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Climate Change Variability and Impacts on Aquifers Performance and Groundwater Production at Akerebiata Area, Nigeria

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ABSTRACT

Aim of the Study: Akerebiata area is located around Latitude N 8° 30' 50.87988", longitude E 4° 33' 10.5598" and Latitude N 8° 31' 2.112", Longitude E 4° 33' 9.417". The study aim to investigate groundwater production in extreme weather conditions.

Methodology: Pumping test and weather variability measurements were carried out between extreme weather conditions to get precise aquifer performance. Dipper, stopwatch, graduated plastic container, riser pipe, 1 h.p submersible pump, 5.5 KVA generator and field notebook were used to collect the field data. Suitable measuring datum of 0.5 m was taken from the ground level. MetPRO weather variability instrument was partly used to collect seasonal data as it's a highly portable, accurate, durable, rugged and designed for wide varieties of environmental study.

Findings/Results: Results obtained showed from 2001-2010 weather pattern, a total of highest 392°**C** maximum air temperature was recorded against the lowest recorded air temperature of 368°**C** and continued till 2012 that recorded a total of 395°C. Recorded values from this 2013 to 2020 ranges from 405°C to 412°C except for 2015 that recorded 399°**C**. The rainfall precipitation varied between highest 1860.4mm in 2010 to 1352 mm in 2006. Sunshine varied from around 10 hours around January to 5.5 hours in August. During dry season, measured SWL ranges from 7.8-9.9 meters, TPT ranges from 27991-49922 secs, TRT ranges from 16834-19848 secs, TDD gave 32.8-45.4meters and yield was measured to be 0.53-0.79liter/sec. Moreover, during the wet season, SWL ranges from 1.2-3.9meters, TPT ranges from 51907-69222 secs, TRT ranges from 17603-29807 secs, TDD gave 41.4-52.2meters and yield was measured to be 0.86-1.22Liter/sec.

Conclusion: As climate change continues to affect precipitation patterns in the Akerebiata area, causing increasing pressure on the existing surface water sources, groundwater offers the buffering capacity to protect humanity and provide a reliable potable water supply to inhabitants.

Keywords: TPT=Total Pumping Time, SWL=Static Water Level, TRT=Total Recharge Time, TDD=Total Drawdown and yield.

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Introduction

Climate change strongly influences freshwater supply and demand globally. Warming of ~1°C over the last half century globally has directly impacted the supply of freshwater through the amplification of precipitation extremes, pronounced floods and droughts increasing evapotranspiration rates, rising sea level, changing precipitation and meltwater regimes. These factors have seriously impacted the groundwater aquifers globally. Groundwater, the world's largest distributed store of freshwater, is naturally well placed to play a vital role in enabling societies to adapt to intermittent and sustained water shortages caused by climate change (Ibrahim et al 2023). Climate change influences groundwater systems directly through changes in the water balance at the earth's surface and indirectly through changes in groundwater withdrawals as societies respond to shifts in freshwater availability (Lall et al., 2020). Climate change directly impacts the natural replenishment of groundwater. This replenishment can occur across a landscape by precipitation directly (i.e. diffuse recharge) and via leakage from surface water, including ephemeral streams, rivers, wetlands or lakes (i.e. focused recharge). The latter process is more prevalent in drylands (Scanlon et al., 2006 and Cuthbert et al., 2019a). Substantial uncertainty persists in global projections of the impacts of climate change on groundwater recharge.

The hydrological cycle teaches us that water is in constant movement. It melts, crystallizes, evaporates, condensates, infiltrates, circulates, dissolves, flowing here and there and even displaces obstacles along its pathway. Indeed, water is inevitable to mankind (Ibrahim et al 2023). The Earth's climate is dynamic and naturally varies on seasonal, decadal, centennial and longer time scales. Each up and down fluctuation can lead to conditions which are warmer or colder, wetter or drier and stormier. These changes in climate may be due to natural internal processes or external forces or to persistent anthropogenic changes in the composition of the atmosphere or in land use. One of the most significant climatic variations in the African Sahel since the late 1960s has been the persistent decline in rainfall (Abaje et al., 2010). The Sahel is characterized by strong climatic variations and an irregular rainfall that ranges between 200 mm and 600 mm with coefficients of variation ranging from 15 to 30%. According to IPCC i.e. International Panel on Climate Change, rainfall decrease of 29-49% has been observed in the 1968-1997 period compared to the 1931-1960 baseline period within the Sahel region (Oluwadare et al 2021).

Location and Climate of the Study Area

The location of the study area is bounded by Latitude N 8° 30' 50.87988", Longitude E 4° 33' 10.5598" and Latitude N 8° 31' 2.112", Longitude E 4° 33' 9.417". Akerebiata serve as the gateway to Nigeria Army Corps i.e. Sobi barracks and further down to Kwara state University, Malete. It is well known sedimentary terrain with few places known to have large crystalline rocks emplacement. The crystalline rocks are more noticeable as soon as one crosses the Abattoir that link the mini bridge in the area and onward to Sobi road with massive emplacement of granitic rocks. The abattoir mini-bridge which is located Latitude N 8° 31' 40.872", longitude E 4° 33' 11.7601" serve as the transition zone of the sedimentary deposit of the study area and the emplacement of the crystalline rocks mostly of granitic origin.

