North East Nigeria Groundwater Surveillance Project

Final Report

November 2021

THE BEST WAY ON EARTH TO FIND WATER

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ABBREVIATIONS

AAH	Action Against Hunger
BCM	Billion Cubic Metres
BGS	British Geological Survey
BHA	Bureau for Humanitarian Assistance
DEM	Digital Elevation Model
EC	Electrical Conductivity
FMWR	Federal Ministry of Water Resources
GIS	Geographical Information System
GSN	Geological Survey of Nigeria
HAWRS	Hydrological Area Water Resources Strategy
IAEA	International Atomic Energy Agency
IDP	Internally Displaced Person
LCBC	Lake Chad Basin Commission
LGA	Local Government Area
mBNS	Metres below natural surface
NIHSA	Nigerian Hydrological Services Agency
NIWRMC	Nigeria Integrated Water Resources Management Commission
NNPC	Nigerian National Petroleum Corporation
NWC	National Water Commission
OCR	Optical Character Recognition
RMSE	Root Means Squared Error
RUWASSA	Rural Water Supply & Sanitation State Agency
SDG	Sustainable Development Goal
SWRC	State Water Regulatory Commission
UNESCO	United Nations Education, Science & Cultural Organisation
UNIMAID	University of Maiduguri
USAID	United States Agency for International Development
USGS	United States Geological Survey
WB	World Bank

EXECUTIVE SUMMARY

Over a decade of conflict in North Eastern Nigeria has seen an exponential increase in the number of new water bores being drilled in areas with a high number of internally displaced persons in and around major urban centres. In 2019, the United States Agency for International Development (USAID) raised concerns over a knowledge gap about the potential impacts and long-term sustainability of exploitation of the region's groundwater resources. In January 2020, Action Against Hunger (AAH) Nigeria engaged Australian specialist consulting firm Geo9 Pty Ltd (the Consultant) to develop a groundwater monitoring and data collection strategy to support sustainable abstraction plans. The Project was developed as a cooperation between the Nigerian Hydrological Services Agency (NIHSA) and key members of the North East Nigeria Crisis WASH Cluster.

The project required the development of a groundwater monitoring strategy and plan providing support for the installation of groundwater monitoring instruments, the collection and digitisation of archival data and training and capacity building of personnel for the sector.

The Consultant identified the lack of an aggregated data and mapping resource that would enable accurate identification of groundwater monitoring locations. Therefore, the Consultant took the initiative to compile available hydrogeological information and groundwater measurement data into a single Groundwater Information System (GIS). All project participants have access to the GIS system that currently incorporates 296 data layers and includes 3,300 individual water points. The dedicated GIS creation was a major undertaking provided by the Consultant to participants during the Project and is the most comprehensive compilation of quality assured groundwater measurement data and hydrogeological information available for Borno and Yobe States.

Using the GIS and in consultation with academics from the University of Maiduguri, the Project was able to clarify the rates of decline in groundwater levels for the different formations. It was found that the groundwater levels have been in decline for over 60 years. The study also identified a range of water quality issues including, salinity, elevated nitrate, fluoride, thallium, arsenic and sulphates associated with different formations. The main drivers for the groundwater issues were identified as the uncontrolled discharge of groundwater from artesian free flow wells that resulted in regional declines in groundwater levels, the diversion of flood waters from aquifer recharge zones and increasing levels of urbanization locally, intensive exploitation and intensive pollution in Maiduguri.

It was identified that another potential contributing factor to the groundwater issues could be the effects of previous drilling from petroleum exploration. This will need to be explored further with access to petroleum industry drilling data, if it can be sourced.

In addition to these drivers, the study identified a range of contributing human resources, governance and regulatory issues. This included poor enforcement of drilling standards, the limited availability of operation and maintenance (O&M) services, gaps in the groundwater monitoring record and the need for modernisation of water bore drilling and groundwater pumping systems.

A groundwater monitoring strategy was developed to address the key groundwater issues and aligned with the pending Water Resources Bill (2020). The Project identified locations for automated monitoring. Due to the current security situation in the region, the decision was taken to install groundwater monitoring instruments in urban areas where AAH have a permanent operational presence. Twenty downhole data loggers and five meteorological stations were installed. Together, these locations have provided good initial spatial coverage that can be progressively infilled into a broader monitoring network in the future.

Moving forward, the strategy identified the need for the following primary monitoring activities to support groundwater management:

1. Improving routine monitoring processes and data sharing including during new water point construction (including the analysis of new digital data capture technologies)
2. Resampling of water points with historic data to check / update on any changes
3. Conduct a hydrocensus (data collection of water point characteristics)
4. Continuing and improved manual monitoring of water levels at water points
5. Ongoing data feedback and monitoring of any future oil and gas exploration in the basin

The Project reviewed the institutional environment and identified the linkages with the new Water Resources Bill (2020). The Bill supports the decentralisation of water management and proposes establishing a Catchment Management Office (CMO) in the eight Hydrological Areas of Nigeria. Reviewing the standards, the Project identified the need to improve enforcement of standards and protocols (in particular for water well construction and water quality), ensuring borehole completion reporting, and establishing the need for recurrent funding for water resources monitoring.

The Project supported the establishment of a WASH Cluster Technical Working Group (TWG) for groundwater monitoring and information management. TWG meetings occurred during the course of the project and brought together the NiHSA, RuWASSA, INGOs, UNIMAID and other key technical and administrative stakeholders. The Project has developed and supported the TWG with recommendations for WASH Cluster Partners to improve current practices. The Project identified new initiatives necessary to support the long-term development of an effective groundwater management strategy in the North East of Nigeria.

The Project developed a number of key recommendations for data collection and maintenance that will contribute to an accurate GIS that can be used by all to ensure long term sustainability of the region's groundwater resources.

BACKGROUND RATIONALE

Historically communities living in Borno and Yobe States have struggled with securing access to stock and domestic water because of the sometimes great depth of the natural water table. It can be as deep as 60-70 m below natural surface level in areas.

The discovery of pressurized groundwater in the 1950's led to a revolution in groundwater development. Free flowing artesian wells became a major source of water for livestock but in subsequent decades, the improvement in water supply was not matched with investment in appropriate rangeland management strategies and groundwater operation and maintenance services. Artesian pressures declined and the reduction in water availability has created a situation of competition and anxiety around access to water which now underpins the protracted conflict.

The conflicts in Nigeria has created a crisis situation, with millions of people internally displaced mostly from rural to urban areas. As a consequence of this crisis, these States have secured major funding for emergency WASH infrastructure. This has resulted in an exponential increase in the number of new water bores being drilled in areas with a high number of internally displaced persons within and around major urban centres.

In 2019, the United States Agency for International Development (USAID) Bureau of Humanitarian Assistance (BHA), raised concerns over a knowledge gap about the potential impacts and long term sustainability of exploitation of groundwater resources in North East Nigeria. These are -

- no groundwater monitoring system in operation
- no central knowledge base consolidating data and information about water resource availability
- large numbers of new boreholes being drilled by the WASH sector, increasing abstraction within the underlying aquifers, and
- no hydrogeological model of the aquifers in the region to support the sustainable management of groundwater resources.

Despite these limitations, and thanks to an earlier USAID funded technical cooperation between the United States Geological Survey (USGS) and the Geological Survey of Nigeria (GSN) baseline hydrogeological information data for the region is good (see Barber, 1965; Miller et al., 1968; Carmalt & Tibbitts, 1969). The baseline data is particularly strong for the aquifers in the artesian zone of Borno State.

A remarkable legacy of the earlier groundwater surveys was the construction of some 224 deep drilled wells, of which 186 wells were free flowing artesian when first installed. At the time of installation and commissioning, the network was releasing an estimated 320,000 gallons per hour (approximately 29 million litres per day) of free-flowing artesian groundwater flow. USGS-GSN investigators forecast that without regulating the discharge, these artesian flows would stop after 30 years.

Regrettably due to the 1967-1970 Nigerian Civil War, USAID support for longer term management of the newly constructed groundwater wells across Borno and Dikwa Emirates did not materialise. In the absence of effective institutions, the initially capped and tapped artesian wells were progressively dismantled in favour of free flowing systems that discharge groundwater into earthen depressions, forming permanent ponds, lakes and wetlands. These became highly prized among nomadic animal herders and sedentary rural communities.

Due to the fact that artesian groundwater discharge was sparsely regulated for the better part of 50 years, confined aquifer pressures have been continuously declining since the original USAID intervention. Annex 1 shows the decline in standing water levels in the original USGS-GSN bores that were re-measured in 2007 and 2012 by Adamu et al (2013). The long term drawdown curves, although based on a small number of measurements, confirm the consistent downward trend. Total falls as much as 60 metres have been recorded in some places.

In the absence of effective State or Federal management of water resources in North East Nigeria, the University of Maiduguri Department of Geology (UNIMAID) had taken on the role of studying the phenomenon. Unfortunately due to the conflict, and continuously worsening security situation, it has been very difficult for UNIMAID researchers and students to conduct ongoing groundwater level monitoring over the last decade.

As of 2019, the Nigerian Hydrological Services Agency (NIHSA) was operating and maintaining only 1 out of the 50 groundwater monitoring points it has plans to establish across the North East. Much like the UNIMAID, progress on groundwater monitoring by the NiHSA has been hampered by the security situation.

