. While it coincided with precipitation for the period of low temperatures, it was vastly different for the period of high temperatures.

Relative humidity was a bit hard to explain, especially for the 2021 dynamics. Going, however, by the average trend for 2011-2021, the period of high relative humidity was July, August and September and that of low relative humidity was January, February and March. For both high and low relative humidity, it occurred later than precipitation by one month. The implications of the dynamics of the climatic variables for water table and well water volume can be critical for groundwater availability in the study area.

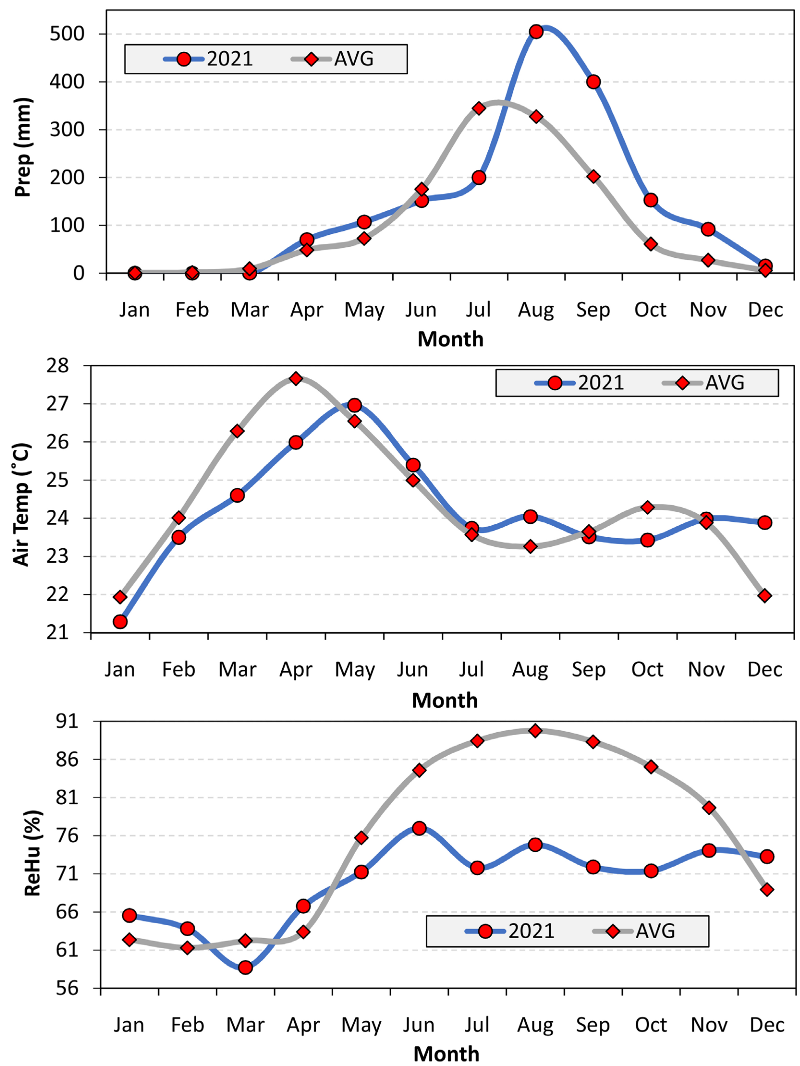

Figure 2. Time-series plots of monthly precipitation, air temperature and relative humidity for 2021 and 2011-2021 average for the study area.

3.2. Water Well Parameters

The depth to water table, well water volume and their correlativity are also plotted as time-series in **Figure 3** for both manually dug and mechanically drilled wells in the study area. The depth to water table was highest (low water table) in May for mechanically drilled well, April for manually dug well and also May for the average for the study area. It was lowest (high water table) in September for the two well types in the study area and the average.

For well water volume, it was highest in September (when depth to water table was lowest) and lowest (when depth to water table was highest) in May for the mechanically drilled well and the average, and in April for manually dug well in the study area.

It then implied that the depth to water and well water volume were negatively correlated, very so clearly confirmed in the bottom plots of **Figure 3**. Strikingly, the correlations ware perfect for both manually dug wells and mechanically drilled wells.

3.3. Well Water Temperature

For both mechanically drilled and manually dug wells in the study area, water temperatures were generally higher for unpurge than purged wells (**Figure 4**). Well water temperatures were highest in January and lowest in August. This was quite different from the trend in air temperature, but nearly the reverse of the in precipitation the study area. For mechanically drilled wells (which were generally deeper than manually dug wells), water temperatures were highest in February and lowest in September (one month delay from the manually dug wells). This suggested that precipitation had a direct effect on well water temperature in the study area.

3.4. Spatial Distribution

The plot of well water temperature over the space of the study area in **Figure 5** shows that temperatures were lowest for manually dug wells and highest for mechanically drilled wells. But there was the case (see left side of the plot) where water temperature in manually dug well was higher than in mechanically drilled well. This suggested that well type was not specifically the sole factor driving well water temperature. Factors like the location and possible the depth affected well water temperature in the study area.

