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The Declining Middle Zone Aquifer of the Southwestern Chad Basin in the last Millenium.

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Abstract: *The Middle zone aquifer is the most extensive and most widely exploited of the three well known aquifers of the Chad Formation. This aquifer is confined by variable thickness of argillaceous deposits of 100 – 150 m thick. This led to the variable heads in boreholes drilled to this zone. Boreholes drilled from 1960 to 2010 shows a drastic decline in piezometric heads. The piezometric heads of over 20 m above ground level (agl) observed in 1960 to 1.2 m agl in 2010 have declined over the last half century. In the present work the heads at 0.2 m/ year giving the present piezometric head at an average of 0.5 m agl. The lower heads in old boreholes are attributed due to siltation, encrustation and ageing of borehole. Furthermore, lack of present day recharge and poor borehole construction methods play a vital role in determining the piezometric head.*
Keywords: *Aquifer, Declined, Piezometric head, Borehole, Encrustation.*

I. Introduction

Groundwater in the Southwestern Chad Basin occurs in the Quaternary Chad Formation. Hydrogeologically it is the most prolific stratigraphic unit in the Basin. Groundwater in this deposit occurs under both confined and unconfined conditions. Three aquiferous zones have been clearly demarcated and named by Barber ad Jones (1960), as the Upper, Middle and Lower aquifers. The Upper aquifer generally unconfined and semi – confined, while the Middle and Lower Aquifers are confined. The Middle zone aquifer is the most extensive and most exploited of the zones. Because of thick clay (in some places over 100m), boreholes drilled to this zone yield artesian flow with piezometic head as high as 20m above ground level. This positive head has significantly decline over the past half a century. The reason for this has been due to over abstraction largely due to the uncontrolled discharge from artesian wells and lack of replenishments. Several authors attempt to estimate the rate of decline in the piezometric head of the Middle zone aquifer for different periods of time. (Offodile, 1972, Adefila, 1975; Oteze and Fayose, 1988, Ndubisi, 1990, Oluboye, 1995, Goni et al; 2000 etc) estimated the rate of decline in piezometric head of the Middle zone aquifer boreholes and also the variability in head observed in boreholes drilled to the Middle zone aquifer, is the focus of this paper.

Previous work.

In 1934, Raeburn and Jones published an account of the Geology and Hydrogeology of the Nigerian part of the basin. Then followed by Barber and Jones (1960) who, in their study of the Geology and Hydrology of Maiduguri, recognized three zones of aquifers named the Upper , Middle and Lower zones. Miller, Johnson, Olowu and Uzoma (1966) published an account of the availability of groundwater in the Chad Basin of Bornu and Dikwa Emirates. In 1968, Miller and others published the result of further studies on the groundwater hydrology of the Chad Basin in the Emirates.

II. Hydrogeology

The Middle aquifer is confined by a clay layer up to 100m thick in some places, with pressure sufficient to cause artesian flow. It is arenaceous in nature and stores water and termed Middle zone aquifer (Barber and Jones, 1960).Because of the heterogeneity of the aquifer materials, there is variability in hydraulic properties. Miller et al (1968) gave the following hydraulic parameters: Hydraulic conductivity range from 0.0000428 – 0.000179 m/sec (90 – 380 gpd per square foot); transmissivity 0.000818 – 0.1141m^2/sec (520 – 72,500 gpd per foot; storage coefficient 0.000014 – 0.00018. They further subdivide the aquifer into six based on water yielding capability.

1.7 SCOPE OF STUDY

The study area is the Middle zone aquifer of the Nigerian sector of the Chad Basin. The area falls within latitude 11°30'N and 13°30' N and longitude 12°00'E and 14°30'E.

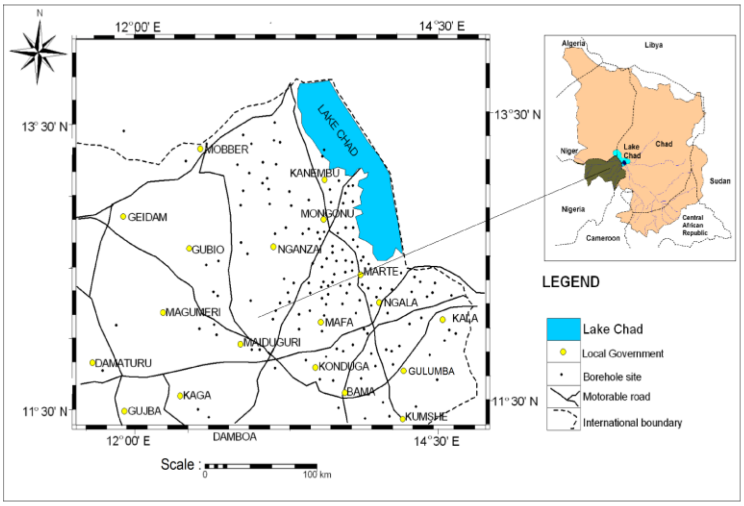

Fig.1: Map of the study area with Middle zone aquifer boreholes sampling sites.

Furthermore, Recharge Estimation (qualitatively) was carried out where the Middle aquifer is suspected to have outcropped or merged with the Upper aquifer, boreholes in that area was monitored for a period of 12 months using groundwater level fluctuation method. This method is chosen because a water level rise is the clearest indicator of recharge if all abstraction remains unchanged and atmospheric pressure effects can be ruled out.

The static water level (SWL) of seventy one Middle zone aquifer boreholes were monitored from February, 2010 to January, 2011 by the use of water level indicator as earlier used by researcher across the study area. These boreholes were drilled in 1960's - 2010's were analysed to determine the rate of decline over the last half century. The SWL of each borehole is measured once in a month.

