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Seasonal changes of groundwater production at Enji, Offa area, traced to climate change variability and aquifer vulnerability, Nigeria

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ABSTRACT

Enji area is located around Latitude N080 10.77' 8.77'', Longitude E04° 42.55' 17.29'' and Latitude N08° 10' 10.50'', Longitude E04° 42' 8.51'' with elevation that varied between 415-429meters a.s.l. 12 wells were studied during the peak of dry seasons of December-March and peak of rainy season that represent August-November. The aim is to establish the seasonal variation of the groundwater production at the extreme weather conditions. Portable, durable and rugged MetPRO weather variability instrument was used to collect the data for the environmental study. Pumping test for aquifer vulnerability assessment included 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 all measurements. Results obtained included first fracture diagnosed at 25-27 meters depth of Enji area and at 33, 36 and 32 meters at Fatraaj, Gbomi and Keraaje respectively. Second aquiferous position was encountered at an average depth of 38, 32.8 and 39 meters. SWL varied from 7.5-9.5meters, DWL gave 18.1-29.6, TDD varied between 34.8-53.9, TRT was from 71734-89872 seconds and Yield varied from 0.49-0.81 L/sec during dry season. Wet season measurement gave SWL to be 2.3-3.9, DWL was 18.1-36.8 meters, yield varied from 0.81-1.04 L/sec, TDD was from 39.62-58.42 and TRT varied from 22321-39896 seconds. Seasonal variation of the climatic condition has greatly impacted the aquifer properties with severely low groundwater production noticeable more during the peak of dry season in the area.

Keywords: SWL= Static Water Level, DWL= Dynamic Water Level, TRT= Total Pumping Time, TDD=Total Drawdown, GWS= Ground Water Storage and Yield

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1. INTRODUCTION

About 400 million people in Sub-Saharan Africa do not have access to potable basic water. The majority of these people live in rural areas (IPCC, 2001a; IPCC, 2001b; IPCC, 2000; IPCC, 2007). Even in cities where household surface water connections are more common, supply outages and unreliable flow due to high and increasing demand traced to urbanization, cost of treating raw water, low infrastructural distribution pipes and exorbitant fossil fuel prize for pumping are the main challenges inherent. Therefore, the overwhelming priority for most countries in Africa today to improve access to potable water for socio-economic activities is currently through underground water sources like deep and shallow wells. However, climate change places a further pressure on available surface and underground water sources, leading to recurrent water scarcity and droughts threatening the little progress made for provision of potable water to the people (Taylor et al., 2012). Extensive increase in water demand due to population growth and rapid urbanization adds to the pressure and increases the need for an expansion in climate-resilient water services in Nigeria and Africa as a whole.

Under a changing climate combined with economic growth in the study area of Enji, Offa, the biggest priority is to adopt best practices to develop and manage groundwater resource in order to meet competing demands while recognizing the important role groundwater plays in sustaining freshwater ecosystems. It is clear that opportunities exist in Sub-Saharan Africa for the increased development of groundwater resource to meet the growing demand caused by population explosion, economic growth, rapid urbanization, increasing irrigation activities, however the development of the resource is the major challenge. Zhou et al., (2010) has published and made it abundantly clear the need to protect groundwater resource as the world is gradually turning to it for the large-scale irrigation of farmlands for dry season farming.

Location of the study area

Enji area is located around Latitude N080 42.11' 16.41'', Longitude E04° 41.55' 17.29'' and Latitude N08° 39' 11.67'', Longitude E04° 28.7' 33.3''. Investigated boreholes varied around Gbomi, Enji, Fatraj, Atooba and Keraaji. The topography of the area is a gentle one with the highest point at Atooba and descends down to Enji down to Gbomi and Fatraaj areas. Gbomi is located on a little higher slope (Figure 1). The study area of Enji commonly have rainfall pattern that peaks around August-November every year. The lowest-average rainfall of the area is around March, April and November with very low or no rain commonly recorded around December-February. 87% of the mean annual flow (MAF) occurs during the wet season of May to October every year with a flow rate of 21.7 Mm2.

The Enji area is commonly flooded yearly with severe disruption of traffic and destruction of properties. Many households around the area depend so much on underground water source as there is no dam in the locality and the whole Offa dam that can act as a buffer to allow storage of large water runoff of the area during rainfall for public township water purification and supply. The population of the investigated settlements for groundwater production is increasing with higher water demand. The last census conducted in 2006 did not give a detailed population density of each settlement of the study area, but another census exercise to be conducted soon is expected and might give a better population figure to assist for better planning of the area. Rock types in the area included porphyritic granite, fine grained biotite granite, banded gneiss, migmatite, migmatite gneiss etc (Figure 1).