4. Discussions

4.1. Precipitation and Water Table

Precipitation had the most effect on water table and well water volume in the study area. When precipitation was high, water table and indeed well water volume in the well were high too. The depth to water table was shortest, implying that there was substantial amount of water in the well. When precipitation was low on the other hand, water table and well water volume were low too. It implied

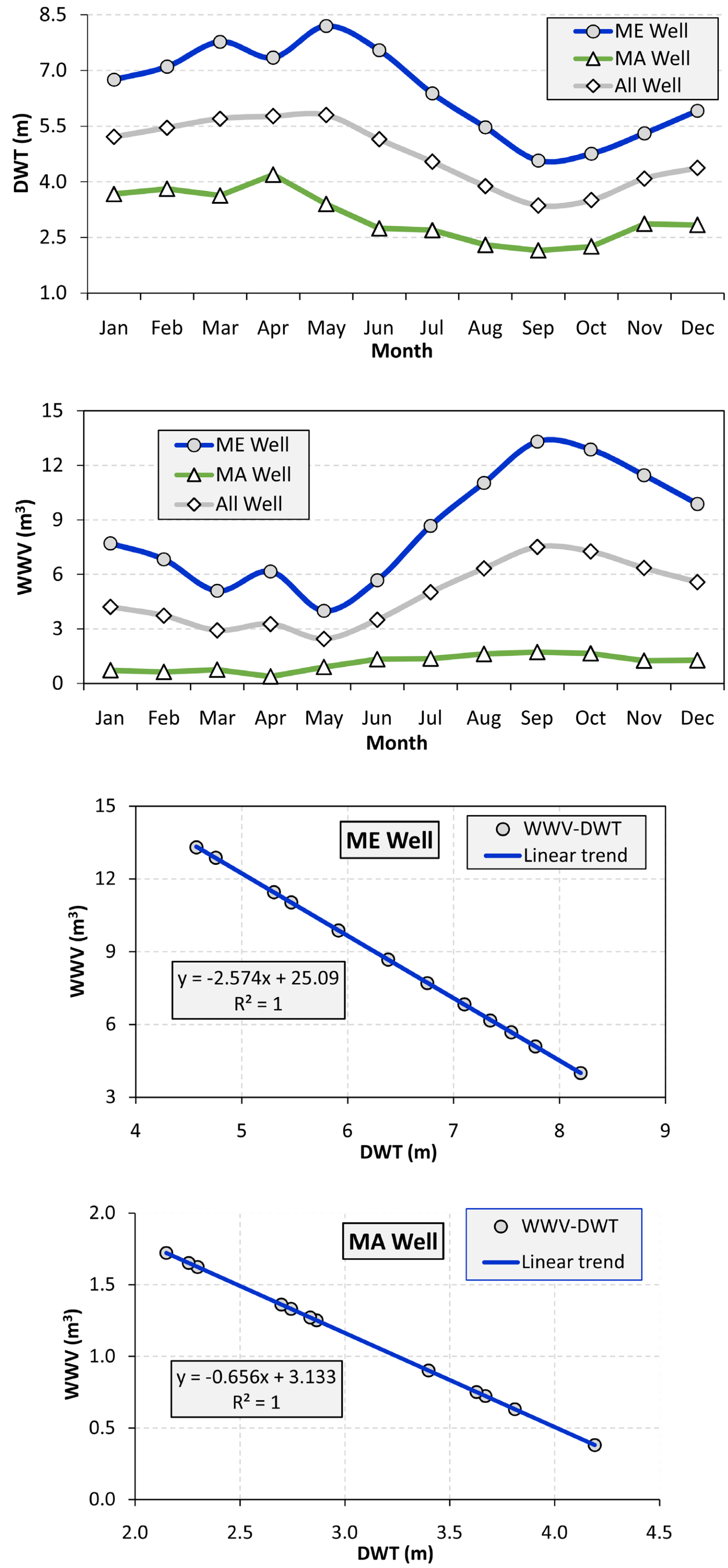

Figure 3. Time-series plots of monthly Depth to Water Table (DWT) and Well Water Volume (WWV) and the corresponding correlations for manually dug (ME) and mechanically drilled (MA) wells in the study area.