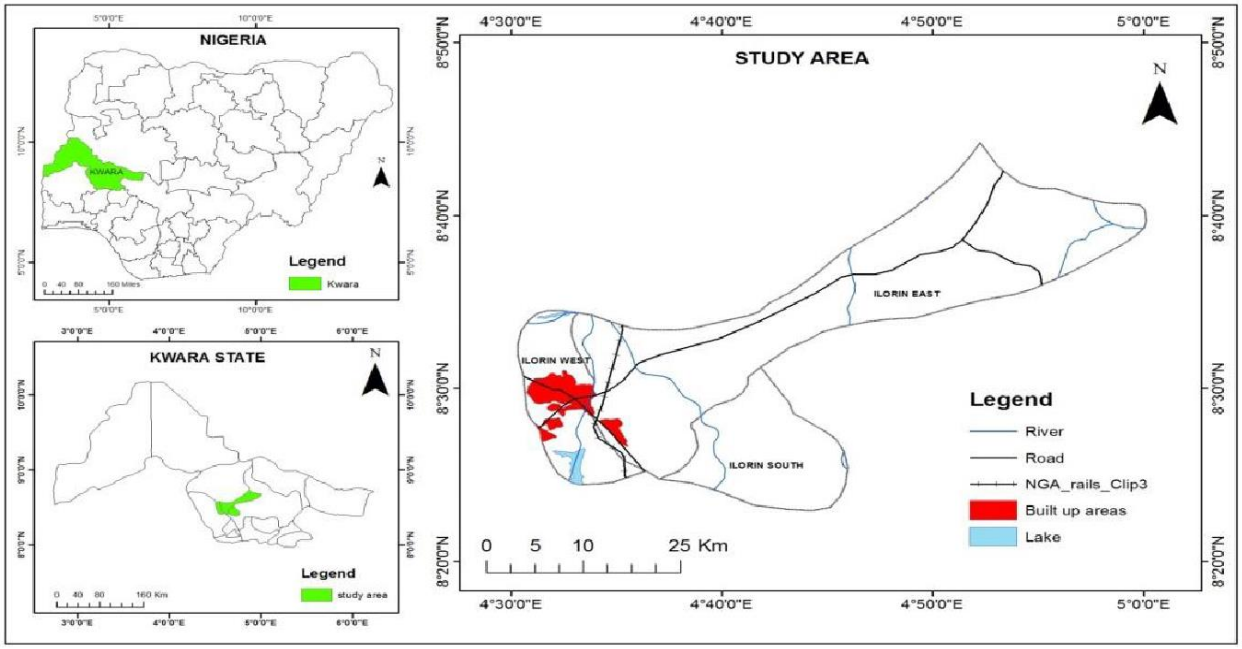

Fig. 1; *Location map of the Akerebiata study area in Ilorin. Source: Office of the Surveyor General of the Federation (OSGOF), Abuja. (2015).*

Developing countries are more vulnerable to the effects of climate change than developed countries because of the low adaptive capacity. On a global scale (Fig. 2), climate extremes have been observed to increase in frequency. This has been reported by the IPCC i.e. the Intergovernmental Panel on Climate Change. It is very likely that over the past 50 years, cold days, cold nights and frosts have become less frequent over most land areas and hot days and hot nights have become more frequent. It is likely that heat waves have become more frequent over most land areas, the frequency of heavy precipitation events has increased over most areas and since 1975 the incidence of extreme high sea level has increased worldwide (IPCC, 2014). The IPCC projects on the African continent projected average temperatures will increase by 1.5 to 3°C by the year 2050. The West Africa region has experienced a marked decline in rainfall from 15 to 30% depending on the area (Fig. 2). The trend was abruptly interrupted by a return of adequate rainfall conditions in 1994 which was considered to be the wettest year of the past 30 years and was thought to perhaps indicate the end of the drought. Unfortunately, dry conditions returned after 1994 (Anomohanran, 2013). The pattern of rainfall in middle belt Nigeria is highly variable in spatial and temporal dimensions with inter-annual variability.

As a result of the large inter-annual variability of rainfall and temperature, it often results in climate hazards, especially floods, severe and widespread droughts. Groundwater accounts for approximately 99% of all liquid freshwater on earth, groundwater has the potential to provide societies with tremendous social, economic and environmental benefits and opportunities. Groundwater already provides half of the volume of water withdrawn for domestic use by the global population, including the drinking water for the vast majority of the rural population who do not get their water delivered to them via public or private supply systems and around 25% of water withdrawn for irrigation are from groundwater (Kehinde and Loenhert 1989).

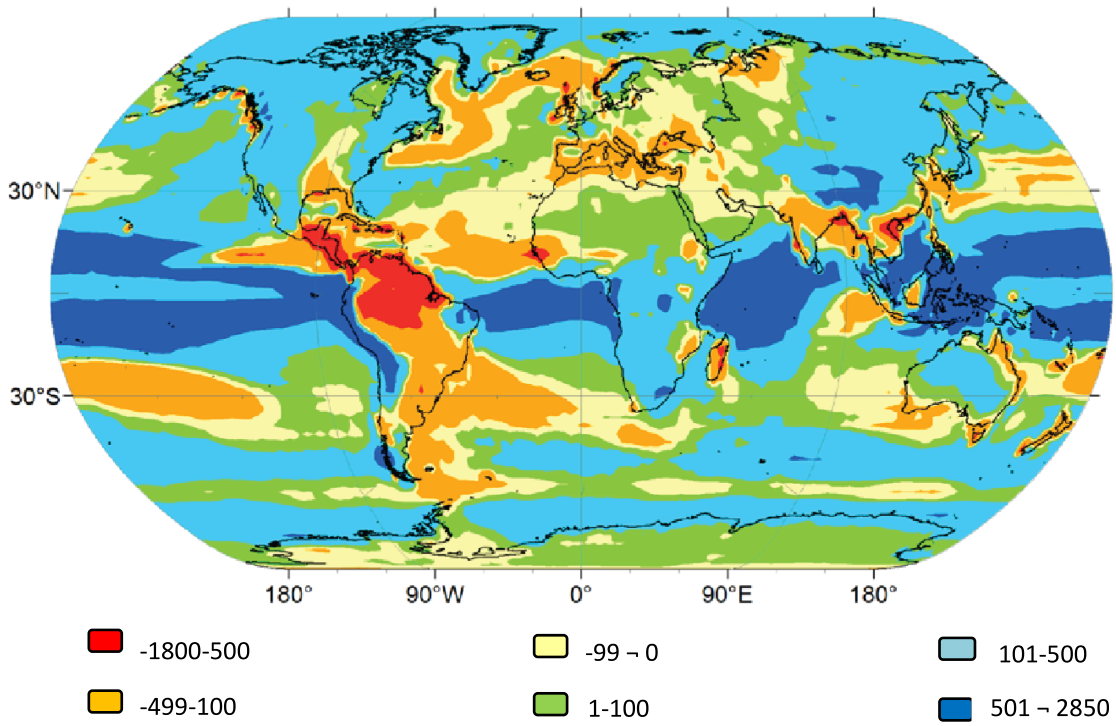

Fig. 2; *Changes in global mean annual precipitation (mm)*

The climate of the Akerebiata is humid and tropical under the influence of the two trade winds prevailing over the country, characterized with high temperatures throughout the year (Ajibade, 2002). Ilorin and indeed Akerebiata enjoy wet and dry seasons. The daily average temperatures are in January with 25ºC, May 27.5 ºC and September 22.5 ºC. The wet season is between May and October with two peak periods in July to September while the dry season spans between November and April. The mean annual rainfall is 1,200mm (Olanrewaju, 2015). The mean annual total rainfall is 1200m (Olaniran, 2002). The temperature in Ilorin is uniformly high throughout the year. The rainy season begins towards the end of April and lasts till October while the dry season begins in November and ends in April. The temperature of Ilorin ranges from 330 ºC to 350 C from November to January while from February to April; the value ranges between 340 ºC to 370 ºC . Days are very hot during the dry season. The total annual rainfall in the area ranges from 990.3 mm to 1318mm. The rainfall in Ilorin city exhibits the double maximal pattern and greater variability both temporarily and spatially. The relative humidity at Ilorin city ranges from 75% to 88% from May to October while in the dry season it ranges from 35% to 80% (Bala and Onugba 2001).