The conflict and insecurity, which started in 2009, has attracted significant new resources for the water supply sector, in the form of INGOs and UN agencies who mostly specialize in humanitarian relief. Concerned with meeting the urgent humanitarian needs, many of these organizations initially overlooked the need for groundwater monitoring. Furthermore, due to a weakness of water resources sector coordination coincident with the pulling back of UNIMAID and NiHSA resources and assets, opportunities to efficiently and effectively fill the gaps in groundwater monitoring capacity were missed for the better part of a decade. As a result, there is a great deal of uncertainty as to what has happened since 2012. Due to the gap in the monitoring records, it is not known whether the inferred rates of decline in artesian pressures have been sustained, declined or accelerated.

Instead the joint State Government and international humanitarian agency (WASH Cluster) systems of collection, storage and transmission of information about drilling works (well construction, geological logs, standing water levels, groundwater chemistry, pump test results, etc.) and the functionality of water points, including information on flow rates and standing water levels over time have struggled to keep up with the pace of development of new water points to meet the ever growing demand. Groundwater data collection and hydrogeological information documentation by many members of the WASH Cluster, including the RuWASSA, has not always been implemented consistently or to the highest standards. Often data and information exists, but the final documentation is scattered or the format is not consistent. In many instances drilling records are submitted without accurate coordinates (latitude/longitude). Further the available data is generally not in a format that makes it easily accessible for sharing between different organizations.

In addition to regular risks of water point failure, communities across Borno State, and also parts of neighbouring Yobe State experience the added risks of declining artesian groundwater levels, seasonal depletion of renewable water table aquifers and / or naturally deep water table levels. While falling artesian groundwater pressure is the most visible and direct groundwater problem, it is not the only groundwater issue negatively affecting the communities of Borno State and neighbouring areas of North East Nigeria. There are also significant water quality issues that threaten human health. These groundwater quantity and quality problems need to be understood in order to be effectively managed and the associated risks mitigated or minimised. For these reasons, the WASH sector has an urgent and recognised need for better information about spatial patterns and temporal trends of groundwater levels and various measures of water quality (especially microbiological and chemical).

In addition to naturally occurring chemicals within the groundwater that can cause human health impacts, there are also other worrying signals that the quality of the groundwater resources have deteriorated as a result of human development.

GROUNDWATER INFORMATION SYSTEM (GIS)

Background

To successfully support and implement the project and fulfil the project objectives, the Consultants Team Leader (Mr. Kimberley Patrick) and GIS Senior Expert (Mr. Ferran Ferrer) advised AAH-Nigeria that it was essential to first build a Geographical Information System (GIS) and populate it with the existing groundwater data, hydrogeological information and other relevant geospatial layers. The subsequent emphasis on development of the GIS (at the Consultants expense) has proven a highlight of the project for stakeholders, acting to catalyze closer collaboration and increased information sharing amongst all parties. GIS development by the Consultants has benefited particularly from data contributions by the University of Maiduguri, Yobe RuWASSA, and various member organizations of the WASH Cluster who shared borehole completion reports from their respective water supply programs.

The creation of the GIS project allows the fulfilment of the National Water Resources Master Plan's intention to create a 'Hydrological Area Catchment Information Systems (CIS) which contains data and information to assess the quantity of water in the various water sources; the status of groundwater aquifers; the quality of water resources and state of the aquatic environment; the use of water resources for irrigation, municipal, industrial and other uses; the extent and quality of coverage of water supply and sanitation services; and compliance with water resource quality objectives'. It also honours the Freedom of Water Information obligation for institutions such as NIHSA to make water resources information available to the public, especially as it relates to mitigating and / or adapting to either natural or man-made disasters and in relation to water quality that could result in harm to human health.

National Policy on Groundwater Information Management Systems

The National Water Resources Master Plan (FMWR, 2012) concluded that at national level, government sectoral monitoring systems were inadequate to properly inform decisions on national sector investments, sub-sector resource allocation, sub-national disbursing, accountability of funds and actual disbursement. Equally, that civil society did not have access to user-friendly, relevant information and that generally, data streams are not harmonized and sector data literacy is poor. The Draft Bill concerning a National Water Resources Regulatory Framework (FMWR, 2020) specifies that to effectively manage and disseminate all types of water resources monitoring data, the Minister shall, through NIHSA, establish national level and catchment level information systems regarding water resources. The objectives of the information systems are to:

(a) store and provide data and information for the protection, sustainable use and management of water resources;
(b) provide information for the development and implementation of the national water resources strategy; and
(c) provide information to government, water management institutions, water users and the public on the status of water resources for the purpose of (i) research and development; (ii) planning and environmental management; (iii) determining licence applications; (iv) public safety and disaster management, and(v) international cooperation.

The Ministry of Water Resources may require that any person shall, within a reasonable given time or on a regular basis, provide any data, information, documents, samples or materials required for the: (a) purposes of respective national or hydrological area monitoring networks or information systems; and (b) management and protection of water resources. Information contained in any national or hydrological area information system shall be made available to the public within a reasonable time frame, subject to any limitations imposed by law and the payment of a reasonable fee.

GIS for North East Nigeria

All stakeholders now have ready access to a GIS developed by the Consultant which includes digital versions of a range of tabulated data and graphical elements (e.g. maps) from earlier intensive hydrogeological research and groundwater survey projects of Borno State. A Lite Version of the GIS is available for download and sharing as either QGIS or ArcGIS formats from the developer Geo9 via email[1] request or alternatively it will be available from both the WASH Cluster and NiHSA websites. From available sources, including past research studies, the Consultant extracted, transformed and loaded available information into the GIS which included:

- Resistivity surveys
- Geological logs
- Well construction details
- Standing water levels
- Pump tests
- Field and laboratory chemical and isotopic analysis
- Wireline geophysical logs
- Depth to the top of the pressurised zone
- Measured rates of artesian free flow

Over 3,300 individual water points have been registered to the system. It is possible that some water points are duplicated because there is currently no unique system of waterpoint numbering applied consistently across the area. The current phase of work includes addressing this issue wherever practical and additional data digitization by Masters students (who were also trained in GIS data entry processes for the various datasets). This initiative is co-managed by Prof. Ibrahim Goni of the University of Maiduguri and the Consultants. The initial focus is on uploading and harmonising data from Borno and Yobe states. The team and their many partners from the INGO WASH Cluster have extensive archival water bore drilling completion report data that incorporates geophysical logs, geological logs, construction details, pump tests and water quality laboratory test analysis.

Videoconference based training has been conducted by the Consultant with various WASH Cluster partners and a video presented to the Final Workshop on May 24, 2021. Further discussion and coordination of management options of the GIS with NIHSA and the Technical Working Group is proposed to build on the strong foundation established during this project. A key challenge for State and Federal level departments is to implement quality systems and processes of collecting and transmitting data from the field into the public GIS .

[1] To request access to a copy of the GIS, please email kim@geo9.com.au or maya@geo9.com.au

Information Base Layers	Bore Identification	Minimum Field Measurements	BOREHOLE DOCUMENT STORAGE	
• Geology • Elevation (DEM) • Drainage • Airborne Mangetics • Radiometrics • Administrative units • Locations • Roads • Satellite Images (Sentinel, LandSAT)	• BIN_Unique_ID • Latitude (Easting) • Longitude (Northing) • Elevation • LGA • Ward • Village (or location name • Aquifer Formation • Water Facility Type • Total Drill Depth (m) • Casing Height above surface	• Standing Water Level (m) • Temperature • pH • Electrical Conductivity (EC) • Dissolved Oxygen (D.O) • Flow Rate	Geological Logs	Pump Tests
			Well Construction	Geophysical Logs

Water Levels & Flows	Major Ion Chemistry	Minor & / or Trace Ion Chemistry		Biological	Isotope Chemistry
• Groundwater Levels • Artesian Bore Flow Rates • Springs • Perennial Soil Moisture. • JRC Water Change (Satellite)	• Ca2+ • Mg2+ • Na+ • K+ • HCO3- • Cl- • SO42- • NO3- • Si • CO3	• Li • B • Sr • F • Br • I • PO4 • NH4 • NO2	• Fe(tot) • Fe-II • Fe-III • DOC • Ba • Zn • Cu • Al • Pb • Mn	• BOD • Fecal Coliforms	• O18 • H2 • C13 • C14 • C14_ERR • H3 • H3_ERR • REMARK_ISO

Figure 1. Indicative hydrogeological information and groundwater measurement data that should be included in North East Nigeria GIS / Catchment Information System (Source: Author).

Next Steps

The GIS developed to date by the Consultant is the most comprehensive compilation of quality assured groundwater measurement data and hydrogeological information available for Borno and Yobe States. Its further development should be continued immediately. The major custodians of outstanding hydrogeological information and groundwater measurement data still to be uploaded to the GIS, include States (initial priority being Borno and Yobe States), WASH Cluster members, Geological Survey of Nigeria (GSN), Nigerian National Petroleum Corporation (NNPC) and Lake Chad Basin Commission. In addition to the digitization project currently underway, future activity is proposed by the Consultants to use satellite imagery to geo-locate water points across Borno and Yobe State that were not documented during the 2015 national water point census undertaken by the Federal Ministry of Water Resources and published in Water Point Data Exchange.

Another recommendation is to complete the digitization of the 1:1,000,000 Scale Geological Map from the UNESCO-Lake Chad Basin Commission (LCBC) Study of Water Resources in the Lake Chad Basin (1972-73) to cover the full area of North East Nigeria. and to re-process, filter and model the original airborne magnetic data for all three conflict states (Borno, Yobe and Adamawa) and upload correctly geo-referenced images to the GIS for wider dissemination to groundwater professionals. Other further developments with the GIS may include extending the functionality of the current GIS to more incorporate data from standing water level hydrographs; major ion chemical analysis as ternary plots; geological logs and well construction logs. The Consultant proposes to get permission from the Federal Ministry of Water Resources to make a copy of all its geo-location and photographic data currently on the WPDx platform and upload to the MWater platform. The Consultant has provided a separate assessment on the MWater platform to AAH.