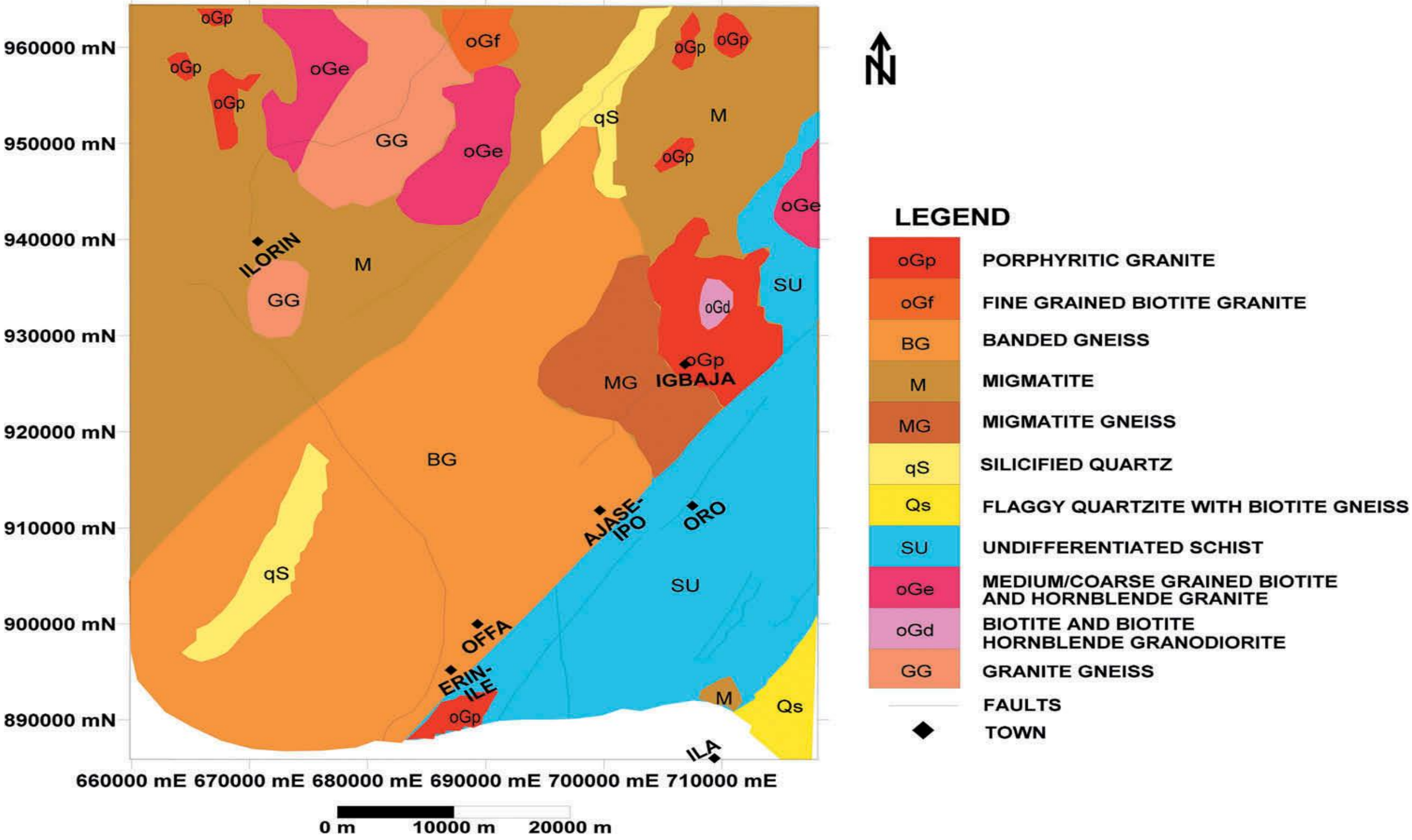

Figure 1 Geologic map of the Enji study area

2. 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. Hydrometeorological equipments used for the study included the MetPRO weather variability measuring instrument (Figure 2) and it's a highly accurate, durable, rugged and designed for a wide variety of environmental study. It includes high quality sensors needed for defensible data in environmental research as well as critical operations dependent on continual weather monitoring. It is solar driven in its operations and 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 and onward to the discharge pipes. The environmental impacts on the investigated boreholes was thus measured and monitored using the MetPRO instrument during the peak of dry and wet seasons of extreme weather conditions (Figure 2). This has effectively allowed proper diagnostic properties of the wells with their response to pumping activities.

Figure 2 MetPRO weather variability instrument

Pumping test being a practical way of obtaining ideal data of the borehole's efficiency and its 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.

3. 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 estimated to find out the effect of climate change on the aquifer vulnerability and/or resilience of the aquifer. The impacts of climate change is obvious at regional scale along the area with massive yearly flooding indicator, but the point of study is to find out the impact on the groundwater production potential during the two most extreme weather conditions. The result of the study is hereby presented for closer interpretation of the available data in the area.

Weather pattern of the study area

Groundwater management is crucial to climate impact mitigation and adaptation and will bring the area and other closer communities to better sanitation condition. Regulation of groundwater abstraction on ecosystems, surface water, land subsidence and more is commonly strengthened during rainy season than dry season in Enji area. Perhaps, one of the most critical components of groundwater management is control of the location and quantity of water withdrawals from the aquifer which is currently affected with variation in weather pattern of the area Shamsudduha et al., (2013a) published the relationship of groundwater and climate change.

The Enji communities and/or groundwater users in the area independently choose to manage well location and groundwater abstraction method to avoid excessive withdrawal that may lead to total depletion of aquiferous water during extreme weather condition. The weather variability parameters used to determine the aquifer performance in Enji area included Air temperature, rainfall pattern and sunshine hours. Global climate models are available for understanding climate and projecting climate change in relation to groundwater potential as advanced by (Wu et al., 2020).

Air Temperature

Air temperature and precipitation are fundamental measurements for describing the climate and can have wide-ranging effects on human life, groundwater aquifers and ecosystems. For example, increases in air temperature can lead to more intense heat waves and larger amount of evapotranspiration where the soil loose most of its moisture and further reduce the potential to exploit groundwater from wells. More importantly at Enji study area, Air temperature pattern in relationship to the underground water aquifer performance for the production of underground water was directly proportional to the dryness of the climate linked to extreme weather. In essence, hydro-meteorological data of Enji study area allowed proper diagnostic interpretation.