Materials and Methodology

Dipper, stopwatch, graduated plastic container, 1 h.p submersible pump, 5.5 KVA generator and field notebook were used to collect the field data. Suitable measuring datum of 0.5 m was taken from the ground level for pumping test measurements. Hydro Meteorological equipment used for the study included the MetPRO weather variability measuring instrument and its a highly accurate, durable, rugged and designed for a wide variety of environmental study. It includes high quality sensors, which are needed for reliable data in environmental research as well as critical operations dependent on continual weather monitoring. It is solar driven in its operations. It typically measures different parameters like wind speed, wind direction air temperature, relative humidity, barometric pressure, precipitation and solar radiation ie sunlight etc. It is worthy of note that these boreholes were pump tested with 1 hp submersible pump and at full discharge and no gate valve to regulate the flow of water from the aquifer to riser pipe and onward to the discharge pipes. Aquifer response was monitored during pumping to get the best data for adequate documentation.

Fig. 3: *Weather variable data collection of the area for 2020-2022*

Pumping tests being a practical way of obtaining ideal data of the borehole's efficiency, aquifer characteristics and optimal production yield was thus adopted for this study. The way in which the water levels responded to the pumping exercise was closely monitored at the peak of dry and rainy seasons for adequate comparative analysis, then analyzed to derive maximum information about the performance characteristics of the boreholes and the hydraulic properties of the aquifers to cover the period of analysis.

Results and Discussion

The investigated area was evaluated for the weather pattern at the critical peak condition of rainy and dry seasons and groundwater production was done to find out the effect of climate change on the aquifer vulnerability and/or resilience in the area. The impacts of climate change are obvious at world and regional scales along the area with massive yearly flooding signature, but the point of study is to find out the impact on groundwater production during the two most extreme weather conditions. The result of the study is hereby presented for closer interpretation of the available data of the area. The data used for the study were collected from Lower Niger River Basin Development Authority, Ilorin and interpreted to explain the impacts it is having on the underground water production of the area. Collected data covered 20 years of 2001-2020. The summary of data is hereby tabulated for interpretation phase to reveal the impact climate change has on groundwater production and aquifer vulnerability of Akerebiata area.

Air Temperature

Air temperature, sunshine hours and precipitation are fundamental measurements for describing the climate and can have wide-ranging effects on human life, structures, groundwater aquifers and ecosystems. For example, increases in air temperature can lead to more intense heat waves and larger amounts of evapotranspiration where the moist soil expected to contribute to aquifer recharge loose most of its moisture. More importantly, at Akerebiata study area, air temperature, rainfall pattern and sunshine radiation hours allowed better interpretation of the underground water aquifer performance. From the 2001-2010 weather pattern, a total of highest 392°**C** maximum air temperature was recorded that represented 2001 and 2003 against the lowest recorded air temperature of 368°**C** of 2008 (Table 1). Air temperature being a strong indicator of climate change revealed a definite pattern for a decade of investigation.

Table 1: *Maximum air temperature pattern (°C) of the study area (2001-2010)*

Year	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV	DEC.	TOTAL
2001	35	35	37	35	32	31	30	28	29	32	34	34	**392**
2002	32	32	31	36	32	32	30	31	31	32	35	35	**389**
2003	34	37	36	34	34	30	29	29	30	32	33	34	**392**
2004	34	35	34	31	35	33	30	29	29	30	32	33	**385**
2005	35	33	32	34	31	32	31	31	30	31	32	33	**385**
2006	34	37	36	29	32	31	30	28	30	32	34	34	**387**

2007	31	32	31	28	32	31	31	31	32	30	33	35	**377**
2008	33	30	31	29	31	30	31	29	30	31	31	32	**368**
2009	32	31	32	32	32	33	30	31	29	30	31	33	**376**
2010	30	31	31	31	32	31	31	31	34	30	34	34	**380**

Conversely, this regular trend of maximum air temperature continued till 2012 that recorded a total of 395°C as maximum air temperature and severe flooding due to excessive rainfall. From 2013 onward, measured maximum air temperature increased gradually and this has been traced to human activities that contribute to increased burning of fossil fuel and emission of more carbon into the atmosphere associated with massive deforestation. Recorded values from 2013 to 2020 range from 405°C to 412°C (Table 2) except for 2015 that recorded 399°**C**.

Table 2: *Maximum air temperature pattern (°C) of the study area (2011-2020)*

Year	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV	DEC.	TOTAL
2011	34	32	31	32	33	31	29	30	28	31	32	33	**376**
2012	31	32	33	34	37	32	33	31	32	33	33	34	**395**
2013	32	33	35	34	33	33	32	34	33	35	36	35	**405**
2014	33	35	34	31	32	35	33	32	34	33	35	36	**403**
2015	32	34	33	31	32	33	34	34	34	35	33	34	**399**
2016	33	31	31	33	56	33	31	32	33	31	32	36	**412**
2017	32	31	32	29	37	33	32	31	31	32	33	33	**402**
2018	35	33	31	32	33	36	32	33	37	33	31	35	**401**
2019	33	36	31	32	33	32	36	36	33	32	33	34	**401**
2020	33	36	31	35	36	36	31	32	34	35	36	37	**412**

The impact of this on groundwater is that the trend of recharge potential changes from 2013-2020 as the capacity of the soil to contribute to the recharge of the underground water diminishes from the 2013 to 2020 (Table 2). The maximum air temperature map revealed a strong influence on the groundwater production of the area and selected settlement was attempted for the study area (Fig. 3).