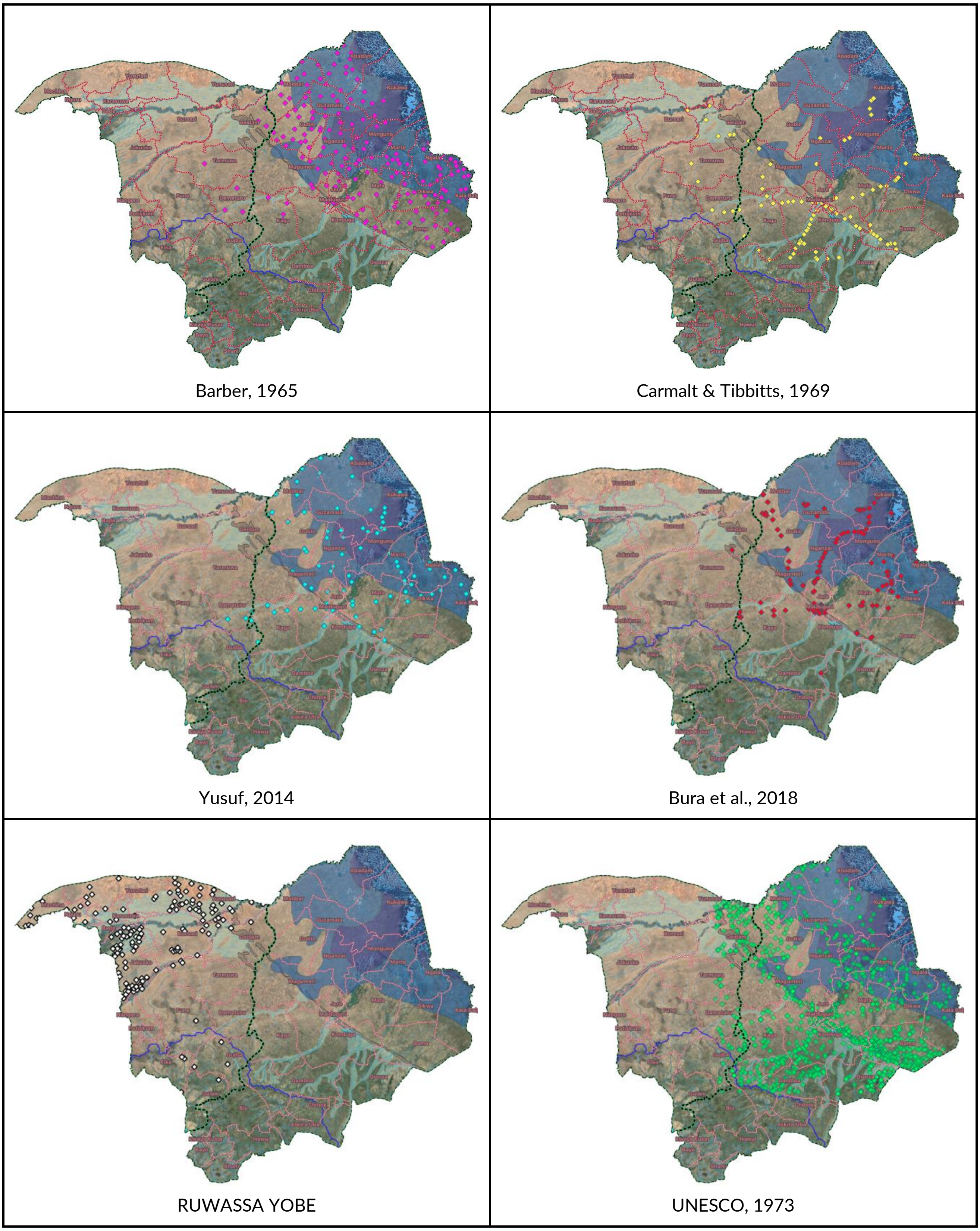


Figure 2: Location of groundwater measurement / investigation / monitoring points from some of the key surveys conducted in Borno or Yobe States uploaded to Project GIS.

HYDROGEOLOGICAL CONDITIONS

The Lake Chad Basin (LCB) is the world's second largest endorheic[2] drainage basin, covering an area of 2.5×10^6 km². It is shared among no fewer than seven countries: Algeria, Cameroon, Central African Republic, Chad, Libya, Niger, Nigeria, and Sudan. The LCB has an estimated population of 49 million (FAO, 2021). The most densely populated areas of the LCB are mostly in North East Nigeria.

The centre of the LCB is located at or about the point of intersection of globally significant tectonic rift structures, specifically the northern extent of the SW-NE trending Benue Basin and the southern extent of the SE-NW trending Termit Basin. These relatively narrow rift basins have been accumulating sediments since the Early Cretaceous period when South America was pulled apart from Central and West Africa (Genik, 1993).

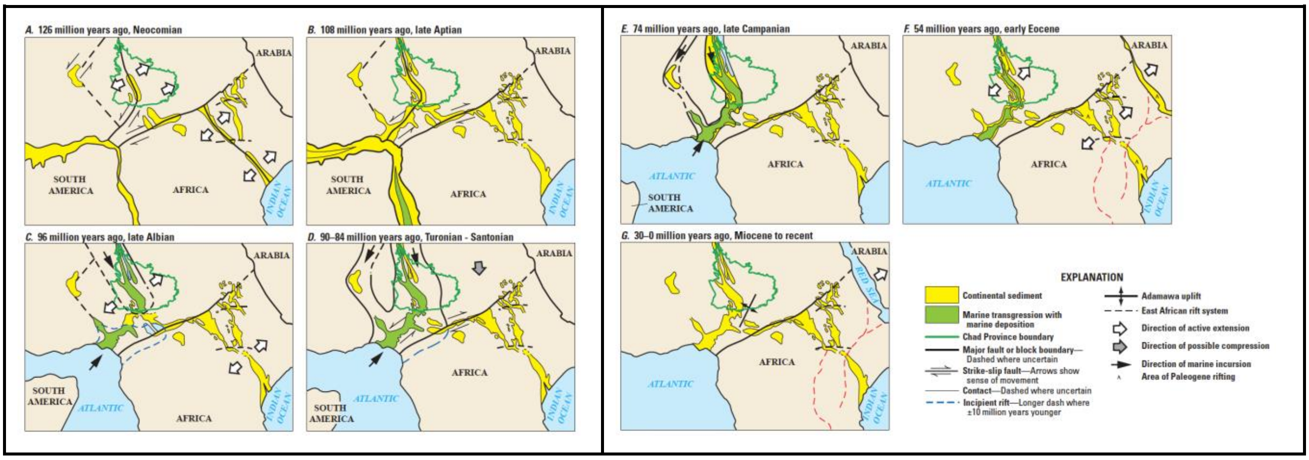


Figure 3. Paleotectonic maps showing the evolution of west and central African rifts. Approximate location of the Chad Basin Province outline in green. (Source: Genik, 1993).

Compared to the Cretaceous Rift Basins, which can be described as narrow and deep, the Lake Chad Basin is best described as wide and shallow. To explain the distinctive form of the LCB, Burke (1976) postulated that it originated in response to peripheral uplifts, with strong association with shield forming volcanic activity, that began to develop 25 m.y. ago. The result is that the LCB has the shape of an annular pediment, averaging about 500 km wide, held up by eleven discrete uplifts (up to 3,000 mASL) forming a crude ellipse 1000 km × 1500 km across with modern day Lake Chad in the middle.

The LCB spans four of the five major bioclimatic zones of West Africa, namely the Saharan, Sahelian, Sudanian, Guinean zones. The distribution of rainfall in the basin is related to the migration of the InterTropical Front (ITF) or InterTropical Convergence Zone (ITCZ) which creates the cycle of a short wet period (3 to 4 months) and a longer dry period (8 to 9 months). Rains first occur to the south of the front, then progress northwards. Consequently rainfall varies greatly, ranging from less than 50 mm in the north of the basin, and rising to 1,200 millimetres in the south.

At the centre of the LCB, with standing water level 286 mASL, is Lake Chad, which is situated between 12°20' and 14°20' latitude North; 13° and 15°20' longitude East. Lake Chad occupies a shallow freshwater lake. Lake

[2] a drainage basin that does not flow to other external water bodies such as rivers or oceans.

water levels vary annually by 1 to 2 metres. The salinity of the lake water is characterised by a strong S-to-N conductivity gradient (50 to 700 µS cm^{-1}; Bouchez *et al*., 2016). The size of Lake Chad has varied greatly during both relatively recent geological history as well as 20th Century history.

The currently visible lake is very small compared to earlier generations of the lake. For example, during the Holocene, from 11,000 until 2,300 years ago, a giant version of the Lake (the so-called Mega Lake Chad) covered an area of more than 350,000 km^2. Data from the Shuttle Radar Topography Mission (SRTM) reveals the former shorelines of Mega Lake Chad reached an elevation of between 320 to 330 mASL. At full capacity the Mega Lake Chad drained to the Atlantic Ocean via the Benue River.