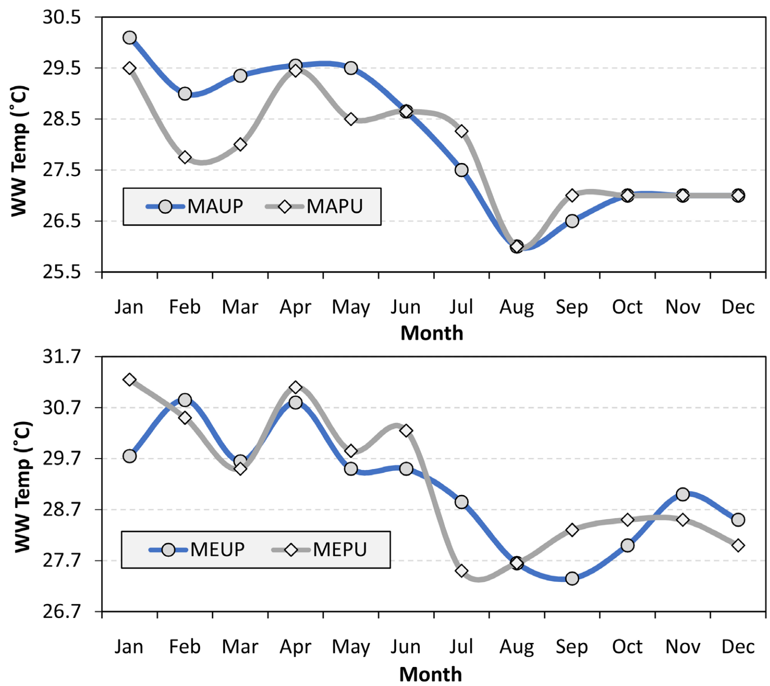

Figure 4. Time-series plots of monthly water temperature (Temp) before (UP) and after (PU) purging of manually dug (MA) & mechanically drilled (ME) wells in the study area.

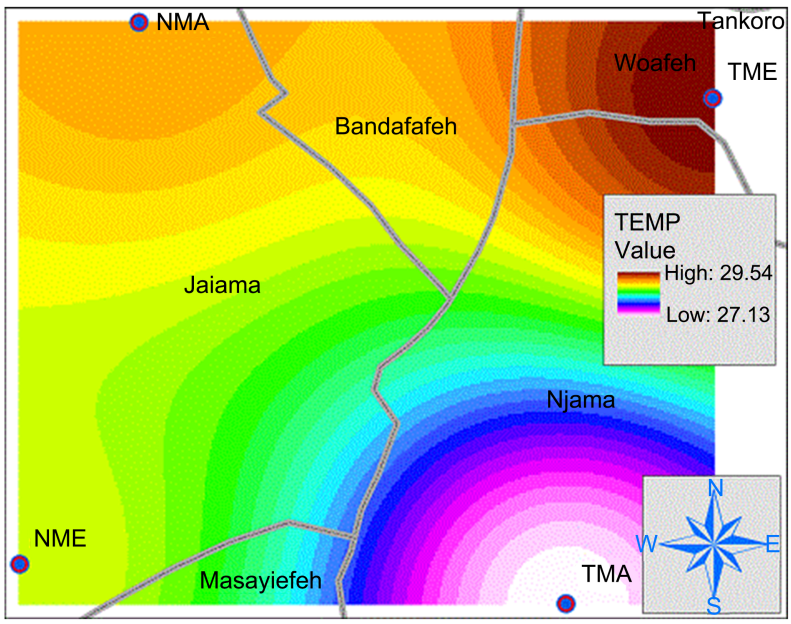

Figure 5. Spatial distribution of average monthly well water temperature (Temp) of in the study area.

that the depth to water table was longest and the corresponding amount of water in the well smallest. There was general one month delay in the response of water table and well water volume to precipitation in the study area [29]. The result sowed that direct correlations existed among water table, well water volume and precipitation in the study area.

4.2. Temperature and Water Table

Air temperature in the study area was highest in April-May and lowest in January. Well water temperature on the other hand was generally highest in January and lowest in August. Then water table and well water volume were highest in September and lowest in April-May. It suggested that while air temperature was largely not in phase with precipitation in the study area, well water temperature was generally in reverse phase with precipitation. This implied that well water temperature (and not air temperature) was negatively correlated with water table and well water volume in the study area. With the coming of rains, well water temperature dropped and the water table and well water volume increased, and vice versa.

High air temperatures triggered precipitation months later in the region. However, with high well water temperatures, there was the possibility of groundwater evaporation and vice versa. The implication was that the potential for groundwater availability was low with high water temperatures and high with low well water temperatures.

4.3. Relative Humidity and Water Table

Relative humidity was lowest in March and highest in August, similar to precipitation but different from air temperature for peak values. In terms of relative humidity, water table delayed by 1 - 2 months for the lowest values but was almost in tune for the highest values. This suggested that relative humidity was not entirely a determining factor of the dynamics of water and well water volume in the study area. Generally, low relative humidity could cause more evaporation of water and vice versa. In this sense, relative humidity enhanced groundwater potential in its high period of August and limited it in its low period of March.

5. Conclusion

The study showed that precipitation was the principal driving factor of the dynamics of water table, well water volume and hence groundwater potential in the study area. The other climatic factors of air temperature and relative humidity were also largely dependent on precipitation. Irrespectively, climatic factors importantly determined the dynamics of water table (or the depth to water table), well water volume and groundwater potential in the study area.

Acknowledgements

The authors wish to thank Mr. Ebenezer Johnson, the Laboratory Technician, for providing the equipment to collect and analyze the data.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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