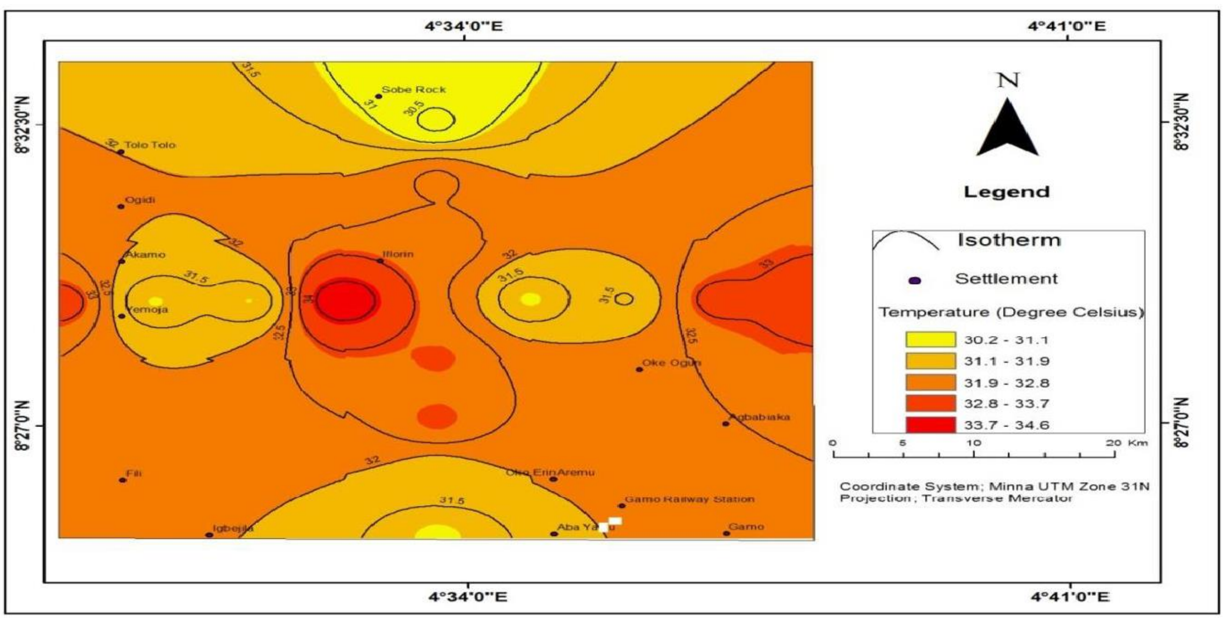

Fig. 3: *Maximum air temperature map of selected settlements in the study area for the Month of April, May, June and July2015. (Adapted from Olanrewaju et al 2015).*

Table 3: *Minimum air temperature pattern (°C) of the study area (2001-2010)*

Year	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV	DEC.	TOTAL
2001	22	20	23	25	24	22	23	21	23	23	20	20	**266**
2002	18	21	25	25	24	21	23	23	22	23	18	16	**259**
2003	20	23	21	21	24	20	23	23	23	23	22	19	**262**
2004	19	20	26	24	22	22	22	22	22	23	19	19	**260**

2005	20	23	23	25	24	22.5	22	24	22	23	22	21	**271.5**
2006	18	21	25	21	24	22	22.5	22.6	22.3	23.1	21.5	18.7	**261.7**
2007	18	23	25	24	24	24	22	23	21	23	22	19	**268**
2008	21	21	23	23	22	24	23	23	23	22	21	20	**266**
2009	19	23	24	24	23	24	23	23	23	23	22	21	**272**
2010	17	20	26	24	22	22	23	23	23	23	22	19	**264**

The minimum air temperature data of the area (Table 3 and 4) was interpreted and findings showed that it did not have a strong influence on the aquifer vulnerability as it only assisted to increase the aquifer resilience by increasing the level of groundwater slightly with the replenishment of the aquifer water, but in very small and negligible amount. Ibrahim et al 2023. The minimum air temperature of the study area showed 259 ºC -272°**C** for the period 2001 to 2010 under review**.** The highest minimum air temperature of the area was in 2002 with 259°C**.** On the other hand, the minimum air temperature of 272°C recorded in 2009 for the same period was the highest. For the period 2011 to 2020 and even beyond, the minimum air temperature of Akerebiata area has revealed moderate values that ranges from 242 ºC to 276**°C.** The highest minimum air temperature was recorded in 2013 ie 272 ºC, while the lowest value of minimum air temperature was in 2016 at 242°C (Table 4).It is worthy of note that the minimum air temperature of the study area within this decade has shown that the groundwater potential due to this factor has had little or no influence on the vulnerability of the wells.

Table 4: *Minimum air temperature pattern (°C) of the study area (2011-2020).*

Year	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV	DEC.	TOTAL
2011	20	22	22	23	24	23	22	22	24	22	23	21	268
2012	16	25	24	25	24	23	24	23	23	23	22	24	276
2013	19	23	25	24	24	23	24	23	23	23	23	18	272
2014	20	21	23	23	22	23	22	23	23	23	22	21	266
2015	21	23	24	24	23	22	23	22	22	24	22	19	269
2016	16	19	21	19	22	24	12	16	18	19	18	22	242
2017	19	21	20	21	22	19	22	19	22	23	23	19	250
2018	18	19	19	22	21	22	25	29	22	18	22	23	260
2019	19	22	25	24	26	16	19	19	22	19	21	21	253
2020	19	22	23	23	26	18	17	16	19	22	22	22	249

Rainfall

Rainfall pattern of the Akerebiata area was measured to give a more robust interpretation of the aquifer's vulnerability and resilience to reflect the impact of climate change on the aquifer at the peak of the rainy and dry season. Rainfall is the greatest factor that impacts the aquifer condition globally and it's a veritable and highly valuable source of recharge for continued production of potable freshwater. The rainfall precipitation varied between highest 1860.4mm in 2010 to 1352 mm in 2006 (Table 5). The peak of rainfall in this decade falls within April and October (Table 5). This is 7 months in the total 12 months of the year. From November, the rainfall trend started dropping. Predictable rainfall pattern in this decade has contributed to the excellent recharge of underground borehole water and has improved crop yield and socio-economic activities of the people in the area.