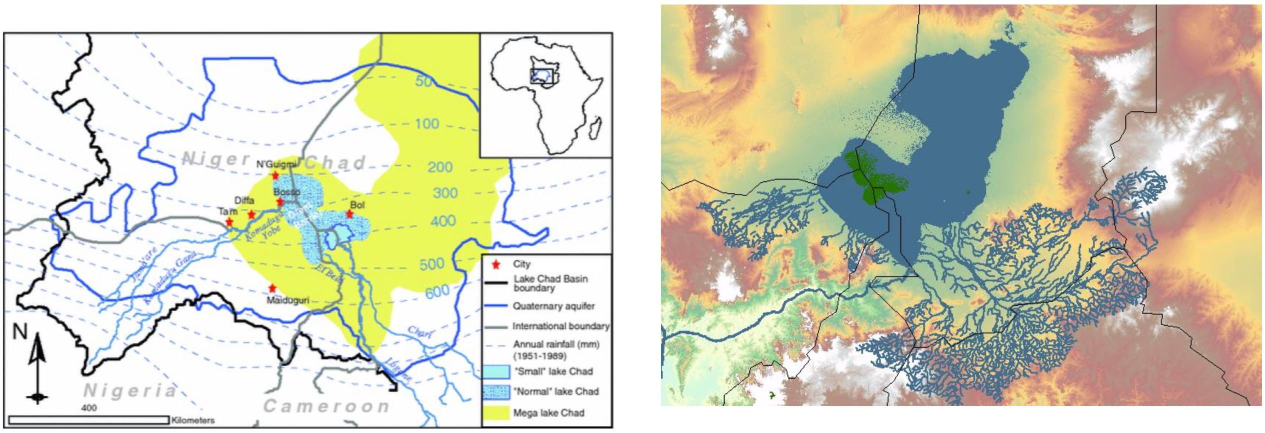


Figure 4: (L) Annual average rainfall (mm) for central to south western Chad Basin (source: Luxereau et al., 2012); (R) Terrain and drainage map showing the major tributaries of Lake Chad (Green) and the Holocene Age Mega Lake Chad.

By the middle of the 20th Century, Lake Chad had retracted to just 25,000 km^2, but at that time was still the world's sixth largest inland water body (by area). Since the 1960's, the Lake's water surface area has reduced dramatically. Today it is only 2000 km^2, up from a historical minimum of 300 km^2 recorded in 1980's (Gao et al. 2011) due in large part to the major drought that occurred over the Sahelian zone during the 1970's (Lemoalle et al. 2012). Since then, the Lake has been split into the northern (small) and southern (big) lakes.

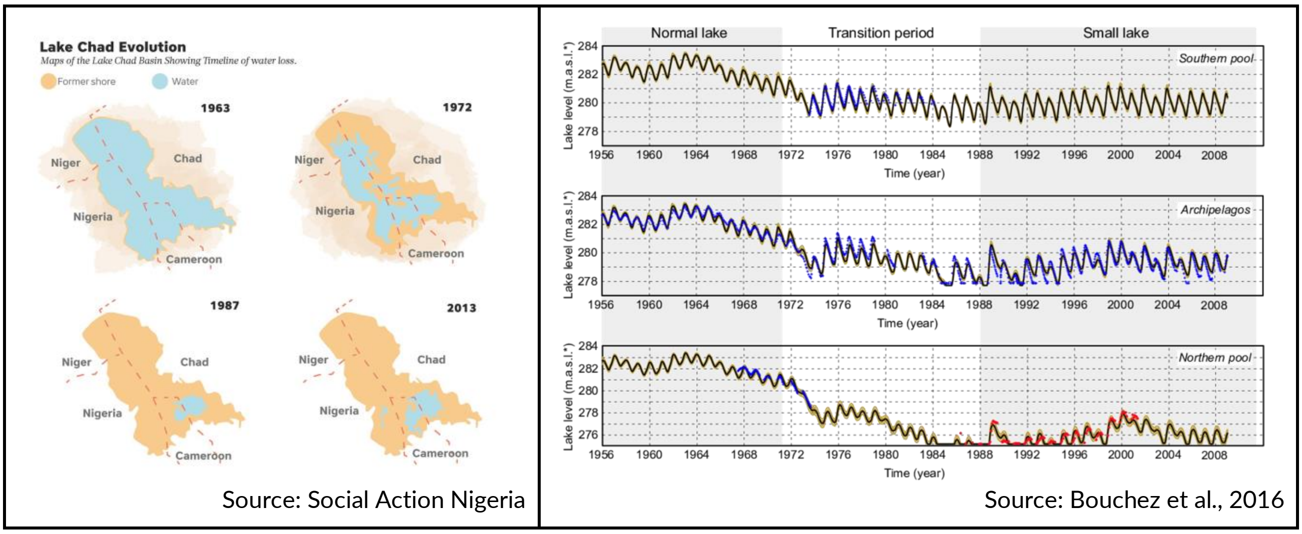


Figure 5: Map view (L) and Standing Water Level Time Series view (R) illustrating changes in Lake Chad Volume during the 2nd half of the 20th Century to Recent.

The main surface water catchments that are the primary source of inflows to the modern day Lake Chad and also the geologically recent Mega Lake Chad are the Chari Lagone and Komadougou-Yobe Basins. An estimated 90 percent of inflows to the lake come from the Chari–Logone river system, which drains a ~ 600,000 km^2 watershed spanning much of Northern Central African Republic (CAR), Southern Chad, and small pockets of Northern Cameroon and Eastern Sudan. Most of the remaining part of the Lake's surface water balance comes via the 148,000 km^2 Komadougou-Yobe river basin, though in recent decades the contribution from this river has almost entirely dried up.

The Komadougou-Yobe River tributaries include the Hadejia River, the Jama'are River and the Komadougou-Gana River. The Komadougou-Yobe basin generates an estimated 7 km^3/annum, the bulk of which is retained in the reservoirs of Kano State, the largest at present being the Tiga Dam, to be used downstream in various irrigation areas. The UNEP-FAO (2011) reported that only 0.45 km^3/annum (or 6.5 per cent) of all runoff generated within the Komadougou-Yobe sub-basin enters Lake Chad. With plans being discussed for the Kafin Zaki Dam in Bauchi State, there is every likelihood that inflows to the North Basin from Nigeria will continue to decrease.

Between the cities of Maiduguri and Bama, located in Borno State of Nigeria, there are several smaller seasonal rivers, including the Yedseram, the Ngadda and the Gubbio, which feed numerous small lakes and wetlands, before fingering out across the former bed of Lake Chad. For the most part these small rivers between Bama and Maiduguri do not contribute to the surface water balance of Lake Chad. The Ngadda River is a particularly important surface water source within Borno State because it flows through the key city of Maiduguri, for which it is a major source of water supply (both directly via storage in the Alau Dam and recharge to local aquifer beneath the city). Based on detailed investigations in and around Maiduguri (e.g. Barber, 1962; Beacon Services Ltd, 1979), the significant contribution of the Ngadda river to water table recharge has been demonstrated conclusively.

As well as providing essential flows into different lakes and wetlands, the various tributaries mentioned above recharge a vast network of variably connected shallow water table aquifers contained within the complex assemblage of Quaternary Age (2.6 Ma to Present Day) shoreline sand barriers, riverine alluvial channel, floodplain and deltaic deposits and assorted lacustrine sediments. Lake Chad is also a source of concentrated recharge to these shallow aquifers. Isiorho *et al*. 1996 estimated that in the case of Borno State, 21% of the annual water input to Lake Chad is lost as leakage to the water table.

Away from the Lake and various permanent water courses, groundwater recharge to Upper Chad Formation is via diffuse rainfall infiltration. Based mostly on the chloride mass balance method, the rate of diffuse rainfall recharge rate for the Upper Chad Formation in Borno and Yobe States have been estimated at between 14 mm/yr and 60 mm/yr (Carter *et al*., 1994; Edmunds *et al*., 1999; Edmunds *et al*., 2002; Goni *et al*., 2005).

In the case of Borno State, an additional source of recharge to the Quaternary Age Upper Chad Formation water table aquifers is from leaking and / or free-flowing wells screened in the Artesian Middle Chad Formation aquifer. The transfer of water from the Middle Chad to the Upper Chad was probably at a peak in the 1960's when the confining groundwater pressures, and rates of discharge, were highest. Since, recharge to the Upper Chad Formation has presumably declined. To what extent groundwater is able to flow from the Middle Chad to the Upper Chad via the gravel pack used around the annulus of most drill wells constructed in Borno State has not been studied to date.

In Borno State, the Upper Chad Formation is quite heterogeneous and is a mixture of unconfined, semi-confined and confined aquifer systems. Generally the thickness of the Upper Chad Formation is between 30 and 70 metres. However in some locations, the depth to the top of the Pliocene lacustrine clay deposit can be as much as 200 metres. The area where the depth to the top of the is greatest is at the point of intersection between the Bama Ridge Fault and the Cretaceous Age Bornu Sedimentary Basin, suggestive of the geologically recent effects of basin subsidence controlled by block faults.

Aquifers in the sand alluvium of the broad riverine flats (fadama) are locally important. They can be several kilometres wide and mostly over ten metres thick, sometimes much thicker, and are composed mostly of coarse unconsolidated sands. Annual recharge is from rivers flowing seasonally. In Borno and Yobe States, the most intensively used Fadama is the Komadougou Yobe valley aquifer. According to Goes and Zabudum 1998, groundwater studies in the region show that the water levels in the alluvial aquifer of the Komadougou Yobe river floodplains range from 1 m to 3 m. Historically, water levels in this aquifer showed seasonal trends but no long-term decline or increase in groundwater level. Example hydrographs in Annex 2 are: 8075; 8076; 8077; 8078. The Komadougou-Yobe river alluvium depends on concentrated recharge from wet season river flows. However, due to the problem of increased surface water diversions for upstream irrigation, flows along the lower Komadougou-Yobe river continue to decline. This could contribute to declines in groundwater levels and quality of these important Fadama aquifers, making it a priority for future groundwater monitoring by AAH.