The Middle zone aquifer is the most extensive and widely exploited of all the zones, extending to Republics of Niger, Cameroon and Chad. Because of the thick clay Formation (in some places over 100m), boreholes drilled to this zone yield artesian flow with piezometric head as high as 20m agl. This positive head has significantly decline over the past half century. The reason for this has been due to over abstraction largely due to the uncontrolled discharge from the artesian wells and lack of or little replenishments (Adefila, 1975, BRGM, 1993).

The pressure heads are falling drastically due to indiscriminate and uncontrolled exploitation of the aquifer. There is still a noticeable decline in pressure surface of the free- flowing artesian wells in the Nigerian sector of the Chad Basin and consequently a shift in the limit of artesian flow in the pressure water of the Middle zone aquifer of the Chad Basin area eastward towards the lake with about 23 km for the last half a century (fig.2).

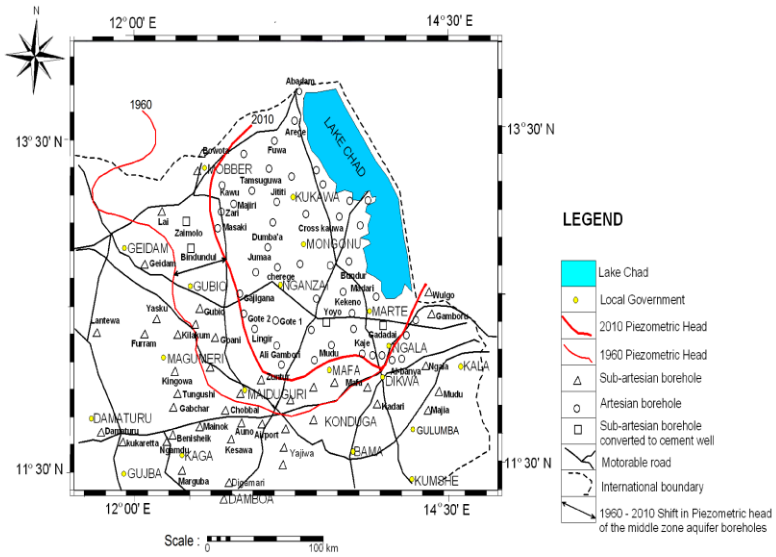

Fig.2. Piezometric Head Declines from 1960 – 2010.

3.5 cm = 100 km (scale)
Shift = 0.8 cm
1 cm = 100/3.5 = 29km
0.8 cm (Shift) = 0.8/1 x 29 = 23 km NE towards the Lake Chad.

The increase in social and economic development in the area has brought about a sharp increase in groundwater exploitation resulting in the decline of the piezometric head of the Middle zone aquifer (Oteze and Fayose, 1988).

The boreholes drilled to the Middle zone in the 1960 yield artesian flow in Maiduguri with a piezometric head of over 8 m agl while in the 2010 boreholes piezometric head of 34 m bgl was recorded in Maiduguri. Furthermore, the artesian wells are now mostly found in the north of Maiduguri towards the Lake Chad. The closest artesian well to Maiduguri is in Zuntur village in Nganzai local government area of Borno State which is about 27 Km northeast of Maiduguri (by road).However, from the above calculations an estimated shift of 23 Km northeastwards towards the Lake is made for the past half a century.

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The water demand has dramatically increased over the last few decades, due to population growth and changes in life style of the people occasioned by modernization. This has brought about a sharp increase in groundwater exploitation resulting in the decline of the piezometric head of the Middle zone aquifer (Goni et al, 2000).

Table 1: The Decline of Piezometric Head of Middle Zone Aquifer Boreholes from 1960 to 2010.

Year	Completion SWL	Completion Yield	SWL in 2010	Yield in 2010
1960	11.2	12.8	+ 1.2	0.7
1970	10.1	8.6	+ 1.0	1.3
1980	6.7	4.9	+ 0.8	1.1
1990	4.7	4.8	+ 0.6	1.1
2000	1.8	2.8	+ 0.5	0.6
2010	0.1	1.4	- 0.5	0.4

The average static water levels of 1960s, 1970s and 1980s boreholes were determined to be 11.2, 10.1 and 6.7 m above ground level (agl) at their times of completion while the 1990s, 2000s and 2010s boreholes had piezometric heads 4.7,1.8 and 0.1m agl at their completion times.

In evaluating the rates of decline both completion static water level and 2010 static water level of 1960s – 2010s boreholes and their present head are considered.

The piezometric head was gradually decreasing from 11.20m agl in 1960s to 0.1m agl in 2010.The high piezometric head decline in1960s – 1970s was from 11.2 m agl to 10.1 m agl, yielding a decline of 1.1 m. From 1970s – 1980s the head dropped from 10.1 to 6.7 m agl, yielding a decline of 3.4 m agl. Furthermore, from 1980s to 1990s the decline was 5.4 m agl; from 10.1 m agl to 9.7 m agl whereas from 1990s - 2000s it was 2.9m agl, from 4.7 m agl to 1.8 m agl, and in 2010 the decline was 1.3m agl from 1.8 m agl to – 0.5 m agl. There is gradual decline in the piezometric head and rates from 1990 to 2000, the declined and rate of decline are from 1.3 m to 0.13 m/year respectively. Population increase in the region and the conversion of many artesian wells to cement wells are believed to be responsible for these change. Furthermore the intervention by the local and state government in drilling boreholes for rural water supply is also a contributing factor. The decline is 1.7m while the rate is 0.2m/year, for 2000 to 2010 boreholes, this is because there is less borehole drilling programme due to high cost of drilling .The head of 1960, 1970 and 1980 boreholes in 2010 are +1.2, +1.0 and + 0.8 m agl respectively, while the heads of 1990, 2000 and 2010 boreholes are + 0.6, + 0.5 and - 0.5 respectively. It is calculated that the pressure head decline in the Middle zone aquifer is at the rate of 0.2 m / year for the past half a century based on piezometric heads of boreholes drilled from 1960 to 2010 tapping the Middle zone aquifer.