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

Year	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV	DEC.	TOTAL
2001	33	34	35	33	32	31	29	27	29	32	34	33	382
2002	31	31	31	34	32	32	30	31	31	31	33	34	389
2003	34	37	36	34	34	30	29	29	30	32	33	34	392
2004	34	35	34	38	35	33	30	29	29	30	32	33	392
2005	35	33	32	34	31	32	31	35	30	31	32	33	389
2006	34	37	36	36	32	31	30	28	30	32	34	34	394
2007	31	32	31	32	32	31	31	31	32	30	33	35	381
2008	33	30	31	29	31	30	31	29	30	31	31	32	369
2009	31	31	31	32	32	30	30	31	27	30	31	32	369
2010	30	28	30	32	31	31	31	31	32	30	34	31	372

From 2001-2010 air temperature pattern, a total of highest 394°C maximum air temperature was recorded for 2006 against the lowest recorded air temperature of 369°C of 2008 and 2009 (Table 1). Air temperature being a strong indicator of climate change revealed a variable pattern for a decade of investigation. In essence, the trend showed it gradually increased from 2001 with a total 382°C air temperature to 389°C recorded for 2002 and 392°C for 2003 and 2004 (Table 1). In 2005, there was a slight drop by 3°C to 389°C after which the highest air temperature in that decade was recorded ie 394°C. From 2007 onward there has been a consistent drop in the recorded air temperature of the area (Table 1).

More importantly, for the period 2011 to 2020 under review, the maximum air temperature reduction continued till 2011 with 372°C, but with the irregular air temperature pattern, it gradually increased again from 2012 a period the study area witnessed the most severe flooding in that decade to 395°C (Table 2). It has been noticeable that since this period 2012, just like the study area witnessed more precipitation, so also the maximum air temperature increases from the 396 to 401°C. This is a clean and clear indicator of extreme weather variables from the past climatic condition recorded within 2001 to 2010 and has led to aquifer vulnerability of that area for groundwater production capacities.

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	33	31	31	32	33	31	29	30	27	31	32	32	372
2012	31	30	32	34	36	32	33	31	32	33	33	34	395
2013	36	33	35	34	33	33	32	34	33	35	35	36	396
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	29	33	36	31	31	32	33	35	384
2018	35	33	31	32	33	36	32	33	37	33	31	35	401
2019	33	33	31	32	33	32	31	36	33	32	33	34	494
2020	33	36	31	35	36	34	31	32	34	35	33	31	401

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	21	18	23	26	22	24	24	21	24	23	20	20	266

2002	18	25	25	25	24	21	23	23	19	21	18	24	267
2003	20	23	21	26	24	20	23	23	23	23	22	19	267
2004	19	20	26	24	22	22	22	22	22	23	19	19	260
2005	18	23	22	23	24	22.5	22	24	22	23	22	21	266.5
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 recorded in Enji study area has shown that night air temperature reduction with some dew formation drastically reduced the air temperature. This has led to almost a constant minimum air temperature of the study area that falls within 266°C recorded in 2001 to 264°C recorded in 2010 (Table 3). During the period under review, reduction in air temperature added an insignificant amount to the aquifer recharge potential because the soil moisture evapotranspiration reduced drastically and reduced evaporation of large water bodies that contributed to the aquifer recharge of Enji area. The highest minimum air temperature was thus recorded in 2009 with 272°C (Table 3), while the lowest within that decade was recorded in the year 2004 with 260°C minimum air temperature (Table 3).

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	19	18	22	23	25	23	22	22	21	22	23	21	258
2012	18	26	23	23	27	23	24	23	23	23	22	24	239
2013	19	23	24	24	24	24	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	26	21	19	251
2018	17	19	17	22	21	22	25	19	22	18	22	23	247
2019	24	22	23	26	23	16	19	19	22	19	21	21	255
2020	24	22	23	23	26	18	17	16	19	22	23	24	257

The minimum air temperature recorded in Enji study area from 2011 to 2020 differs slightly from what was obtainable from 2001 to 2011 (Table 4). This night minimum air temperature pattern with some characteristics dew formation is responsible for this reduction. The minimum air temperature recorded in Enji study area has shown that night air temperature reduction can be traced to dew formation and has contributed to the drastically reduced air temperature recorded. 2013 recorded the highest minimum air temperature of 272°C (Table 4). with the lowest recorded in 2012 with 239°C. The minimum air temperature became constant from 2017 till date, as it recorded 251°C, 2018 recorded 247°C, 2019 and 2020 recorded 255 and 257°C respectively (Table 4). This regular pattern of minimum air temperature from 2017 occurred till 2020 and till date.

Rainfall

Rainfall data pattern of Enji area gave valuable insight into the robust interpretation of the aquifer vulnerability and resilience to reflect the impact on the groundwater production at the peak of rainy and dry season. This is the most obvious and most crucial that impacts groundwater storage and recharge of the area. In essence, the peak of dry and rainy seasons were reference points for the pumping test to determine the aquifer vulnerability and or its resilience. The rainfall precipitation varied between 744.2mm to 1255.5mm for a decade that covered the period 2001 to 2010 (Table 5). This period revealed better enhancement on the aquifer performance due to the variability of rainfall recharge available for the aquifers.

It is noticeable that no rainfall was recorded in the months of December and January for that decade, while in the months of February and November there were partial rainfall precipitation, in essence, dry season for the period under review covered November to March with little or no rainfall precipitation that amounted to 288.8mm (Table 5). As such, the peak of dry season for that decade was declared to be December and January where no single drop of rainfall precipitation was recorded. This period in turn means no single recharge of borehole underground water aquifer from rainfall source. The active rainy season was from April to October with rainfall precipitation ranging from 1144.9mm to 1848.4mm. This translates that the recharge of most aquifers in the area was well enhanced and most shallow wells functioned optimally with static water levels rising to 1.8 meter in most investigated boreholes compared to 7.3-9.7 meters during dry season.

In summary, the more prolonged the dry season, as we are already witnessing today 2024, the less the aquifers are saturated with potable fresh groundwater storage, the less the recharge to replenish abstracted water and the less groundwater available for humanity, since 100% of the inhabitants don't have access to surface water connection. The decade 2001 to 2010 under review, 2013 with 1215.94mm rainfall precipitation is the highest with the lowest recorded rainfall being 2006 with 1356mm precipitation. It is worthy of note that April (1144.9mm) to September (1140.9mm) had the highest amount of rainfall precipitation (Table 5) for that decade. This is in variance with what is obtainable today and between 2011 to 2020 (Table 6).