Figure 6: Alluvial floodplain deposits associated with the contemporary Bama Ridge Sand Barrier. Also shown shaded in blue tones are the Middle Chad high yield artesian aquifer (a1) and moderate yield artesian (b1) and moderate yield sub-artesian (b2) aquifers. The Middle Chad trends parallel the modern shoreline and tributary trends.

A detailed surface geological map for a large part of the LCB in the vicinity of Lake Chad was published in 1973 by the Lake Chad Basin Commission with financial and technical assistance from UNESCO and FAO. A copy has been uploaded to the Project GIS. Detailed geological logs of these Quaternary formations, prepared by the UGSS-GSN Team, are also available in the Project GIS. In Annex 2 to this report, there are hydrographs for 81 hand dug wells that were monitored monthly during the period 1963 to 1968 and reported previously in Carmalt & TIbbitts (1969).

UNESCO published the results of a hydrogeological study of Lake Chad Basin in 1973. A survey covering close to 1,000 individual water points, many of them traditional hand dug wells, the UNESCO survey provides the best state-wide baseline of the water table levels for Borno State just after the onset of large scale development of the Middle Chad Formation artesian aquifer system that happened during the 1960's. The depth to water table ranges from 5 metres to as much as 75 metres below natural surface (mBNS) depending on location. Unfortunately since the beginning of the 1970's there has been no systematic monitoring of the phreatic aquifer water levels covering all of Borno State.

The Quaternary Formation water table aquifers rest upon extensive lacustrine sediments deposited during the Pliocene (2.4 to 6.3 Ma). With a maximum thickness of over 260 metres directly beneath modern day Lake Chad, this formation is composed of interbedded sandy claystone, argillaceous diatomite, diatomite, pelite and argillaceous sandstone with structures ranging from massive to finely laminated (Moussa *et al*., 2016). These sediments were deposited in a lacustrine setting similar to today's Lake Chad (Sylvestre *et al*., 2020). The Pliocene Age lacustrine formation, separating the Quaternary Upper Chad Formation water table aquifer from the Miocene Middle Chad Formation pressurised aquifer, becomes thinner towards the margins of the basin.

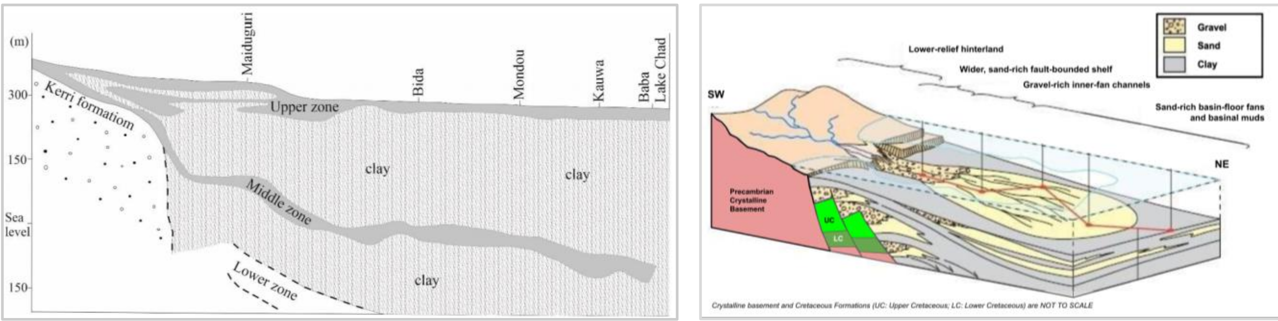


Figure 7: (L) Cross-section of the aquifers in Borno State north eastern Nigeria from the north of Bama to Lake Chad (after Miller, 1968 and Offodile, 2002) (source: CIWA, 2020); Schematic representation of Borno state Lower Neogene depositional environments for the Continental Terminal Formation (or Lower Zones). Not strong block fault controls.

Based on detailed geological logs published by Barber (1965), the Pliocene Age lacustrine clay can contain clean sand and gravel zones, typical of alluvial channel deposits. These are most common towards the margins of the basin. They do not constitute viable aquifers, rather they are evidence of changes in the size of the lake.

Further detailed study of the paleo stratigraphy of the Pliocene Age lacustrine formation, with a focus on these channel deposits, using the Borno State historical records could aid research into paleo climate reconstructions for this region complimentary with the CHADRILL Consortium research project.

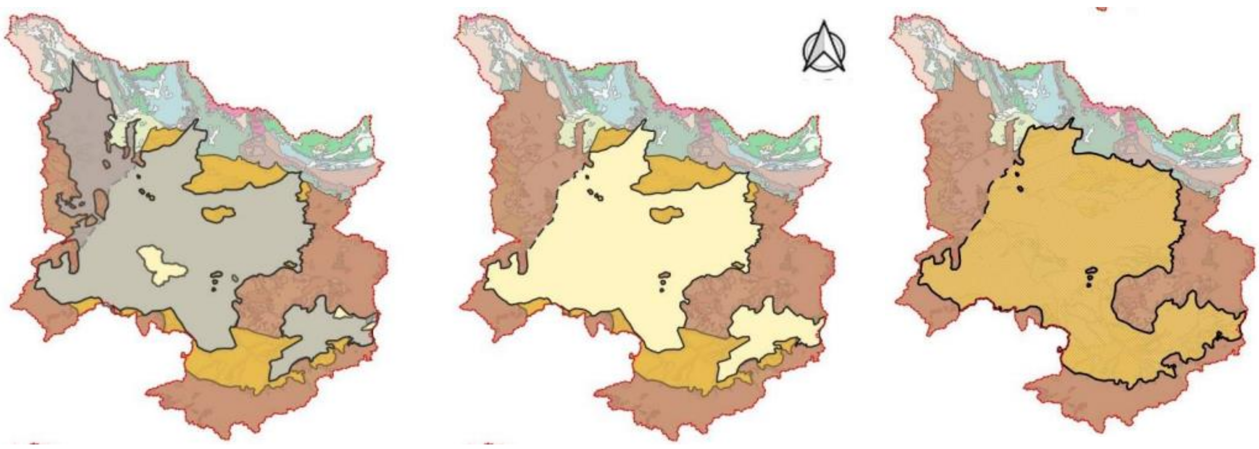


Figure 8: Spatial extent of major geological formations represented in CIWA 2020 numerical groundwater model for the Lake Chad Basin. Gray: Quaternary; pale yellow: Upper Pliocene Clay; orange: CT ± Middle Chad Formation; brown: Bedrock (including Cretaceous Basins & Pre Cambrian Basement).

One of the major limits of deposition of the Pliocene Age lacustrine formation was possibly the Bama Ridge Fault. This major fault line that extends from the Geidam (Yobe State, Nigeria) to Bongor (Mayo-Kebbi Est Region, Chad) is of great hydrological significance with the LCB. It has clear structural controls on the shape of some of the deepest and oldest basin structures, namely the Cretaceous Age Bornu Basin. It defines the extent of the Holocene Age Mega Lake Chad, evidenced by the accumulation of shoreline barrier deposits from Bama to Geidam and its control on the position of the Mega Lake Chad spillway outlet near Bongor. It also strongly determines the western extent of artesian groundwater conditions in the Middle Chad Formation beneath Borno State.

Another effect of fault block escarpment features like the Bama Ridge is that they can act as shoreline traps for accumulation of coarse grained sands and gravels, resulting in features like the modern day Bama Ridge sand barrier. Such fault controlled shoreline sand barriers then act as barriers that restrict the flow of streams during high flow flood events, thus promoting sediment accumulation as back barrier alluvial floodplains on the landward side of the barrier. One such modern example is the Goya Kyauwa Stream Alluvium situated south east of Maiduguri MMC.

Directly beneath the Pliocene lacustrine deposits, there exists a very important aquifer system of Upper Miocene Age known as the Middle Chad Formation. It has been the objective of the most comprehensive scientific groundwater survey and research activities of perhaps any aquifer in the LCB. It is perhaps also the aquifer in the LCB that has been the most intensively exploited to date.

The Middle Chad Formation is a well sorted sand-rich layer 1 to 70 metres thick (Miller et al., 1968) with an estimated surface area in excess of 50,000 km^2. Based on the results of extensive drilling, the top of the Middle Chad Formation aquifer ranges from 260 to 365 metres below natural surface (mBNS). Yields of boreholes tapping this aquifer range from 5 to 10 l/sec (Yusuf, 2015). Based upon the original USGS-GSN investigations (Barber, 1965; Miller *et al*., 1968) the spatial variability in yield of Middle Chad was inferred and used to create a zonation map (see Figure 9). When the Middle Chad Formation resource was first developed, the limit of artesian free flowing wells screened approximated the Bama Ridge sand barrier.

Geological Survey of Nigeria Bulletin No. 35 "*Pressure Water in the Chad Formation of Bornu and Dikwa Emirates, North-Eastern Nigeria*" (Barber, 1965) provides a pre-development baseline of groundwater levels in the Middle Chad Formation. Based on a comparison of SWL measurements taken during the period 2007 to 2012 (Yusef, 2014; Adamu et al., 2013) and the original baseline SWL, it is clear that the rate of consumption of groundwater from the Middle Chad Formation has been in excess of the rate of recharge since the resource was first opened to intensive development. Annex 1 plots the Barber (1965) and Adamu et al (2013) data as a series of 2nd order polynomial drawdown curves.