That their yields are also decreasing gradually from 1960 (12.8 l/s) to 2010 (1.4 l/s) is explained by the increase in the rate of exploitation, borehole construction method, borehole age among other factors. The boreholes locations used for the analysis of the decline in the piezometric head in the area over half a century is shown in fig.1.

The decline in the Pressure head of the Middle zone aquifer boreholes is caused principally by three (3) parameters. These are: The Percentage Screen, Yield and development period of boreholes.

In the 1960's boreholes, percentage screening does not follow the trend of 50-70% screening increases the yield of borehole. It is obvious that screening boreholes up to 50-70%; increases yield than does screened <

50-70%. In this case some boreholes have high yield corresponding to the % screen while others have the reverse showing the haphazard methods of screening of boreholes in the Nigerian sectors of the Chad Basin, hence, showing scatter points without definite trend/relationship between the yield against the percentage screened of boreholes in 1960's (fig.3.).

The piezometric head of the Middle zone aquifer boreholes has declined over the past 30 years. The main reason for the declined has been the over abstraction and lack of replenishment. However factors such as the deterioration of the boreholes, boreholes interference and differences in borehole construction methods may also contribute to the observed declined.

The differences in the borehole construction methods, percentage of aquifer thickness screened and development hour's results in differences in the yield of boreholes drilled to the same depth, place and time. The three parameters of percentage screened, well diameter, and development hours have been analysed for boreholes from 1960 -2010.

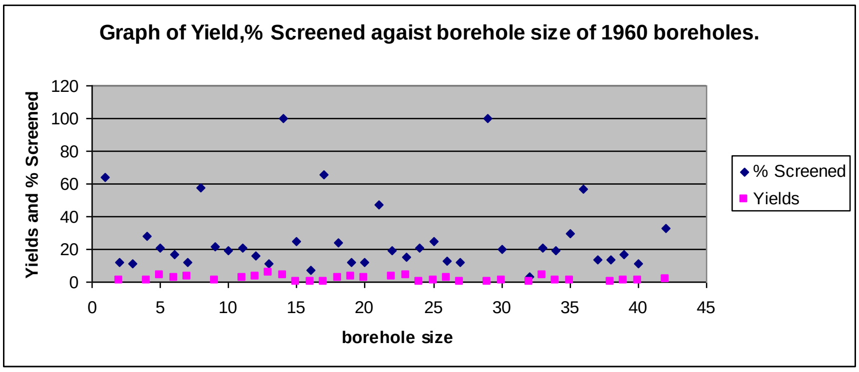

Fig. 3: Indicates the relationships between Percentage Screened and Yields against Borehole Size of 1960's boreholes. The plots does not show any cluster/ relationships hence show scattering of points.

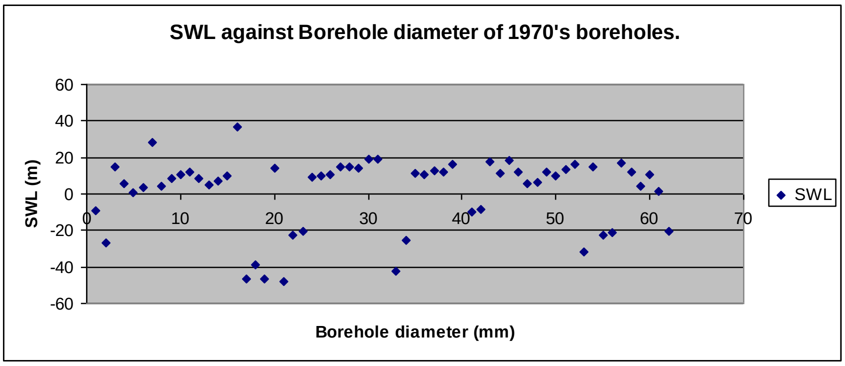

Fig.4: Graph of well diameter against static water level of 1970's boreholes. They are independent parameters that are not proportional to each other. The result shows no particular trend depicting scattering.

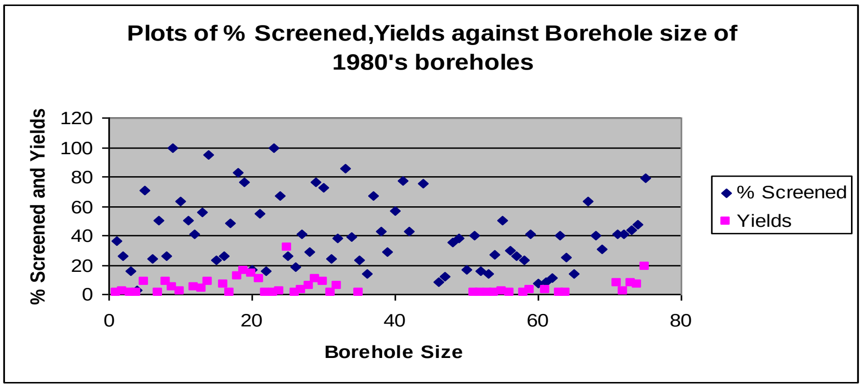

Fig.5: Is a plot of Percentage Screened and Yields against Borehole Size of 1980's boreholes. The three parameters are independent from each other. The result shows complete scattering of points indicating no relationships between the plotted parameters.