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	176.7	6.5	0	1068.8
2003	0	14	12.4	93.9	124.54	360.7	123.2	130.9	176.2	133.4	46.7	0	1215.94
2004	0	33.1	4.67	260.5	159.2	211.4	145.4	243.5	98.1	31.6	0	0	1187.47
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	11.5	74	91.6	132.3	186.2	201	117.3	22	0	0	845.11
TOTAL	0	159.6	213.7	1144.9	1277.8	1848.4	1604.8	1240.6	1836.3	1140.9	129.2	0	-

Conversely, the peak of monthly rainy season was June and September with rainfall precipitation of about 1848.4 and 1836.3mm respectively. 2003 and 2007 represented the period of maximum rainfall precipitation with 1215.94mm and 1255.5mm respectively. The lowest amount of precipitation was recorded in the months of December and January, but low precipitation actually started in November till March (Table 5). On the other hand (2011-2020), there has been a drastic change in the rainfall pattern as May (113.2mm) to October (1257.8mm) recorded as active rainfall period within this period. Furthermore, the rainfall pattern of the Enji study area between 2011 to 2022 has shown a marked difference in the weather variability fuelled by climate change when compared to that of 2001 to 2010 (Table 5).

In essence, dry season has changed substantially to occur between November and April where low or no amount of rainfall precipitation was recorded in the last decade of 2011 to 2020 (Table 6). Within this period under review, only 701.3mm total rainfall was recorded. A prolonged period of no or low amount of rainfall precipitation (November to April) of Enji area is quite dangerous for underground water production users (all inhabitants of the area) as water table drastically remained low with most shallow wells going completely dry and no alternative source of recharge into the very few producing boreholes of the area.

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

Year	JAN.	FEB.	MAR.	APR	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	198	323	1113.2	1317.3	1366.5	2063.9	1829.1	1257.8	180.3	0	-

This has been traced to effect of climate changes in the area with unpredictable rainfall pattern creating dwindling groundwater storativity and attendant aquifer under performing at extreme weather conditions. This has resulted in severe low groundwater production in the area of study at various times of investigation especially at the peak of dry seasons. Herewith Dragoni and Sukhija, (2008) similarly published their article to elucidate the impact of climate change on underground water and was titled: Climate change and groundwater: a short review.

Sunshine Hours

The sunshine hours of the area in 2022 data revealed same pattern, as it varied from around 5.4 hours around August to 10.3 hours in January when the study area experience peak of dry season. It dropped to around 10.1 hours in February. This further dropped to around 9.8 hours in the month of March. In April, the value drops to 9.6 hours (Figure 3). This equally dropped to 8.4 and 7.9 hours in the months of May and June respectively. July and August similarly recorded 6.9 and 5.4 hours respectively. In the month of September, it increased to around 5.7 hours. It further increased to 7.9 in October. 8.3 and 9.1 hours for the months of November and December respectively (Figure 3) were recorded in the study area. 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 and evapotranspiration of soil and plant moisture (Figure 4) that both lead to drastic reduction in recharging the aquiferous underground water.