Based on a GIS analysis of different parameters (EC, Temp, pH, SAR, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, HCO_3^{-}, Cl^{-}, F^{-}, Fe_{tot}, Mn^{2+}, PO_4^{3-}, Si) it is apparent that there is a good level of zonation within the Middle Chad Formation.

There is debate as to whether the Middle Chad Formation aquifer continues to receive modern recharge or whether it is 100% paleo water. Based on the sustained drawdown of a number of hand dug wells along the Bama Ridge, which were monitored during the period (1963 to 1968), this is possibly consistent with a hydraulic connection between the Middle Chad Formation and the Upper Chad Formation in the area of the Ngadda River.

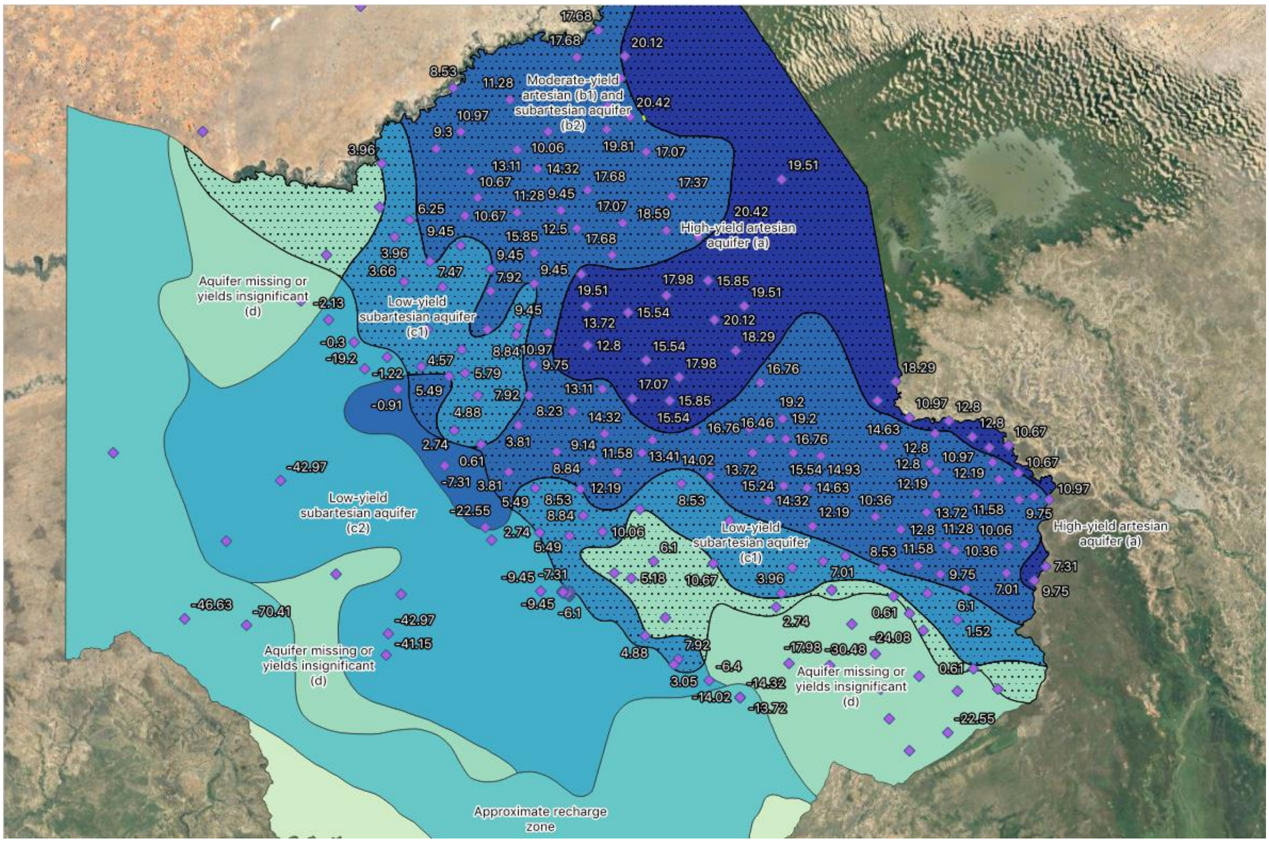


Figure 9: Zonification of the Middle Chad Formation (source: Miller et al., 1968) and Baseline Middle Chad Formation Standing Water Levels - mRNS (source: Barber, 1965)

The other key line of evidence for modern recharge to the Middle Chad Formation comes again from this earlier monthly monitoring period, which detected annual recharge pulses even as groundwater levels declined (see observation well hydrographs: 9249; 9205; 9250; 9252; 9251; 9220; 8058; 9206; 9219; 9207; 8082; 8086). These Middle Chad Formation bores with a strongly discernible recharge pulse are mostly west of the Bama Ridge in the Damaturu-Gaidam-Magumeri Triangle. Even in the middle of basin at Sabasawa (see observation well hydrographs: 8091, 8092, 8093) an annual uptick in SWL counter to the long term sustained downward trend, consistent with recharge, is evident.

The initial concept of the early investigators that the Middle Chad Formation contains only fossil groundwater has likely contributed to a bias that assumes if the Middle Chad Formation is fossil then the deep formations must also be fossil. We do not concur with such an inference. Rather, we find that based on geological and geophysical data gathered as part of petroleum exploration activities, which have been targeting the Bornu Basin of Nigeria, it is reasonable to infer that the original development of deep groundwater by the USGS-GSN during the 1960's, which was then mostly reproduced by subsequent water bore drillers for the next 50 years, largely ignored the larger system of deeper aquifers, some of which have excellent potential to receive modern recharge.

There are several deeper aquifer systems of potentially strategic importance to meeting the ever increasing water demands across the LCB. These include the Neogene Continental Terminal Formation (also referred to as the Lower Chad Formation in Nigeria), the Upper Creacteous to Lower Cenozoic Gombe Sandstone, and the Lower Cretaceous Bima Sandstone. The other Cretaceous Formations do not generally form good aquifers and the limited groundwater which they do contain is often highly mineralised. Because of the sustained influence of deep seated tectonic rift structures on the basin landscape evolution and depositional patterns over time, the greatest potential for discovery of major aquifers within the CTF, Gombe or Bima formations is anticipated to mirror the underlying shape of the rift basins that were initiated as far back as 126 million years ago.

Borno State has been the subject of quite intensive study by the petroleum sector. The interest of the petroleum sector in Borno State has been directed at the Cretaceous Age Bornu Basin, which is coincidentally directly beneath the highest yielding zones within the Middle Chad Formation. Thanks to investigations of the petroleum sector, it is now much clearer that the original USGS-GSN survey only scratched the surface of the full groundwater development potential of the Chad Basin. Based on petroleum sector research findings, there are favourable aquifer targets, which are still technically achievable and economically justifiable, down to as much as 1200 metres (e.g. at North Ngor). Another example is sand rich deposits nearly 100 metres thick occur in the depth range of 800 to 950 metres below natural surface, east and north of Kukawa township. By comparison, the maximum drill depth achieved on the original 218 hole USGS-GSN survey was 427 metres.

The preponderance of favourable aquifer formations with the interior of the LCB, especially in so much of Borno State, can be attributed to the enormous contribution of quartz and feldspar rich sands and gravels delivered into the basin by rivers draining the Precambrian crystalline basement areas of Northern Nigerian and Cameroon. By virtue of its location at the intersection between several converging rift basin structures, the combined effects of preferential subsidence has meant that beneath much of Borno State (and in turn beneath the shores of Lake Chad itself) there are great thicknesses of both the Upper Cretaceous Gombe Sandstone and the unconformably overlying Continental Terminal Formation. Both formations were deposited under continental (meaning freshwater) conditions.

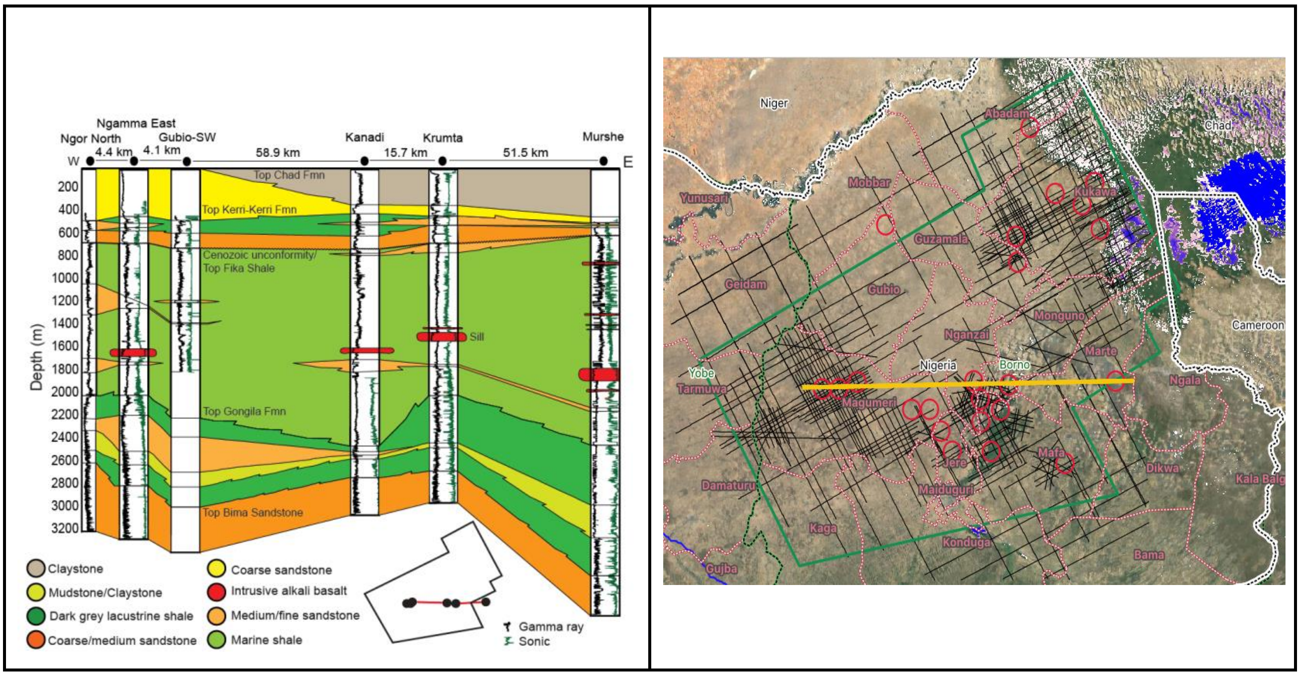


Figure 10: (L) Stratigraphic cross section based on petroleum sector wireline geophysical logs; (R) Location of cross section, petroleum wells (O) and seismic lines.