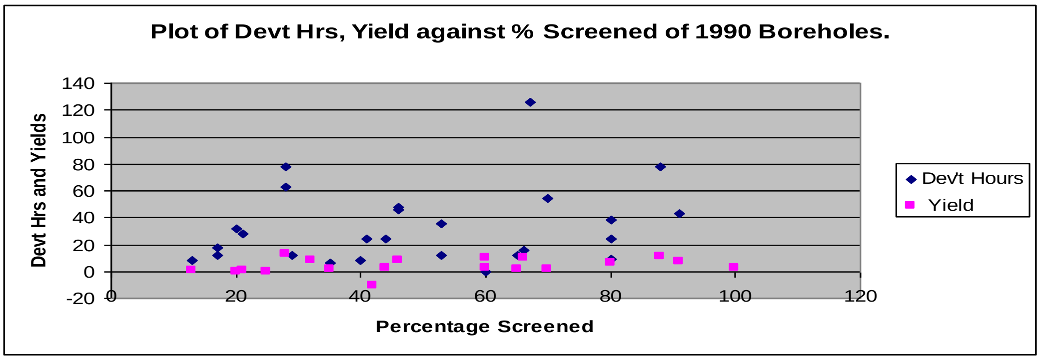

Fig.6: Shows the plots relationship of Development Hours and Yields against Percentage Screened of 1990's boreholes. The development hours and percentage screened does not control the yield of a borehole but rather it is controlled geologically (porosity, permeability, availability of water in the aquifer etc). The three parameters show no relationship hence showing scattering of points.

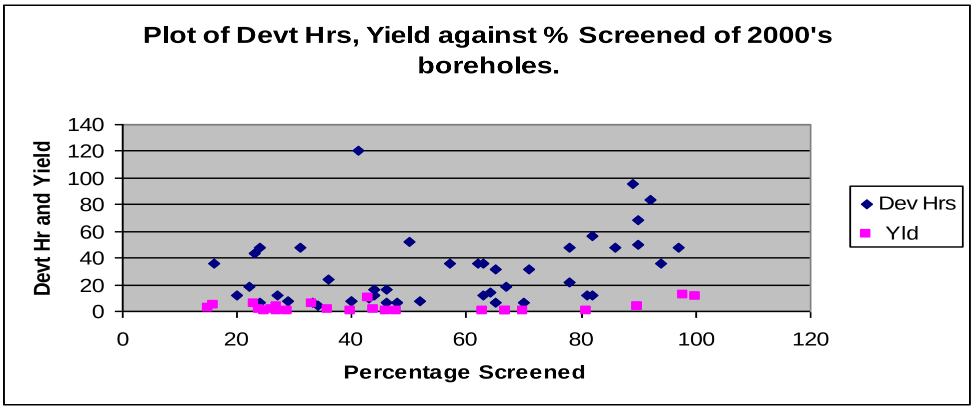

Fig.7: Is a plot of Percentage Screened of 2000's borehole against their yield and development hours. The geology of an area determines the yield of an aquifer and not external induced factors like percentage screened and development hours. The result shows no definite trend hence the three entities are independent from each other.

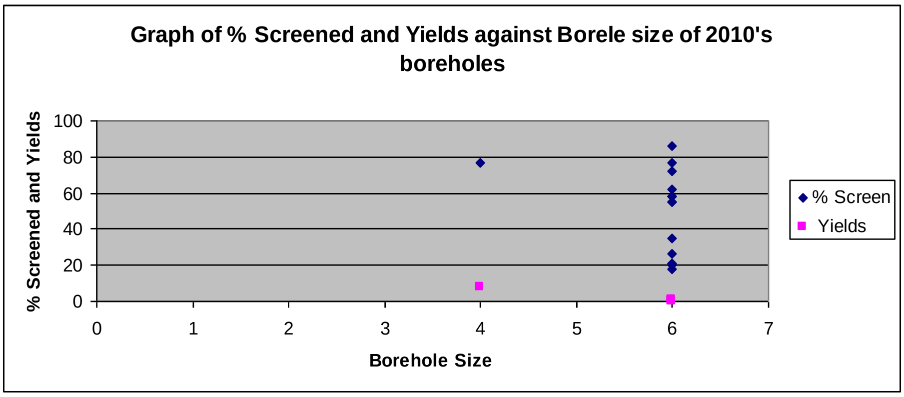

Fig.8: Depicts the relationship of Percentage Screened, Yields and Borehole size of 2010's boreholes. Yield is geologically controlled and not by borehole construction method. The plot does not show any particular trend hence depicts scattering of points.

The pressure heads are falling drastically due to indiscriminate and uncontrolled exploitation of the aquifer. There is still a noticeable decline in pressure surface of the free- flowing artesian wells in the Nigerian sector of the Chad Basin and consequently a shift in the limit of artesian flow in the pressure water of the Middle zone aquifer of the Chad Basin area eastward towards the lake with about 23 km for the last half a century (fig.2).

The water demand has dramatically increased over the last few decades, due to population growth and changes in life style. Not only has the demand increased due to the population growth, but there has also been a change in the life style of the people occasioned by modernization. This brought about a sharp increase in groundwater exploitation resulting in the decline of the piezometic head of the Middle zone aquifer (Oteze and Fayose, 1988).

III. Conclusion

The pressure head in the Middle zone aquifer is declining at the rate of 0.2 m / year for the past half a century. Their yields are also decreasing gradually from 1960 (12.8 l/s) to 2010 (1.4 l/s). This is explained by the increase in the rate of exploitation, borehole construction method, borehole age among other factors. Furthermore, lack of present day recharge to the Middle zone aquifer, heterogeneity and variable thickness of clay layer confining the zone play important role in the piezometic head declines of the Middle zone aquifer.