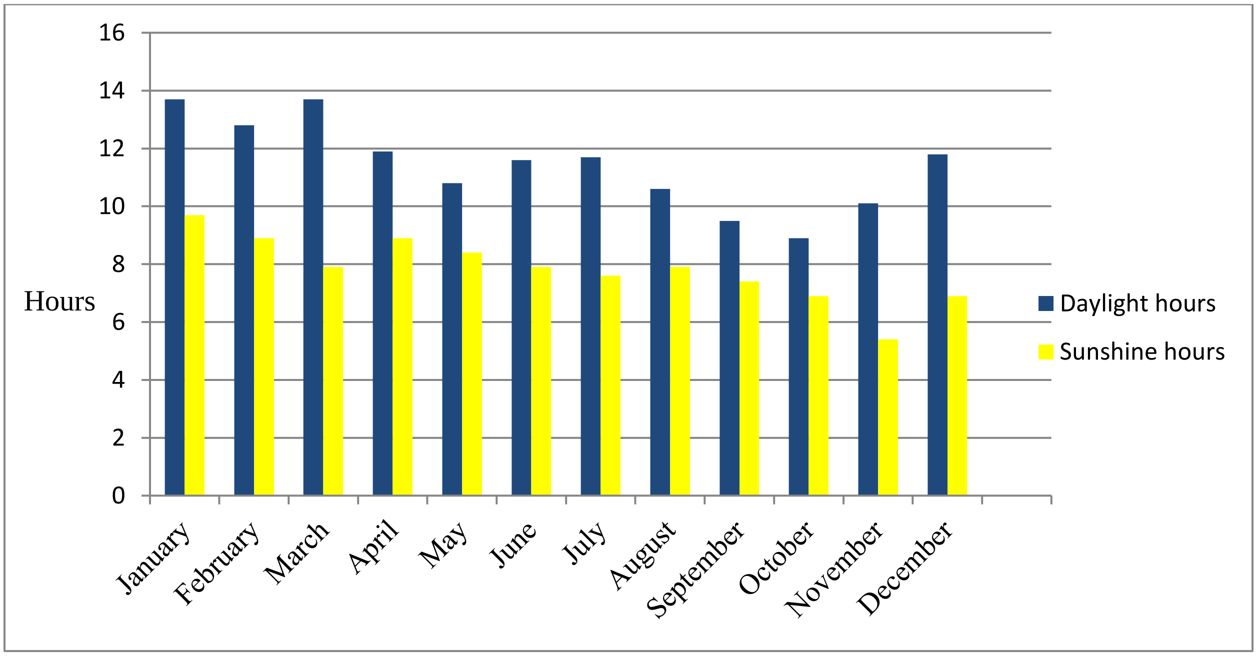

Figure 3 Sunshine and daylight hours of the study area collected 2022

Pumping test analysis

A constant discharge pumping test was adopted and initiated on selected 15 boreholes of the area to test the aquifer vulnerability during the peak of dry and wet seasons. This facilitated the establishment of the hydraulic conductivity of the aquifer and its variability with climate change impacts and other recharge sources of the area notably Enji surface runoff. Observation wells gave insight into the laterally extensiveness of the aquifers of the area and how extensive abstraction of the water will affect the aquifer vulnerability. Yield, static water level, dynamic water level, drawdown, residual drawdown and discharge rates ie total pumping time, recharge rates were measured. 3 selected boreholes from each location facilitated an extensive analysis of the main aquifers ie 15 boreholes of the study area were tested during the study.

Groundwater aquifers and yield in the study area

Groundwater in Enji area is that of shallow one as the commonest aquifer 1 is located at 24.8- 29 meters depth. This aquifer is known to be prolific at the peak of rainy season of August-October and its laterally extensive to areas of Atooba, Enji, Fatraaj, Gbomi and even Keraaje at varying depths. It has a thickness that varies between 4-7 meters. Aside Atooba area, this same fractural aquifer was diagnosed at 25-27 meters depth of Enji area at the peak of dry season. It is well established that at Fatraaj, Gbomi and Keraaje, the first aquiferous point was encountered via drilling at an average of 33, 36 and 32 meters respectively, in essence, the aquifer though prolific was able to produce water at deeper depths of occurrence. But the second aquiferous position was encountered at an average depth of 38, 32.8 and 39 meters respectively in most drilling operations in the investigated areas.

The ditch cutting examination of drilling activities has also revealed numerous minor fractures at the interval of this first and second fractural zones. The total depth across the investigated areas was Atooba, Enji, Fatraaj, Gbomi and Keraaje at 53, 56, 55, 49 and 48 meters respectively, but the third fracture missed in most investigated boreholes. Another major finding is that the first aquifer is at shallow depths of 24.8-29 meters depths across the areas and the second fracture that is also thick but not laterally extensive like the first aquifer in the areas was found at 32.8-39 meters. The screen casings covered the aquiferous depth ranging from 23-59 meters to allow proper influx and filtering of the aquiferous water into the wells.

Pumping test exercise conducted revealed 0.58 and 0.62 liters/second yield for the Atooba and Enji wells. Similarly, Gbomi, Fatraaj and Keraaje wells recorded groundwater yield of an average of 0.51, 0.55 and 0.58 liters per second respectively during the peak of dry season. Conversely, this aquifer vulnerability measurement to climate change has clearly shown that during the peak of rainy season there was an appreciable increase of the yield to an average of 0.75, 0.77 and 0.69 liters/seconds for measured wells in Gbomi, Fatraj and Keraaje areas respectively. This has shown that the laterally extensive aquifer 1 occurring at shallow depth is more saturated with the aquiferous water that supports the maximum production of the underground water. Another major finding of this study is that the rainy season hardly last 4 months in the study area and with dry season becoming more predominant (about 8-9 months) yearly and this leads to significant aquifer stress in the area for the production of underground water.

This clearly shows the vulnerability of the aquifers to produce the needed aquiferous water at the peak of the dry season. It is worthy of note that river Enji that crosses the area is also a major recharge energy source for the groundwater yield of the area (Figure 4). Rosenberg et al., (1999) studied the impact of climate change on the water yield and groundwater recharge of the Ogallala aquifer in the central United States. Three different GCMs were used to predict changes in the future climate due to anticipated changes in temperature and CO2 concentrations. The study found that recharge was reduced under all scenarios, ranging up to 7%, depending on the simulation conditions, as such, the historical record of the wells of Enji area are more reliable than such models as it is practical and more feasible and visible.