Lower Chad Formation (or Continental Terminal Formation)

The Lower Chad Formation first described during groundwater drilling programs in Borno State is assumed to be the equivalent of the Kerri-Kerri Formation, which is outcropping around Potiskum in Yobe State. Outside of Nigeria, the Lower Chad Formation beneath Borno State is the **Continental Terminal Formation** of the Chad Basin.

At present time, the groundwater development potential of the Continental Terminal Formation (or Lower Chad) beneath Borno State has not been very well characterised by researchers and investigators. In the case of Borno State, this has been due to the fact that the Middle Chad Formation proved to be so productive for many years, there was not the incentive to drill, explore and characterise the deeper formations of the Chad Basin.

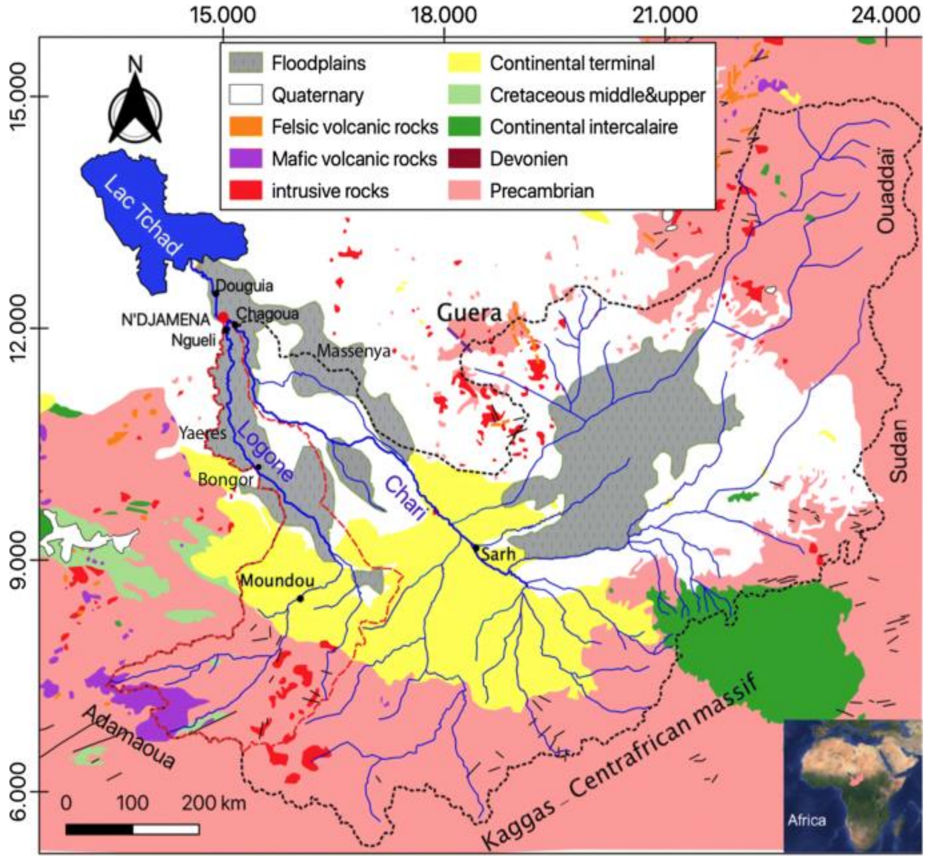


Figure 11: Simplified surface geology of the Chari Lagone River Basin (Source: Mahamat Nour et al., 2020)

The Lower Zone aquifer has been quite intensively investigated within the Maiduguri area as part of urban water supply projects, dating back to the end of the 1950's. The first water bores constructed in the Lower Zone aquifer beneath Maiduguri had a SWL of about 5 to 7 mBNS. The quality of the Lower Chad Formation Aquifer is generally very good. The electrical conductivity of the groundwater is generally less than 800 µS/cm. The freshest groundwater in the Lower Chad Formation Aquifer occurs beneath Maiduguri City, with a range between 270 and 340 µS/cm. In the vicinity of Baga Township on the shores of Lake Chad, the Lower Chad Formation EC is between 1,000 and 1,500 µS/cm. The clay layer separating the Lower Chad and Middle Chad Formation can be as much as 100 metres thick and in other places it is completely absent.

Gombe Sandstone

According to Yangoin and Obajem (2004) the Gombe Sandstone is the topmost unit of the Cretaceous sediments in the Bornu Basin. It is underlain by the marine Fika Shale Formation and overlain by the Tertiary Kerri Kerri Formation (also known as the Continental Terminal Formation or Lower Chad). The Gombe Sandstone consists of mud stones, ironstones, siltstones, shales, and stones and clays along with sandstones. Based on the paleoenvironmental diagnostic characteristics, the lithofacies, sedimentary structure, ichnofossils and petrology, estuarine and deltaic depositional environments have been recognized. Fluvial (distributary channel) and paralic (interdistributary channel) environments have also been identified. The distributary channel sandstone facies are presumed to constitute the most prospective aquifer of the Gombe Sandstones.

The lowstand systems tract in the Gombe Sandstone may be associated with much better reservoir quality than the Kerri –Kerri Formation highstand systems tract. This is due to presence of hematite and clay cements which was reported by Odedede (2002) in the reddish cross–bedded quartz arenite of the Kerri–Kerri Formation around Biri fulani. These cements have great effects on permeability and other properties of the rock and may seriously reduce its reservoir potential.

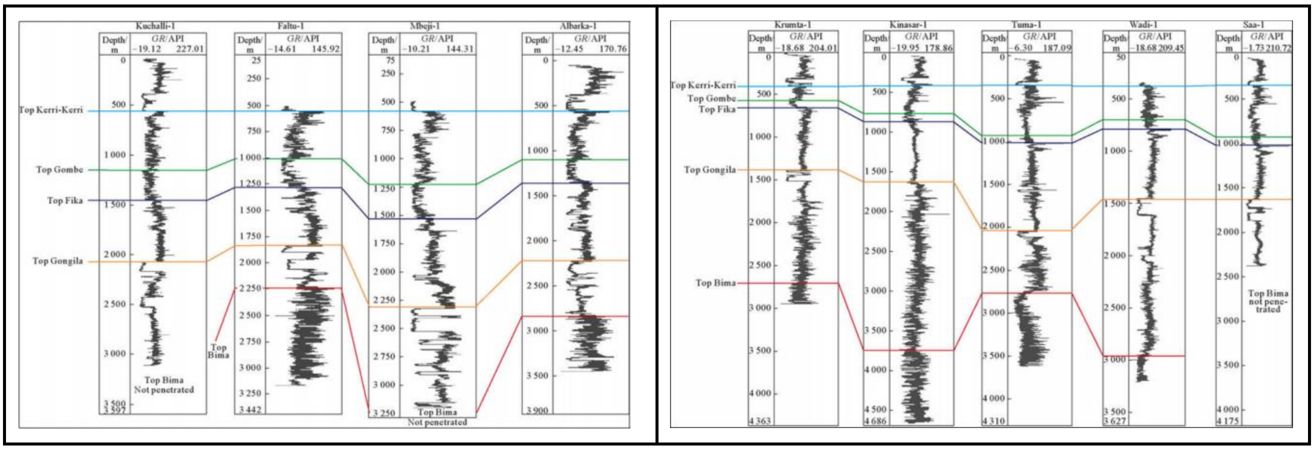


Figure 12: Downhole logs showing formation depths

Bima Sandstone

Least well understood is the potential recharge to the deepest systems associated with the fractured Lower Cretaceous Bima Sandstone. The first tectonic and sedimentary stage (Burke et al. 1971, Freeth 1978) corresponds to the deposition of the alluvial Bima Sandstone, infilling the whole area of the northeastern Benue-Gongola Troughs from the late Aptian to the late Albian (Allix & Popoff 1983). The Bima Sandstone rest unconformably over highly dissected and block faulted PreCambrian Crystalline Basement horst and graben blocks are exposed around the edge of the basin, often in areas with higher rainfall and /or cross cut by perennial streams and rivers (e.g. Gongola River Basin). This makes them potentially very important concentrated mountain block recharge zones for Fractured Bedrock Basin aquifer systems (also known as Megawatersheds). Such aquifers are largely unaccounted for in the existing water balance of the Lake Chad Basin, and consequently are not factored into water resource management plans for the basin.