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Appendix 2: Boreholes Parameters of 1960's Boreholes.

S/No	Loc	LGA	Lat	Long	Elev(m)	Swl 2010	Pop	Cat.	pH	T°C	EC	Yld l/s	TDC	Aq.Enc.	Scr. Pos.	% Scr.	Dev Hr	Cpl SWL	P.Yld	Cons.Yld	Scr.thk	Aq.th
1	Yetcen'y	Monguno	12°40.153'	13°36.401'	297	0.7	500	320	7.32	38.3	394	0.4	374	333 - 372	349 - 370	54		6.9		12.4	21	39
2	New.M. ISQ	Marte	1215.09	1308.09	277	0.8	1000	1200	7.85	40.5	680	0.5	310	116 - 305	276 - 304	15	108	10.8		N.D	28	189
3	Mogole	Mafa	1314.781	1202.892	296	0.7	380	2600	7.2	37.7	1224	0.4	299	244 - 299	245 - 290	82	98	13.6		1.3	45	55
4	Fermari	Mafa	1310.206	1210.284	298	-1.5	300	800	7.2	37.6	960	Pump	308	260 - 278	261 - 277	89	83	15.2		1.5	16	18
5	Mbutta	Mafa	1320.087	1200.01	296	-10.2	510	700	6.9	39.1	820	0.8	313	277 - 313	279 - 299	89	56	10		1.2	20	36
6	Musa	Mafa	1320.694	1155.542	295	-24.8	2500	-	7.1	38.2	1126	2	283	256 - 283	268 - 274	22		N.D		0.01	6	27
7	Mijigine	Mafa	1348.262	1207.864	291	0.8	520	700	6.86	36.4	1026	0.2	268	263 - 268	256 - 259	60		14.2		1.3	3	5
8	Fuye	Ngala	1408.642	1215.489	286	0.4	260	700	7.82	36.8	908	0.3	290	262 - 290	274 - 280	21		14.6		1.7	6	28
9	Masawaji	Ngala	1408.364	1226.867	277	0.6	820	2500	7.6	37.4	840	0.4	315	286 - 315	289 - 296	24		15.8			7	29
10	Gubio	Gubio	1252.329	1230.126	298	-5.5	1500	2000	7.4	38.2	472	6	325	307 - 325	317 - 323	33		6.1		1.3	6	18
11	Ardimini	Gubio	1215.826	1228.943	308	N.A.	320	-	7.2	36.8	408	2	333	286 - 333	318 - 324	13		-0.9	2.2		6	47
12	Gomma	Marte	1342.629	1212.457	290	1.4	1200	10,000	7.1	37.3	1005	0.4	280	266 - 280	271 - 274	22		13.9		1.3	3	14
13	Masaki	Mobbar	1216.894	1256.464	298	0.7	280	950	7.05	38.2	366	0.5	312	292 - 312	297 - 303	30		6.2		1	6	20
14	Masu	Magumeri	1324.067	1212.052	291	-5.1	250	2000	6.8	40	882	1.2	353	312 - 351	314 - 344	77	94	12.12		35.4	30	39
15	Kesa Ngala	Magumeri	1208.362	1320.087	295	-5.15	560	20,000	6.8	38.6	846	2	352	310 350	311 - 341	75	88	12.12		34.7	30	40
16	Gacene	Kukawa	1322.261	1325.492	280	1.26	400	1200	6.54	36.8	1170	0.6	344	318 - 344	326 - 332	23	72	20		4	6	26
17	Kanema	Kukawa	1316.334	1312.551	283	1.1	560	3000	6.4	36.8	1080	0.8	369	334 - 368	350 - 356	18		20.3		4	6	34
18	Bowata	Mobbar	1241.671	1307.924	298	-22.5	740	1400	7.12	36.6	940	2	332	281 - 302	281 - 287	29	144	3.9		0.2	6	21
19	Pala	Gubio	1247.891	1252.416	296	0.3	180	250	7.2	36.4	870	0.3	312	285 - 312	292 - 298	22		7.4		2.5	6	27
20	Chingowa	Gubio	1250.861	1238.654	294	1.04	420	2500	7.3	37.7	485	0.4	361	304 - 361	345 - 351	11		8.2		3.3	6	57
21	Basam	Gubio	1253.629	1238.891	295	0.4	460	1200	7.4	35.5	842	0.4	318	287 - 318	292 - 298	20		4.6		1	6	31
Total										107.3												

□

Appendix 3: 1970's Boreholes Parameters.