Table 5: *Rainfall pattern of the study area (mm) (2001-2010)*

Year	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV	DEC.	TOTAL
2001	0	0	18	45	139	121.8	138.7	44.5	176.4	60.8	0	0	**744.2**
2002	0	0	59.4	163.2	57.2	97.8	180.8	182.7	144.5	116.7	6.5	0	**1018.8**
2003	0	14	12.4	93.9	124.5	360.7	123.2	130.9	176.2	133.4	46.7	0	**1215.9**
2004	0	33.1	4.6	260.5	159.2	211.4	145.4	243.5	98.1	31.6	0	0	**1187.4**
2005	0	5.5	25.5	75.5	187.6	171	130.2	93.6	282.6	109.8	10.5	0	**1091.8**
2006	0	16.1	27.5	106.6	163.7	259.6	224.1	88.2	276.2	190	0	0	**1352**
2007	0	29.3	37.6	115.2	150.3	235	198.1	124.7	203.6	137.9	23.8	0	**1255.5**
2008	0	39.4	47.3	87.6	106.7	131.5	151.4	193.2	199	186.7	41.7	0	**1184.5**
2009	0	13	17.5	123.4	98	127.3	126.7	139.3	162.4	92	0	0	**899.6**
2010	0	9 21	115	74	91.6	132.3	186.2	201	117.3	22	0	0	**1860.4**
TOTAL	**0**	**159.6**	**364.8**	**1144.9**	**1277.8**	**1848.4**	**1604.8**	**1441.6**	**1836.3**	**1080.9**	**129.2**	**0**	

Table 6: *Rainfall pattern of the study area (mm) (2011-2020)*

Year	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV	DEC.	TOTAL
2011	0	0	13	74	124	179.6	146	260.3	178.5	155.3	29	0	**1159.7**
2012	0	0	43	35.3	134.7	77.6	144.7	228	179.1	134.5	23	0	**999.9**
2013	0	0	0	29.5	35.7	67.3	163.9	172.8	189.1	98.7	2	0	**759**
2014	0	0	37	45	66.4	124.3	173.6	193.8	207	79.6	45	0	**971.7**
2015	0	0	23	63.2	121.7	148.7	154.6	224.2	181.7	127.3	31.3	0	**1075.7**
2016	0	0	17	28	132.2	167.1	122.2	221.1	198.2	119.3	28	0	**1033.1**
2017	0	0	19	25	122.2	157.1	102.2	201.1	178.2	132.3	22	0	**959.1**
2018	0	0	19	23	127.1	158.6	123.9	217.1	179.2	138.3	0	0	**986.2**
2019	0	0	19	0	162.2	138.8	133.2	211.7	169.2	123.3	0	0	**957.4**
2020	0	0	16	0	87	98.2	102.2	133.8	168.9	149.2	0	0	**755.3**
TOTAL	**0**	**0**	**206**	**323**	**1113.2**	**1317.3**	**1366.5**	**2063.9**	**1829.1**	**1257.8**	**180.3**	**0**	

On the other hand, the climatic episode of the 2011 to 2020 has dramatically changed from the 7 months of rainfall recorded in 2001- 2010 to just 6 months i.e. May (1113.2 mm) to October (1257.8mm) (Table 6). Year 2011 recorded the highest amount of rainfall of 1159.7mm, while the year 2020 with 755.3mm rainfall recorded the least. This trend continued till today as rainfall precipitation reduces across the decade. When it rains in this decade, it is quite heavy within the months of August, September and October and it leads to extensive flooding of coastal areas as urbanization has made people build along waterways with increase in population, generation of more solid waste that block drainages generally leads to destruction of lives and properties. Olubanjo (2019) also corroborated this finding of a gradual reduction in rainfall precipitation in Ilorin traced to climate change.

Sunshine Hours

The sunshine hours of the area in 2021 and 2022 data revealed same pattern, as it varied from around 10 hours around January to 5.5 hours in August.

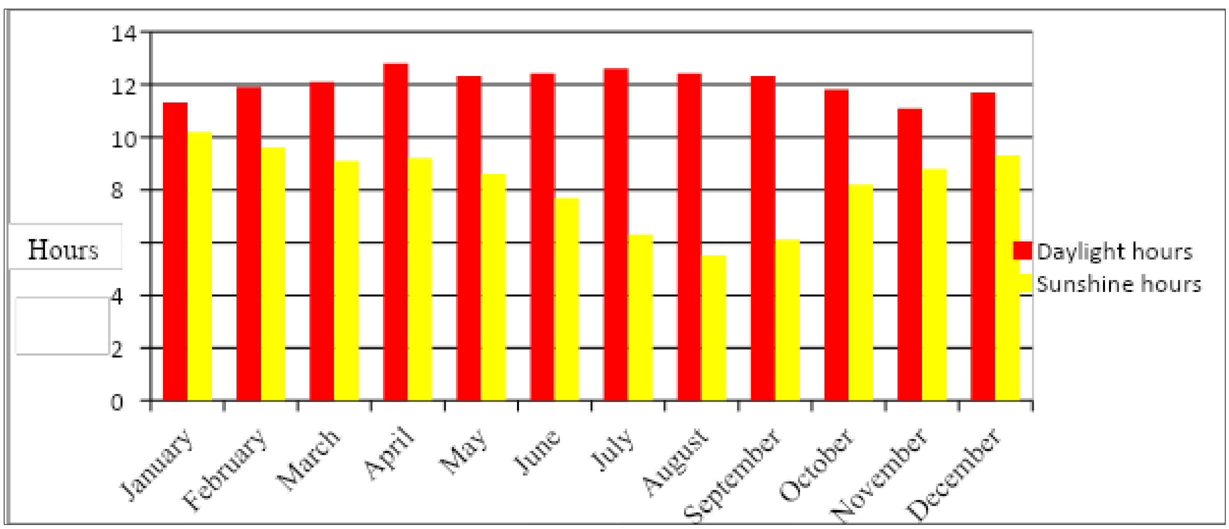

Fig. 4: *Sunshine and daylight hours of the study area*.

It dropped from the peak of 10.2 hours to around 9.6 hours in February. This further dropped to around 9.1 hours in the month of March. In April, the value slightly increased to 9.2 hours. This equally dropped to 8.6 and 7.7 hours in the months of May and June respectively. July, August and September similarly recorded 6.3, 5.5 and 6.1 hours respectively and the lowest in the series. In the month of October, it picked up to around 8.2 hours. It increased to 8.8 and 9.3 hours for the months of November and December respectively (Fig. 4). Moreover, the corresponding daylight hours increased from 11.1 hours in November to 12.8 hours in April, It is crucial to put the sunshine hours into consideration in predicting the aquifer response to climate changes because of its enormous energy that fuel the evaporation of surface water, evapotranspiration of soil and plant moisture that all lead to drastic reduction in recharging the aquiferous underground water. Ibrahim et al 2023.

Pumping Test Data

Pumping test exercise was conducted on selected 10 boreholes in the study area to measure the aquifer performance including their vulnerability and or resilience.