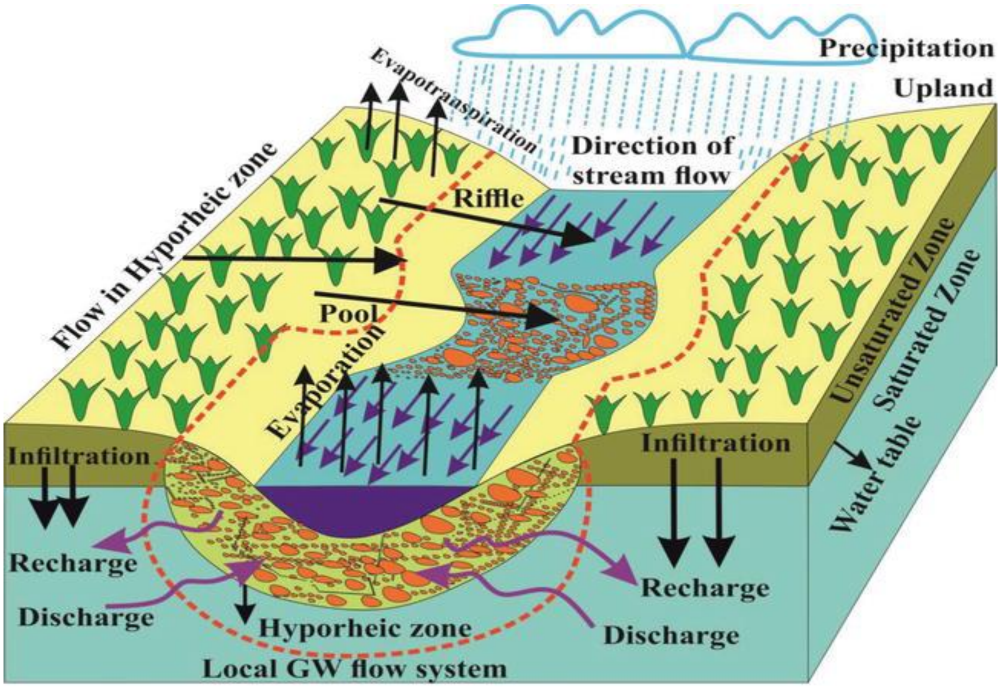

Figure 4 Sketch of Groundwater recharge and discharge of Enji study area

Static and Dynamic water levels

Static and dynamic water level of 15 boreholes were measured with great accuracy during the peak of rainy and dry season some of which the drilling reports and ditch cuttings were available. During the dry season peak, 3 wells of Atooba had the SWL measured to be averagely 8.5, 7.6 and 7.9 meters. Similarly, Enji wells gave static water levels of 7.9, 7.9 and 9.8 meters representing EG1, EG2 and EG3. Gbomi recorded an average of 8.5, 8.6 and 9.8 meters SWL. More importantly, Faraaj recorded 9.3, 8.1 and 8.3 meters. Keraaje gave a result of 8.1, 8.4 and 8.5 meters SWL (Table 7). Moreover, at the peak of wet season the results obtained showed Enji wells gave 3.0, 2.8 and 3.5 meters SWL. Gbomi recorded 2.5, 3.6 and 3.8 meters SWL. More importantly, Faraaj recorded 3.8, 3.1 and 2.3 meters SWL. Keraaje gave a result of 2.9, 2.6 and 2.5 meters SWL. A major finding is that all the measured wells displayed a robust water storage and transmissivity from the aquifer to the wells during the wet/rainy season (Tables 7 and 8).

Dynamic water level (DWL) of the wells revealed there is momentary standstill of the water column during the pumping exercise, as such, revealed the DWL at such positions of the wells as equilibrium was established at such depths. This clearly shows the major fracture supplying water into the well is located at such depths of occurrence. During the peak of dry season, at Atooba, the DWL was found to be the same at 28.2, 19.3 and 18.1 meters respectively for AT1-3. The DWL of other boreholes ranges from 29.6 ie FT2 to 21.9 ie GB1 (Table 7). The peak of rainy season has witnessed a similar DWL in most of the investigated boreholes at Enji study area. In essence, DWL varied between 36.8 ie KJ1 to 18.1 ie AT3 (Table 8).

Table 7 Peak of dry season measurement of aquifer properties

Peak of dry season measurement that represent December-March 2020								
BCDs	Depth (m)	SWL (m)	TPT (secs)	DWL (m)	Yield (L/sec)	TDD (m)	TRT (sec)	RDD (m)
AT1	48.2	8.5	47956	28.2	0.59	39.7	78483	0.04
AT2	59.1	7.6	39219	19.3	0.63	51.5	71734	0.01
AT3	42.7	7.9	29892	18.1	0.64	34.8	81832	0.03
EG 1	49.3	7.9	29497	23.4	0.49	41.4	72021	0.09
EG 2	61.3	9.8	29011	25.9	0.59	51.5	81729	0.08

EG 3	57.4	7.5	37991	24.3	0.77	49.9	61945	0.03
GB 1	49.1	8.5	38893	21.9	0.81	40.6	81834	0.04
GB 2	47.2	8.6	39922	24.6	0.82	38.6	81989	0.08
GB 3	52.3	9.8	29912	22.3	0.77	42.5	71978	0.06
FT 1	61.2	7.3	28764	27.3	0.56	53.9	89872	0.03
FT 2	57.2	8.1	29834	29.6	0.61	49.1	78823	0.07
FT 3	59.1	8.3	26749	26.9	0.62	50.8	78563	0.07
KJ 1	56.9	8.1	38873	26.6	0.59	48.8	78903	0.06
KJ 2	59.2	8.4	29834	25.9	0.58	50.8	83733	0.09
KJ 3	58.3	8.5	27693	28.3	0.57	49.8	87102	0.09

Drawdown and Total pumping rate (TPT)

Total drawdown for the boreholes were measured to give more detail aquifer properties of the wells at the 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 pumping i.e. 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 rainy season gave an estimate of the TDD of each of the investigated boreholes. AT1, AT2 and AT3 recorded varying Drawdown and Total Pumping Time TPT (Table 7). EG1, 2 and 3 gave 49.3, 61.3 and 57.4 meters. GB1, 2 and 3 recorded 29497, 29011 and 37991seconds TPT (Table 7). GB1, 2 and 3 wells recorded 40.6, 38.6- and 42.5-meters drawdown with a total pumping time of 38893, 39922 and 29912 seconds.

FT1, FT2, FT3, KJ1, KJ2 and KJ3 all recorded a drawdown of 53.9, 49.1, 50.8, 48.8, 50.8 and 49.8 meters at total pumping time intervals of 28764, 29834, 26749, 38873, 29834 and 27693 seconds. This peak of rainfall witnessed a slower depletion rate of the underground water. Moreso, Croley and Luukkonen, (2003) investigated the impact of climate change on groundwater levels in Lansing, Michigan. The groundwater recharge rates were based on an empirical streamflow model which was calibrated using the results from two GCMs. The results of the study indicated that the simulated steady-state groundwater levels were generally predicted to increase or decrease due to climate change, depending on the GCM used, but highly faulty compared to practical field work.

Residual drawdown (RDD)

RDD ie residual drawdown is the minute 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 with characteristic formation of cone of depression to reflect total area of influence during abstraction ie pumping. During peak of wet ie rainy season of the study area, AT1, AT2, AT3, EG1, EG2 and EG3, the residual drawdown recorded were 0.91, 0.82, 0.69, 0.92 and 0.77m respectively. In GB1, GB2, GB3, FT1, FT2 and FT3 recorded drawdown of 0.81, 0.72, 0.79, 0.66, 0.91 and 0.55 respectively. KJ1, KJ2 and KJ3 recorded 0.59, 0.88 and 0.69 meters. During peak of dry season in the study area, AT1, AT2, AT3, EG1, EG2 and EG3, the residual drawdown recorded were 1.02, 0.99, 1.01, 1.04, 0.99 and 0.98m respectively. In GB1, GB2, GB3, FT1, FT2 and FT3 recorded drawdown of 0.91, 0.82, 0.99, 0.76, 0.93 and 0.75 respectively. KJ1, KJ2 and KJ3 recorded 1.19, 1.08 and 1.22 m.