S.No	Loc	LGA	Lat	Long	Elev(m)	Swl 2010	Pop	Cat.	pH	T°C	EC	Yld l/s	Year	TDC	Aq.Enc.	Scr.Pos.	% Sc	Dev Hr	Cpl Swl	P.Yld	Cmp. Yld	Scr.thk	Aq.thk
1	Fuccam 1	Maguneri	1215.78	1247.946	311	-24.6	380	800	7.6	32.5	894	well	1976	340	283 - 323	283 - 331	68	71	-9.05	8.5		40	48
2	Gulhera	Borsari	1238.25	1141.667	352	-47.6	300	100	7.6	33.8	395	1	1976	246	0 - 232	127 - 230	9	82	-26.85	13.7		16	232
3	Laraba Kor	Kukawa	1220.63	1337.032	298	N.A.	580	-	6.5	34.3	825	well	1977	354	320 - 346	321 - 343	85	-	15.16		22.7	22	26
4	Kwa	Gubio	1243.8	1230.862	293	N.A.	220	400	7.2	39.2	892	5	1977	325	300 - 325	306 - 315	36		5.8		0.6	9	25
5	Kilakam	Mobbar	1254.29	1215.694	300	N.A.	340	800	7.32	37.6	362	2	1977	298	274 - 298	289 - 295	25		0.6		0.1	6	24
6	Biodundul	Gubio	1325.47	1246.291	298	-12.4	420	800	7.2	28.6	960	well	1977	319	292 - 307	300 - 306	40		3.6		0.9	6	15
7	Zaimolo	Gubio	1325.63	1248.123	299	-12.8	330	-	-	-	-	well	1977	326	298 - 326	318 - 324	21		28		1.2	6	28
8	Lai	Gubio	1325.93	1254.21	297	-21.6	1200	3000	7.8	34.8	860	6	1977	321	300 - 321	303 - 306	15		3.9		0.1	3	21
9	Zari	Mobbar	1148.76	1312.257	319	1.3	420	1500	6,06	42.6	1382	1	1977	323	286 - 323	288 - 318	81	111	8.39		36.8	30	37
10	Tamsugwa	Mobbar	1312.16	1258.056	293	1.23	120	160	6.46	39.8	862	0.8	1977	318	296 - 318	297 - 316	96	76	10.91		6.1	19	22
11	Shehu Buk	Mobbar	1320.49	1256.068	295	0.6	100	150	6.3	38.7	977	0.6	1977	326	304 - 326	304 - 310	27		11.8		1.5	6	22
12	Gashagar	Mobbar	1322.17	1`247.806	300	1	5200	6000	6.33	40	844	2	1977	381	299 - 318	298 - 316	89	88	8.5		15	17	19
13	Bul Mitiri	Monguno	1218.73	1324.467	298	3.6	450	800	7.4	33.4	462	1.4	1977	366	300 - 351	327 -345	35	34	5		4	18	51
14	Malba	Nganzai	1220.25	1310.125	310	0.7	300	650	7.4	36.8	720	0.4	1977	383	315 - 376	342 - 375	46	26	7		6.5	28	61
15	Foguwa L	Kukawa	1327.26	1256.354	296	0.5	450	1000	6.8	34.2	682	0.3	1977	386	338 - 370	339 - 369	94	60	10.1		5.5	30	32
16	Ladi Isa	Maguneri	1211.67	1219.512	342	-26.3	600	1250	6.2	38.6	394	well	1977	231	219 - 231	218 - 227	75	72	36.4		7	9	12
17	DA/6 DTR	Damaturu	1144.53	1157.767	362	-53.8	1000	-	7.4	35.5	380	2	1977	280	90 - 151	85 -147	60	162	-46.7	12.2		37	67
18	DA/9 DTR	Damaturu	1147.32	1158.211	363	-56.2	700	-	7.3	38.6	410	2	1977	303	139 - 200	156 - 202	27	89	-38.6	2		22	79
Average					-2.6						1.25							10.1		8.6			
Total											125												

Appendix 3: 1970's Boreholes Parameters.

S.No	Loc	LGA	Lat	Long	Elev(m)	Swl 2010	Pop	Cat.	pH	T°C	EC	Yld l/s	Year	TDC	Aq.Enc.	Scr. Pos.	% Sc	Dev Hr	Cpl Swl	P.Yld	Cmp. Yld	Scr.thk	Aq.thk
1	Fuccam 1	Maguneri	1215.78	1247.946	311	-24.6	380	800	7.6	32.5	894	well	1976	340	283 - 323	283 - 331	68	71	-9.05	8.5		40	48
2	Gulhera	Borsari	1238.25	1141.667	352	-47.6	300	100	7.6	33.8	395	1	1976	246	0 - 232	127 - 230	9	82	-26.85	13.7		16	232
3	Laraba Kor	Kukawa	1220.63	1337.032	298	N.A.	580	-	6.5	34.3	825	well	1977	354	320 - 346	321 - 343	85	-	15.16		22.7	22	26
4	Kwa	Gubio	1243.8	1230.862	293	N.A.	220	400	7.2	39.2	892	5	1977	325	300 - 325	306 - 315	36		5.8		0.6	9	25
5	Kilakam	Mobbar	1254.29	1215.694	300	N.A.	340	800	7.32	37.6	362	2	1977	298	274 - 298	289 - 295	25		0.6		0.1	6	24
6	Biodundul	Gubio	1325.47	1246.291	298	-12.4	420	800	7.2	28.6	960	well	1977	319	292 - 307	300 - 306	40		3.6		0.9	6	15
7	Zaimolo	Gubio	1325.63	1248.123	299	-12.8	330	-	-	-	-	well	1977	326	298 - 326	318 - 324	21		28		1.2	6	28
8	Lai	Gubio	1325.93	1254.21	297	-21.6	1200	3000	7.8	34.8	860	6	1977	321	300 - 321	303 - 306	15		3.9		0.1	3	21
9	Zari	Mobbar	1148.76	1312.257	319	1.3	420	1500	6,06	42.6	1382	1	1977	323	286 - 323	288 - 318	81	111	8.39		36.8	30	37
10	Tamsugwa	Mobbar	1312.16	1258.056	293	1.23	120	160	6.46	39.8	862	0.8	1977	318	296 - 318	297 - 316	96	76	10.91		6.1	19	22
11	Shehu Buk	Mobbar	1320.49	1256.068	295	0.6	100	150	6.3	38.7	977	0.6	1977	326	304 - 326	304 - 310	27		11.8		1.5	6	22
12	Gashagar	Mobbar	1322.17	1`247.806	300	1	5200	6000	6.33	40	844	2	1977	381	299 - 318	298 - 316	89	88	8.5		15	17	19
13	Bul Mitiri	Monguno	1218.73	1324.467	298	3.6	450	800	7.4	33.4	462	1.4	1977	366	300 - 351	327 - 345	35	34	5		4	18	51
14	Malba	Nganzai	1220.25	1310.125	310	0.7	300	650	7.4	36.8	720	0.4	1977	383	315 - 376	342 - 375	46	26	7		6.5	28	61
15	Foguwa L	Kukawa	1327.26	1256.354	296	0.5	450	1000	6.8	34.2	682	0.3	1977	386	338 - 370	339 - 369	94	60	10.1		5.5	30	32
16	Ladi Isa	Maguneri	1211.67	1219.512	342	-26.3	600	1250	6.2	38.6	394	well	1977	231	219 - 231	218 - 227	75	72	36.4		7	9	12
17	DA/6 DTR	Damaturu	1144.53	1157.767	362	-53.8	1000	-	7.4	35.5	380	2	1977	280	90 - 151	85 - 147	60	162	-46.7	12.2		37	67
18	DA/9 DTR	Damaturu	1147.32	1158.211	363	-56.2	700	-	7.3	38.6	410	2	1977	303	139 - 200	156 - 202	27	89	-38.6	2		22	79
Average					-2.6						1.25							10.1		8.6			
Total											125												