4.2.1 Groundwater aquifers and yield in the study area

Groundwater in Akerebiata aquifers is that of shallow one as the commonest aquifer 1 is located at 19- 27 meters depth. This aquifer is known to be fairly prolific at the peak of dry season of December-February and its laterally extensive to areas of Orisumibare area (transition zone) with varying depths of sediments. Beyond this area is the emplacement of crystalline rocks of granitic origin with noticeable reduced porosity and permeability as clearly evidenced with low water yield boreholes as one approaches the Iyawo poultry area. The Sobi rock outcrop (Fig. 5).extends a wide area in that vicinity and led to reduced porosity of wells in the vicinity with low borehole yield. Around Bovas retail outlet, the aquifer 1 is commonly encountered at 19 meters depth, while at Karuma secondary school, it is known to have a depth of about 22 meters. The Babasoji stream that cuts across the area is another major underground water aquifer recharge source, besides the infiltrated rain water and abattoir river water from the northern end into the saturated and unsaturated zones of the areas. The aquifers 1 and 2 are laterally extensive and thick enough (4-9m thickness) to support groundwater abstraction in the area (Fig. 5).

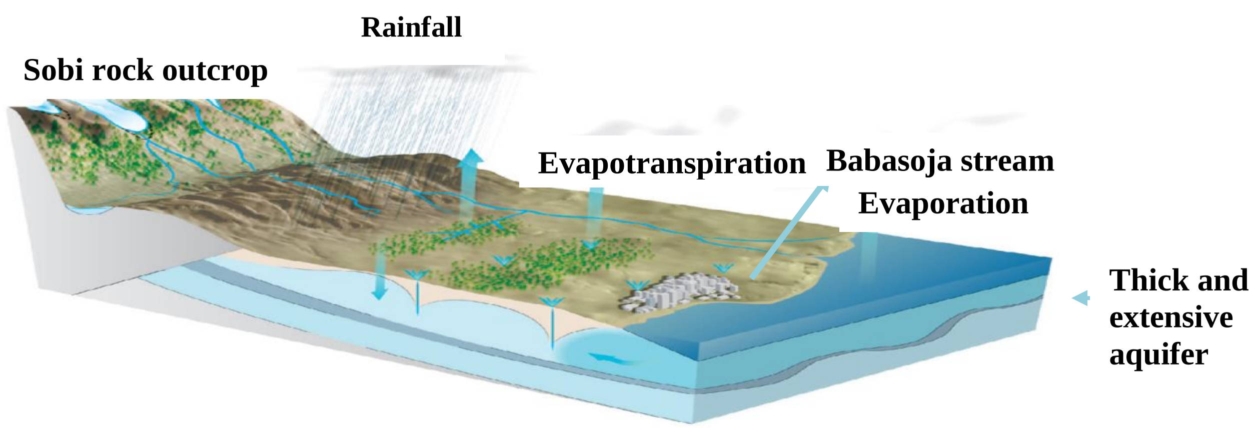

Fig. 5: *Model of Aquifer and groundwater recharge and discharge in Akerebiata area*.

Conversely, the aquifer vulnerability measurement was done during the peak of the rainy season of the study area. This has shown that the laterally extensive aquifer 2 is known to be deeper to about 29-39 meters depth, but the saturated water zone has increased higher with adequate recharge from the infiltrated water into the two main aquifers of the area. It is worthy of note that seasonal Abattoir river and Baba Soja stream that crosses the area are major recharge energy sources for the aquifer 2 of 29-39 meters thickness and also assist to enhance the groundwater yield of the area. Water production measurement of these boreholes revealed good yield during the wet and fair during dry season period with significant variation. More importantly, during the peak of the dry season, the yield of the wells were measured and varied considerably. AB1, AB2, AB3, AB4 and AB5 recorded yield of 0.79, 0.53, 0.64, 0.49 and 0.59 liter/sec respectively. AB6, AB7, AB8, AB9 and AB10 recorded yield of 0.77, 0.61, 0.62, 0.77 and 0.56 liter/sec respectively. Yield of the wells during the peak of wet season varied between 0.91 to 1.31 liter/sec (Table 7).

Table 7: *Borehole measured parameters during the peak of dry season*.

BCDs	Depth (m)	AQUIFER Depths (m)	SWL (m)	TPT (secs)	DWL (m)	Yield (L/sec)	TDD (m)	TRT (sec)	RDD (m)
AB1	48	19.2 and 31.1	9.9	47956	28.2	0.79	38.1	19848	0.56
AB2	44	19.1 and 29.2	8.6	49219	19.3	0.53	35.4	19734	0.45
AB3	52	20.2 and 34.1	9.9	39892	18.1	0.64	42.1	17832	1.01
AB4	51	19.1 and 39.4	8.9	39497	23.4	0.49	42.1	17021	0.79
AB5	51	19.8 and 37.1	7.8	49011	25.9	0.59	43.2	18729	0.33
AB6	45	18.8 and 36.2	9.5	27991	24.3	0.77	35.5	19945	0.89
AB7	48	16.2 and 31.5	9.5	38893	21.9	0.61	38.5	16834	0.37
AB8	55	20.2 and 38.2	9.6	49922	24.6	0.62	45.4	17989	0.38
AB9	52	19.9 and 38.9	8.8	49912	22.3	0.77	43.2	17978	0.77
AB10	42	21.1 and 37.1	9.2	48999	33.1	0.56	32.8	17988	0.98

Static and Dynamic Water Levels

Static and dynamic water levels of the 10 boreholes were measured with great precision and accuracy during the peak of rainy and dry seasons. The static water level is the water level at rest before pumping of the boreholes and there existed substantial variation recorded in the wet and dry season of the wells linked to changes in the amount of recharge available between the two measured extreme weather conditions and source of recharge. Selected boreholes had their SWL ranging from 7.8-9.9 meters during the dry season (Table 7) and 1.9- 3.9m during the wet season (Table 8). The measured dynamic water level (DWL) showed position of temporary equilibrium of column water standstill signifying an important fractal network at that position energizing the wells. The DWL varied across the investigated wells and ranges from 18.8-27.1 meters during the rainy season (Table 8) and 18.1-33.1 during the dry season (Table 7).

Drawdown and Total pumping time (TPT)

Total drawdown for the boreholes were measured to give more detailed aquifer properties of the wells at the extreme weather conditions. It thus commonly reflect the capability of the well to cope with extreme weather conditions The total drawdown (TDD) refers to the total depleted column of water from the initial water level at rest i.e SWL. Pumping exercise continued till the point the borehole stopped ie total exhaustion of the borehole water. In essence, the difference in varying depths at these points and the static water levels at the peak of the rainy season gave an estimate of the TDD of each of the investigated boreholes. AB1, AB2 and AB3 recorded 44.5, 41.4 and 50.1meters within 58772, 59566 and 53908 seconds as the total pumping time (TPT) respectively. AB4, AB5 and AB6 gave values that ranged from 47.1, 48.8 and 42.9 meters within 59772, 62987 and 52429 seconds as the total pumping time (TPT) respectively. AB7, AB8, AB9 and AB10 all revealed 46.1, 52.2, 50.2 and 40.8meters within 51907, 68562, 69222 and 60222 seconds as the total pumping time (TPT) respectively. Similarly, the peak of the dry season recorded a total drawdown that varied from 32.8 to 45.4m (Table 8).