Table 8 Peak of wet//rainy season measurement of aquifer properties

Peak of rainy ie wet season measurement that represent August-November								
BCDs	Depth (m)	SWL (m)	TPT (secs)	DWL (m)	Yield (L/sec)	TDD (m)	TRT (sec)	RDD (m)
AT 1	48.2	3.5	47956	28.2	0.89	44.54	38481	0.06
AT 2	59.1	3.6	49219	19.3	0.93	55.31	27341	0.09
AT 3	42.7	2.9	59892	18.1	0.84	39.62	28322	0.08
EG 1	49.3	3.9	49497	23.4	0.99	45.22	20215	0.08
EG 2	61.3	2.8	59011	25.9	0.89	58.42	27293	0.08

EG 3	57.4	3.5	37991	24.3	0.97	53.83	39452	0.07
GB 1	49.1	2.5	48893	21.9	0.81	44.56	28346	0.04
GB 2	47.2	3.6	49922	24.6	0.82	43.52	39896	0.08
GB 3	52.3	3.8	39912	22.3	0.97	48.44	39787	0.06
FT 1	49.1	3.8	38712	24.4	0.89	45.22	27678	0.08
FT 2	43.4	3.1	39864	22.8	1.04	40.21	29989	0.09
FT 3	51.9	2.3	3986	21.8	1.03	49.54	23421	0.06
KJ 1	52.5	2.9	49823	36.8	0.99	49.52	22321	0.08
KJ 2	48.2	2.6	46753	24.4	0.98	45.53	22984	0.07
KJ 3	48.6	2.5	48903	25.5	0.96	46.04	29097	0.06

In essence, the yield for groundwater in the study area reduces with low amount of rainfall precipitation that serve as the main source of recharge of its aquifers in the area. There is massive fluctuations in this yield of the groundwater as the changing climate has impacted heavily on the aquifer's performance. Evapotranspiration of the soil moisture and decreased recharge rate of low precipitation pattern for about 8-10 months of the year has led to low groundwater storage and low production capacities across the areas. This is visibly seen as most shallow wells go completely dry, while some shallow drilled boreholes stop producing potable water at the peak of the dry season of the year.

Climate change influences groundwater systems in several other ways as advanced by Croley and Luukkonen, (2003) and also affects the aquifer performance in the study area. In terms of the hydrological cycle, climate change can also affect the amounts of soil infiltration, deeper percolation and hence groundwater recharge so they are also critical to volume of underground water production in any area of study. More importantly, rising temperature pattern in Enji area (Tables 1 and 2) increases evaporative demand over land and this limits the amount of water to replenish groundwater pumping and was similarly advanced by Crosbie et al., (2010) and was also corroborated by (Gleeson and Richter, 2017).

However, Crosbie et al., (2010) also investigated episodic recharge with reference to climate change in the Murray-Darling Basin, Australia. In semi-arid areas, episodic recharge can form a significant part of overall recharge, dependent upon infrequent rainfall events. With climate change projections suggesting changes in future rainfall magnitude and intensity, groundwater recharge in semi-arid areas is likely to be affected.

By contrast, the anthropogenic effects on groundwater resources of Enji area are mainly due to groundwater pumping with an indirect effect on public and private township supply. The yield of water production was thus estimated (Figure 5) throughout the year and inference from this practical measurement clearly revealed that the wet seasons produced more yield than dry season across the investigated areas with the aquifers ie the porous and permeable rock saturated with underground water tilting more to the northern part of the area as evidenced with the generated model (Figure 6). The aquifer is prolific but its GWS is mainly from rainfall precipitation.

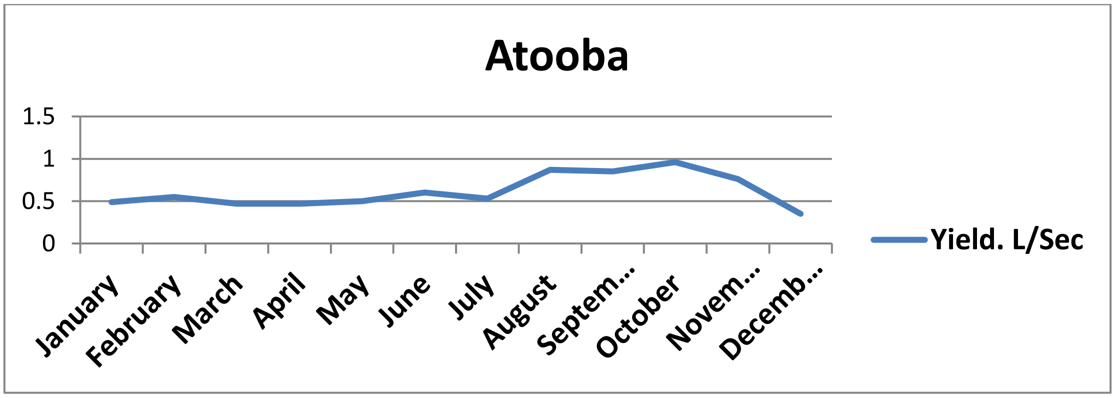

Figure 5 Yield of underground water boreholes across the year of Atooba study area