Appendix 5 : 1990's Boreholes Data.

S/No	Loc	LGA	Lat	Long	Elev(m)	SWL, 2010	Pop	Cat.	pH	T°C	EC	Yld l/s	TDC	Aq.Esc	Scr. Pos.	% Screen	Dev Hrs	Cmpl SWL	Pump Yld	Cmp. Yld	Scr.thick	Aq.Thick
1	Maiwa Mal	Mafa	1152°.93	13°27.11'	299	-1.3	230	1000	6.5	33.6	970	Pump	258	226 - 256	228 – 249	70	54	12.5		2	21	30
2	Ngaşanoam	Mafa	1152.93	1334.55	292	-1	150	780	6.8	32.4	964	Pump	362	312 - 358	314 – 335	46	46	10.3		8.7	21	46
3	Mafa West	Mafa	1152.93	1335.75	298	-0.4	2500	-	6.4	30.6	961	Pump	277	260 - 277	261 - 276	88	78	8.5		10.6	15	17
4	Ajiri Yoberi	Mafa	1152.93	1342.5	300	-0.5	780	500	6.5	35.7	950	Pump	312	287 - 310	288 – 309	91	43	4.8		7.2	21	23
5	Facjalaci	Mafa	1158.82	1359.11	272	0.2	160	300	6.8	32	970	Pump	361	320 - 358	325 – 350	66	16	9.4		9.7	25	38
6	Shuwari	Maiduguri	1148.35	1304.91	334	26.7	3600	-	6.5		390	Pump	362	226 - 351	321 – 342	17	12	-26.1	1		21	125
7	Ngomari BK	Maiduguri	1149.87	1304.82	336	22.4	4000	-	7.2		388	Pump	342	304 - 334	310 – 334	80	24	-21.6	3		24	30
8	Ngomari B.S	Jere	1149.5	1308.87	338	20.6	3900	-	7.4		394	Pump	368	312 - 364	326 – 350	46	48	-19.6	2.5		24	52
9	Bolabolin	Maiduguri	1153.52	1308.92	328	21.5	6000	-	7.5		391	Pump	308	268 - 302	282 – 300	53	12	-20.6	3		18	34
10	Monguno,E	Monguno	1241.03	1336.5	305	0.5	1200	-	7.3		430	0.3	381	342 - 378	333 – 348	42	-	4		11	15	36
11	Gubio Centr	Gubio	1229.39	1249.99	294	-5.4	2500	4000	7.2		458	Pump	377	336 - 375	351 – 372	54		-1.2	1.6		21	39
12	Gubio Cross	Gubio	1229.58	1247.17	299	-5	1200	1300	7.1		4870	Pump	384	346 - 383	357 – 381	65	12	1		1.3	24	37
13	Yale	Konduga	1145.314	1343.712	316	-33.2	1200	-	6.8	32	845	Pump	374	223 - 381	360 – 372	9		-31.8	1.6		12	153
Average						- 0.5												4.7		4.8		
Total												70.8										