The recorded total pumping time varied between 51907 to 69222 seconds (Table 7). This peak of dry season witnessed a faster depletion rate of the underground water due to low and almost zero precipitation and infiltration recharge of the aquifers. Moreover, two other main sources of recharge for the underground aquifers of Akerebiata include the Baba soja stream and Abattoir river that traverses most parts of the investigated boreholes in the study area (Fig. 5). They are only active during the period of rainfall in the area for recharge.

Residual drawdown (RDD)

RDD ie residual drawdown is the difference in water column of the original level before pumping began ie SWL and the level reached after full recovery ie recharge of such boreholes. Studies have shown that this difference in this water depth is a function of the hydraulic conductivity and transmissivity of the aquifer. At Akerebiata study wells, substantial RDD were recorded and an obvious difference was recorded between the dry and rainy season values gotten in this study. During the peak of wet in rainy season of the study area, AB1, AB2, AB3, AB4 and AB5 recorded values of 0.26, 0.25, 0.29, 0.26 and 0.29m respectively. In AB6, AB7, AB8, AB9 and AB10 recorded residual drawdown of 0.26, 0.31, 0.35, 0.11 and 0.19 respectively (Table 8). During the peak of dry season in the study area, AB1, AB2, AB3, AB4 and AB5, recorded residual drawdowns of 0.56, 0.45, 1.01, 0.79 and 0.33m respectively. AB6, AB7, AB8, AB9 and AB10 recorded residual drawdown of 0.98, 0.37, 0.38, 0.77 and 0.98m respectively (Table 7).

Aquifer recharge potential of the wells during the wet season compared to what is obtainable during the dry season is calling for the uncertainty in the future recharge of most of these wells. This is because the Akerebiata area is witnessing more dry season in recent time than 2 decades ago and this is the main source for the recharge for any underground potable water for the people. More importantly, surface water is no longer available to 100% of inhabitants in the study area. In essence, indiscriminate drilling of boreholes to tap from these aquifers is ongoing at an alarming rate in the area all depending on rainfall recharge source. The vulnerability of the aquifers is high in this area in the absence or reduced rainfall precipitation.

Table 8: *Borehole measured parameters during peak of wet i.e., rainy season*

BCDs	Depth (m)	AQUIFER Depths (m)	SWL (m)	TPT (secs)	DWL (m)	Yield (L/sec)	TDD (m)	TRT (sec)	RDD (m)
AB1	48	19.2 and 31.1	2.5	58772	27.1	0.99	45.5	17828	0.26
AB2	44	19.1 and 29.2	2.6	59566	19.9	1.31	41.4	17603	0.25
AB3	52	20.2 and 34.1	1.9	53908	18.8	0.92	50.1	19032	0.29
AB4	51	19.1 and 39.4	3.9	59772	21.5	0.95	47.1	29222	0.26
AB5	51	19.8 and 37.1	3.2	62987	24.7	1.09	47.8	18936	0.29
AB6	45	18.8 and 36.2	2.1	52429	23.3	0.86	42.9	29807	0.26
AB7	48	16.2 and 31.5	1.9	51907	20.9	0.93	46.1	21114	0.31
AB8	55	20.2 and 38.2	2.8	68562	23.6	0.91	52.2	22902	0.35
AB9	52	19.9 and 38.9	1.8	69222	22.1	1.22	50.2	19084	0.11
AB10	42	21.1 and 37.1	1.2	62908	32.1	1.02	40.8	29085	0.19

Climate Change Impact on the Wells in the Study Area

There is a clear manifestation of climate change impact on the groundwater production potential of the area. Though substantial uncertainty persists in global projections of the impacts of climate change on groundwater recharge, Akerebiata groundwater aquifers are currently witnessing serious strain as the period of dry season continues to expand a wider period and this translates to gradual reduction in recharge potential from rainwater source. To nullify this uncertainty in the study area necessitated the stochastic model (Fig. 5). Climate and land cover of Akerebiata area largely determine rates of precipitation (P) and evapotranspiration (ET), whereas the underlying soil and geology dictate whether a water surplus (P - ET) can be transmitted to an underlying aquifer 1 and 2 in the study area. Much more importantly, around the study area, 2 decades ago, the rainy season started around March-September, while the dry season started from October-February. That has come and gone. Today, the variability of the weather pattern has changed substantially and fuelled by climate change variability as a sustainable rainy ie wet season starts around July-October with established peaks recorded at exactly September and October (Fig.6). Furthermore, November-June represents the period of dry season that peak around January and February. (Fig.6). This variability in weather pattern has greatly impacted the underground water aquifers to store, transmit and produce underground water in that area.

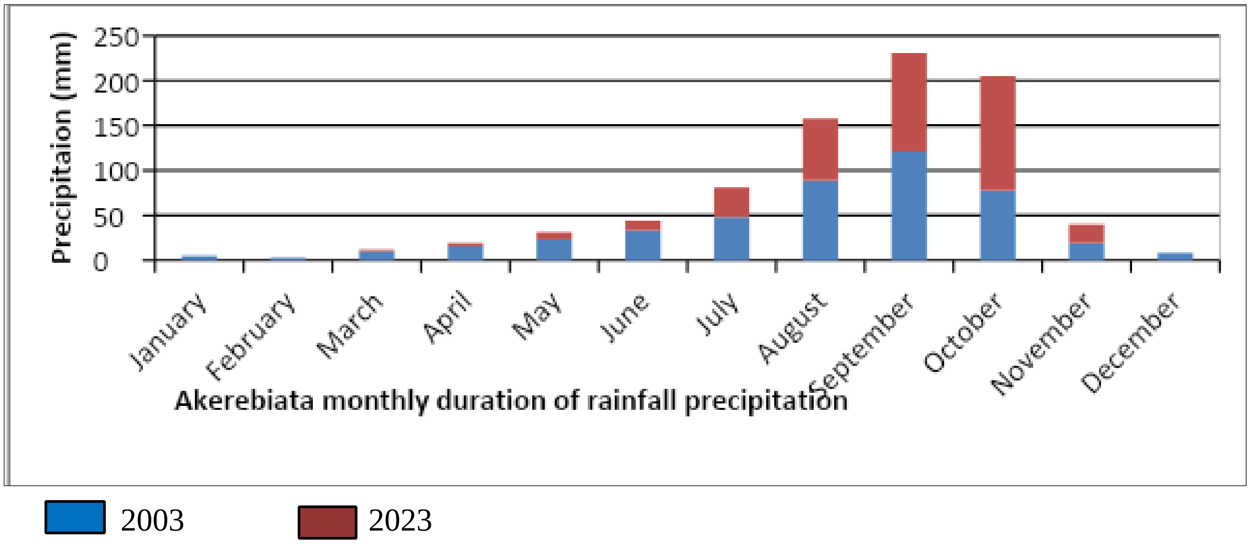

Fig. 6: *Precipitation intensity in the study area 20 years ago i.e. 2003 and today 2023*.