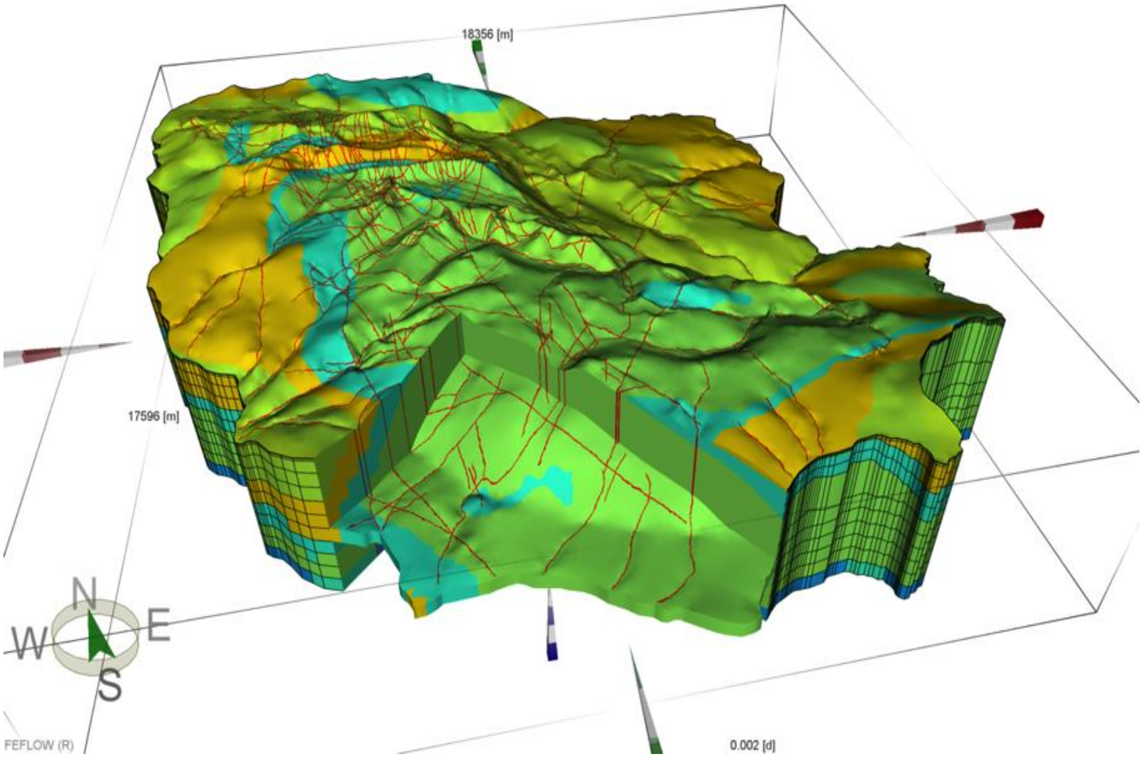

Figure 6 Enji aquifer geometry model tilting towards the northern area

The aquifer geometry tilting towards the northern side of the study area has also revealed that the tectonic historical review of the investigated Enji area has witnessed different orogenies that made the emplacement of massive granitic rocks that constitute the aquifers of the area possible. Moreover, Wu et al., (2020) also predicted the geometry of underground aquifer in the mid latitude aquifers with diverse opinions in a published article titled: Divergent effects of Climate change on future groundwater availability in key mid-latitude aquifers.

4. CONCLUSIONS

Seasonal variation of the Enji study area has greatly impacted the aquifer vulnerability with rainy season favoring high and better groundwater production, while the dry season with low to average precipitation leaving most aquifers less saturated with enough recharge to sustain most boreholes for underground water production. Air temperature, rainfall and sunshine hours are the most important environmental factors utilized in the study and have all shown great impacts on the aquifer performance and groundwater production of the investigated areas. From 2001-2010 air temperature pattern, a total of highest 394°C maximum air temperature was recorded for 2006 against the lowest recorded air temperature of 369°C of 2008 and 2009. 2011 to 2020, the maximum air temperature reduction continued till 2011 with 372°C, but with the irregular air temperature pattern, it gradually increased again from 2012 a period the study area witnessed the most severe flooding in that decade to 395°C.

Rainfall and sunshine hours across the areas is now irregular with attendant severe impacts on the aquifer's performance to produce underground water. The yield varied between 0.51-0.62 liters/seconds in the area. First fracture was diagnosed at 25-27 meters depth of Enji area at the peak of dry season and at Fatraaj, Gbomi and Keraaje at an average of 33, 36 and 32 meters respectively. Second aquiferous position was encountered at an average depth of 38, 32.8 and 39 meters. Atooba had the SWL measured to be averagely 8.5, 7.6 and 7.9 meters. Enji wells gave static water levels of 7.9, 7.9 and 9.8 meters representing EG1, EG2 and EG3. Gbomi recorded an average of 8.5, 8.6 and 9.8 meters SWL. Another major finding is that all the measured wells displayed a robust and prolific water storage and transmissivity from the aquifer to the wells during the wet/rainy season than dry season, as such, point towards a better underground water production in the peak of wet than dry season of the area.

Recommendations

The aquifer 1 and 2 at shallow depth of 25-27- and 32-39-meters depth respectively are becoming exhaustible during the peak of dry season for groundwater production, as such, it is highly recommended that aquifer 3 which is at deeper depths of 41-52 meters should be the viable alternative for potable water exploitation now and for the nearest future as the changing climate is already drastically reducing the rainfall percolation to recharge the aquifers. Drilling activities for potable water production will need extend to this depth to mitigate the impact of the climate change on the aquifer's performance and increase the amount of water available for the socio-economic activities of the people. This will need be done with detail geophysical exploration exercise to pinpoint the third fractural zone ie fracture 3 of the area for adequate groundwater production that will serve the peak of dry season production of the area.

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Ethical approval

Not applicable.

Informed consent

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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Data and materials availability

All data associated with this study are present in the paper.

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