Appendix 6 : 2000's Borehole Data

S/No	Loc	LGA	Lat	Long	Elev(m)	Swl 2010	Pop	Cat.	pH	T°C	EC	Yld l/s	TDC	Aq.Esc.	Screen Pos.	% Sc	Dev Hr	Cpl Swl	P Yld	Cpl Yld	Scr.th	Aq.Th.
1	Garadai	Marte	12°14.127'	13°52.134	260	0.5	500	-	6.9	34	877	well	296	273-292	275-287	63	36	0.6			12	19
2	Ba'ale	Mafa	1148.46	1328.53	242	0.9	500	850	6.9	37	920	2	309	280 - 291	278 - 290	81	12	0.6		0.5	9	11
3	Mal Maja	Dikwa	1210.55	1352.23	281	0.6	1100	540	6.6	36	800	0.4	275	229 - 256	230 - 242	44	12	0.8		0.6	12	27
4	Kilangilawa	Kala Balge	1226.66	1348.23	322	-1.3	425	460	6.9	36	900	-	322	246 - 322	308 - 320	16	36	-1.3	2		12	76
5	Gawa	Mafa	1136.79	1334.54	294	0.8	1220	900	6.9	33	920	0.6	240	215 - 238	220 - 235	65	6	-1.2	3		15	23
6	Zowo	Gubio	1256.94	1215.86	375	1.9	950	##	7.3	40	850	1.3	375	330 - 375	362 - 374	27	2	1.9		0.3	12	45
7	Wulari 3	Maiduguri	1147.11	1313.21	326	-24.5	####		7.4	39	392	"	274	235 - 274	236 - 260	62	36	-21.6	N.A		24	39
8	CBN Qtrs	Maiduguri	1132.69	1307.44	338	N.A.	-	-	-	-	-	Dead	248	216 - 248	220 - 238	56	-	-22.8	6.2		18	32
9	Unimaid S.1	Maiduguri	1144.34	1311.35	333	-25	1000	-	6.8	33	386	Pump	282	255 - 282	261 - 282	78	48	-24.3	5.6		21	27
10	Mrt Kkw	Maiduguri	12°55.431	13°33.604	267	1.2	200	100	8.3	39	468	0.2	489	413 - 483	454 - 483	43	10	1.1		9.4	29	67
11	Kingerwa	Guzamala	1248.18	1321.15	312	0.6	580	250	7.1	39	755	0.6	375	319 - 361	346 - 360	33	6	1.3		5	14	42
12	Kareto	Mobbar	1307.41	1313.32	352	-1.2	1160	-	7.2	40	410	-	301	284 - 301	284 -298	82	12	-1.5		-	14	17
13	Gamboru Ah	Ngala	1221.27	1408.81	248	-2.8	####	-	6.8	37	850	-	354	282 - 336	309 - 333	44	16	-1.2	2.5		24	54
14	Ngomari LC	Jere	1159.45	1308.62	344	N.A.	####	-	7.2	37	380	Pump	324	252 - 306	275 - 305	97	48	-25.6	4.8		30	31
15	Modu Ajiri	Jere	1354.36	1305.66	321	-22.2	1000	500	7.1	40	540	Pump	268	231 - 268	247 - 268	57	36	-20.6	2.4		21	37
16	Jiddari	Jere	1157.46	1307.72	333	-26.5	####	-	7.2	37	390	Pump	258	224 - 258	244 - 258	41	120	-25.2	8.4		14	34
17	Magumeri	Magumeri	1208.67	1243.37	345	-28.2	1000	500	6.5	40	906	Pump	333	279 - 316	285 - 309	65	32	-26.4	5.7		24	37
18	S.Dikwa	Dikwa	12°02.650	13°55.267	287	0.8	980	-	7	36	810	0.5	270	240 - 270	256 - 268	40	8	0.4		0.3	24	30
19	Ali Turaumi	Jere	1202.49	1303.36	292	-1.2	280	-	6.9	31	668	-	299	258 - 293	280 - 292	34	4	-4.2	2		12	35
20	Tongule	Ngala	1400.58	1216.04	312	0.8	620	140	38	38	900	0.7	312	246 - 306	283 - 298	25		0.8		0.4	15	60
Average						- 0.2												1.8	2.8			
Total												114.4										

Appendix 7: 2010's Boreholes Parameters.

S/No	Loc	LGA	Lat	Long	Elev(m)	Swl 2010	Pop	Cat.	pH	T°C	EC	Yld l/s	Year	TDC	Aq.Enc.	Scr.Pos.	% Sc	Dev Hr	Cpl Swl	P.Yld	Cmp. Y	Sc.th	Aq.Th.
1	Dikwa	Dikwa	1202.65	1355.27	288	-1.8	850	-	6.8	36.1	822	Pump	2010	272	241 - 272	246 - 270	77	50	-2	1.5		24	31
2	Damasak	Mobbar	1308.54	1234.02	354	-6.2	1000	-	7.4	35.3	428	Pump	2010	446	420 - 446	429 - 444	58	48	-7.3	2.5		15	26
3	Baga	Kukawa	1305.71	1349.22	267	-0.7	1300	-	7.3	33.3	418	Pump	2010	420	395 - 420	399 - 417	72	10	0.5		0.3	18	25
4	Gamboru	Ngala	1221.27	1408.81	271	-412	800	-	6.8	32	839	Pump	2010	358	322 - 353	332 - 350	58	8	0.4		0.3	18	31
5	Kainowa	Mobbar	1216.22	1340.39	346	0.2	250	-	7.4	34.1	764	Pump	2010	382	354 - 382	372 - 378	21	-	0.3		0.2	6	28
6	Magumeri	Magumeri	1207.41	1244.31	322	-27.5	420	-	6.9	35.8	394	Pump	2010	298	262 - 296	281 - 293	35	-	-24.5	2	-	12	34
7	Abadam	Abadam	1318.43	1336.58	294	-0.5	1600	-	6.8	37	971	Pump	2010	388	281 - 388	365 - 386	20		-0.5	2	-	21	107
8	Shuwari	Mafa	1324.66	1156.39	308	-30.2	200	-	6.8	35.2	958	Pump	2010	265	224 - 265	250 - 262	21	48	-	1.5	-	12	58
9	Gashagar	Mobbar	1322.17	1247.81	301	0.4	300	1800	6.4	38.9	851	Pump	2010	306	240 - 306	290 - 302	18	24	1.4	-	0.6	12	66
10	Fuwa	Mobbar	1320.16	1337.89	282	1	150	700	6.9	37.8	1182	0.7	2010	408	303 - 361	343 - 358	26	-	1		0.7	15	58
11	Garunda	Mobbar	1304.63	1306.29	290	0.5	250	400	6.6	40	898	0.4	2010	321	299 - 321	306 318	55	10	1.6	-	0.6	12	22
Average					**- 1.0**													**0.1**		**1.4**			
Total											**15.8**												