Aquifer Vulnerability and Resilience

Comparative study of the aquifer vulnerability between the two most extreme weather conditions has revealed that a changing climate with a longer period of dry season emerged in the study area of Akerebiata and this is already manifesting in the yield of the analyzed wells (Fig. 7). The yield of the wells during the peak of dry and wet seasons revealed that there is need for sustainable recharge that will keep the water flowing from the aquifer and as rainfall dwindles, the recharge reduces and this leads to reduction in accessibility of potable water to the people (Table 7, 8 and Fig. 6). More importantly, the recharge time i.e. prolong total recharge time (TRT) of the investigated wells is another main indicator for a changing climate affecting the groundwater production of the area (Tables 7, 8 and Fig. 6).

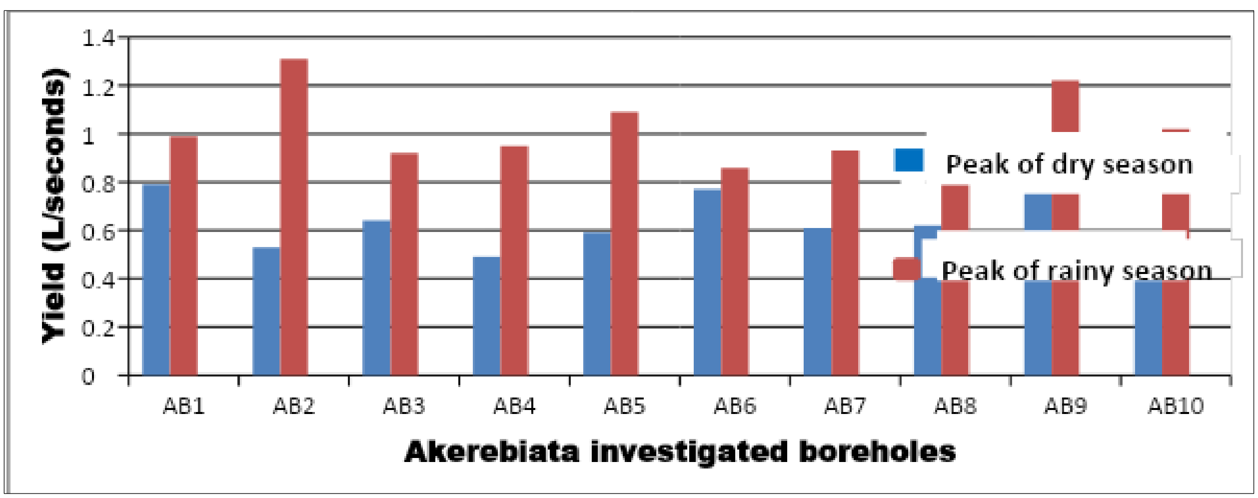

Fig. 7: *Yield of the boreholes during the peak of rainy and dry seasons*.

From all indications the yield of the boreholes during the peak of rainfall is quite higher than the yield of the boreholes during the peak of dry season, as such, the more the recharge source to reinvigorate the aquifer, the better for the aquifer performance. In essence, a changing climate with good precipitation will allow a better recharge of the aquifer. From 2001-2010 weather pattern of the area, a total of 392°C maximum air temperature was recorded that represented 2001 and 2003 against the lowest recorded air temperature of 368°**C** of 2008. Rainfall of 1144.9mm in April to 1080.9mm in October (2001-2010) compared to 1113.2mm in May to 1257.8mm in October (2011-2020) has revealed climate change is gradually shifting the weather condition of the study area to more dry than wet season (Tables 5 and 6). This major finding was corroborated by different researchers in their published journals, two of which included that the West Africa region has experienced a marked decline in rainfall from 15 to 30% depending on the area (Niasse, 2005, Udo-Inyang and Edem, 2012).

Conclusion

The resilience of aquifer systems to climate change varies considerably and is controlled primarily by geology, vegetation, topography and climate. Akerebiata area has an extensive and thick pile of aquifer to tap underground potable water which typically transmit and store large volume of groundwater and are more resilient to climate variability. 2001-2010 weather pattern has revealed a total of highest 392°**C** maximum air temperature was recorded against the lowest recorded air temperature of 368°**C** and continued till 2012 that recorded a total of 395°C. Recorded values from this 2013 to 2020 ranges from 405°C to 412°C except for 2015 that recorded 399°**C**. The rainfall precipitation varied between highest 1860.4mm in 2010 to 1352 mm in 2006. Sunshine varied from around 10 hours around January to 5.5 hours in August. During dry season, SWL ranges from 7.8-9.9 meters, TPT ranges from 27991-49922 secs, TRT ranges from 16834-19848 secs, TDD gave 32.8-45.4meters and yield was measured to be 0.53-0.79liter/sec. Moreover, during the wet season, SWL ranges from 1.2-3.9meters, TPT ranges from 51907-69222 secs, TRT ranges from 17603-29807 secs, TDD gave 41.4-52.2meters and yield was measured to be 0.86-1.22 Liter/sec.

As climate change continues to affect precipitation patterns, causing increasing pressure on the existing surface water resources, groundwater offers the buffering capacity to protect humanity against these uncertainties and provide a more reliable potable water supply. Due to the huge volume of groundwater i.e. representing 99% of all liquid water stored on earth, aquifer water can serve as a buffer in times of water scarcity, enabling the inhabitants of Akerebiata to survive in even the driest of climates. Depending on their depth and geological setting, the aquifers are comparatively well protected against pollution incidents than surface water sources. Changes in the earth's water cycle through processes of precipitation and evaporation have their impacts on groundwater recharge to a lesser extent, but far more on surface water sources. With extreme weather conditions in the study area where most surface water goes completely dry due to climate change, mitigation and adaptation of Akerebiata groundwater wells offer the solutions.

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