Need for an Oil to Groundwater Approach

The geophysical and geological logs from petroleum exploration wells drilled in Borno State highlight the very significant spatial variability in the presence of geological formations with the potential to be prolific aquifers. The depositional environment of the Kerri Formation resulted in the accumulation of a combination of channel fill sandstones and interfluve areas. The channel fill sandstone deposits include coarse grained cross bedded quartz arenites. An increase in sandstone content and coarseness of sand grains at the lower part of the Kerri Kerri Formation has been observed (Odedede and Adaikpoh, 2011).

Similar characteristic signals in the gamma ray data appear in other oil exploration wells drilled in Borno State, but not all. This may indicate that the most favourable deep groundwater exploration targets of the Chad Basin will be discrete channel deposits (or channel fill sandstones). Such channel deposits may be associated with the major paleo tributaries of the Eco Shabi River System that Griffith that others postulate flowed north from the modern day Chad Basin through Libya to the Mediterranean Sea. These ancient tributaries are likely to be originating (i) to the south east of Modern Lake Chad in following the NW-SE trend of the Chari Lagone catchment main tributary, and (ii) to the south west of Modern Lake Chad.

At present there is not enough data available to confidently trace the path of these deep (Lower Tertiary to Upper Cretaceous) channel deposits to successfully reduce the exploration risk for this potentially very important class of aquifer within the Chad Basin of Nigeria. However, there is sufficient information from existing petroleum exploration to select a number of sites to prioritise for deep drilling and groundwater testing and long term secure monitoring. This is necessary to further understand the development potential of this groundwater resource ahead of making any plans for investment in its longer term development. More work can be done to map the deep leads of the lower most Tertiary and upper Cretaceous through targeting re-processing, imaging, interpretation and modelling of oil and gas data held by the Nigerian National Petroleum Corporation.

GROUNDWATER MANAGEMENT ISSUES

Water Levels

Regional Declines in Middle Chad Formation Groundwater Levels

Groundwater pressures in the Miocene Age Middle Chad Formation aquifer have been in decline for the better part of the last 60 years. Based on a comparison of Middle Chad Formation groundwater level measurements taken by the USGS-GSN investigators during the 1950's and 60's (Barber, 1965) and the UNIMAID researchers between 2007 and 2012 (Adamu et al., 2013; Yusuf,, 2014) the average rate of decline is estimated at between 0.25 and 1.0 metre per annum. Composite 2-D polynomial drawdown curves, based on data from Adamu et al., 2013 and Barber, 1965 are plotted in Annex 1.

Localised Steep Declines in Middle Chad Formation Groundwater Levels

Based on groundwater level in 2007 and 2012 (Adamu et al., 2013) a number of instances of anomalously steep rates of decline (greater than 2 metres per year) were detected (see drawdown curves for bores: 9248; 9192; 3077; 9219). Although these anomalies were inferred based on only 2 measurements each, the overall size of the anomaly and the relatively geographical clustering of Middle Chad Formation bores that exhibit steep groundwater level declines, does give credence to the possibility that the system has reached some boundary condition (e.g. the contact with a major block fault NO-FLOW boundary or a bedrock defined basin margin).

Standing Water Level Declines in Upper Chad Formation Sub Zone "C"

The Upper aquifer is a phreatic aquifer separated by thin clay layer into "A" sub-zone with depth ranging from 1 to 10 m, "B" sub-zone with depth ranging from 10 to 60 m and "C" sub-zone with depth ranging from 60 to 100 m. From the study, it can be deduced that the C sub-zone is not recharging from seasonal infiltration of meteoric water or from the horizontal stream flow, it rather shows a depleting groundwater level. It was proved that rain of wet seasons do not recharge Upper C sub-zone to the previous wet season level, and thus the water table in the Upper C zones will be exhausted if the aquifer is not recharged at the present level of abstraction.

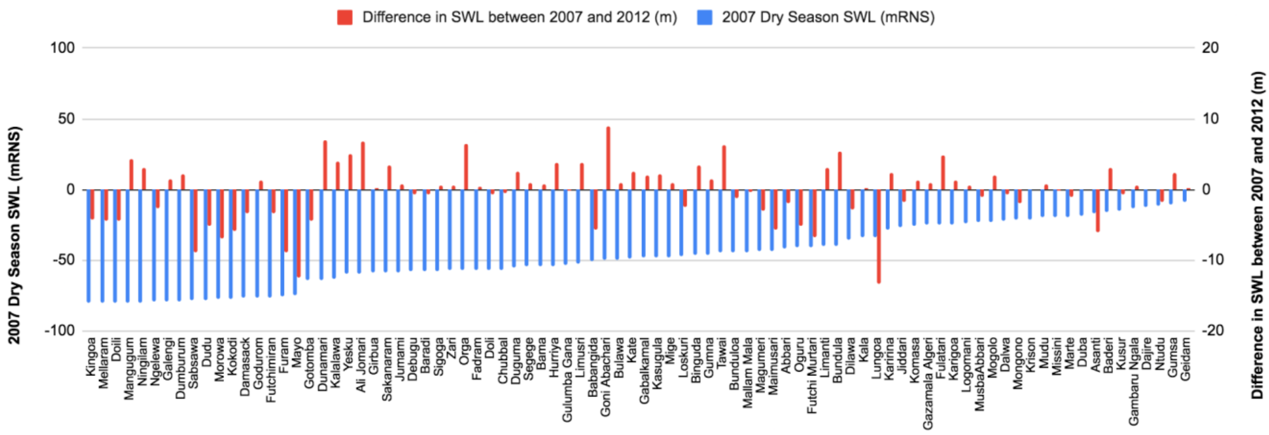


Figure 13: Changes in SWL by location

Local Declines in Upper Chad Formation Groundwater Levels

Less is known about the long term pattern of decline of the unconfined water table aquifer across Borno and Yobe States. As part of the USGS-GSN water level monitoring programme carried out between 1963 and 1968, 81 village water supply hand dug wells were manually measured monthly. The results of that monitoring, which were contained in Carmalt & Tibbitts (1969), have been converted to standing water level hydrographs presented in Annex 2.

Standing water level monitoring of the upper zone (less than 70 mBNS) aquifer was carried out at a number of sites across Maiduguri City starting around 1981 and ending in 1995. The longest record is about 10 years, during which time the water table levels fell at an average rate of 0.8 to 1.0 per year. The groundwater level changes measured in and around Maiduguri between 1981 and 1995 followed different patterns. Some of the wells were more resilient and did not show any sustained decline, although in a number of cases the duration of monitoring was not sufficient to be conclusive.

Water Quality

To better understand water quality characteristics of the Middle Chad Formation, the authors compiled available field and laboratory chemical analysis data from a number of major sources including Barber (1965), Kolomi (2014), Bura et al., 2018, and unpublished data from a cooperation between UNIMAID and the British Geological Survey. Whilst it is a good start, it represents only a fraction of the water points that exist. Considering the number of water points that have either been constructed or rehabilitated by the INGO WASH Cluster members since the crisis began, it is quite surprising that so little data on water quality has actually been generated and archived to date. The hope and expectation is that the data set for groundwater quality will be further enriched once all remaining data is assembled from the large records held by the members of the WASH Cluster including the RuWASSA. To explore the water quality data currently available, the reader is welcome to request a copy of the QGIS Project.

Elevated Electrical Conductivity

Apart from the known issue of salinity especially in areas associated with former marine sediments (e.g. Fika Shale), there is an area of higher salinity (EC > 3,000 uS/cm) shallow groundwater centered on south-west Kukawa, south Guzamala and east Nganzai. The zone of blue coloured wells (EC < 500 µS/cm) centered on parts of Magumeri, southern Gubio, northern Nganzai, southern Guzamala, southern Kukawa and central Monguno LGAs has water of a quality likely highly suitable for groundwater irrigation development. Drilled wells screened in the zone of the Middle Chad Formation with the lowest EC also have amongst the highest yield (or artesian flow rates). The same zone is situated above the main depocentre of the Cretaceous Age Bornu sedimentary basin. The quality of groundwater in the Middle Chad Formation above the main depocentre of the Bornu Basin varies laterally, becoming slightly more saline from west to east. There is a marked change in quality that mirrors the inferred position of the northern extension of the Benue Axial Ridge that trends NS through the Bornu Basin. Unfortunately the soils above the zone with the best quality (lowest EC) water within the Middle Chad Formation tend to be sandy of low fertility.

Elevated Nitrate

In the North East, there are serious problems with groundwater pollution. Perhaps nowhere is groundwater than in the older sections of the state capital Maiduguri where many hundreds of thousands are dependent on groundwater sources that are contaminated by uncontrolled sewerage waste streams. Maiduguri city is built on shoreline sand barrier deposits of former Mega Lake Chad. Due to the porous soils, and the susceptibility to flooding, human waste streams percolate down to the water table, contaminating the source of drinking water for many residents (Goni et al., 2019). In a study of nitrate levels in the shallow aquifers beneath Maiduguri (Goni et al., 2019) the nitrate concentration in groundwater was found to range between 1 and 700 mg/L. 37 percent of the 128 samples had nitrate concentrations above the WHO limit of 50 mg/L. Depth of each of the boreholes could not be obtained, but they all fall within the Upper aquifer system of the Chad Formation and between the depths of 45 – 70 m as the limit of the manual drilling method.

Elevated Thallium

There are high rates of occurrence of kidney diseases in Yobe State (Sulaiman et al., 2019) of unknown origin. Hydrogeologists from the Yobe RuWASSA provided anecdotal evidence of an association between areas with high rates of kidney disease in northern Yobe State (e.g around Gashua) and the presence of shallow potash geological formations intersected during water bore drilling. As an evaporite deposit, potash can accumulate a number of chemical ions that can be toxic to human health (e.g. Thallium).

Elevated Sulphate

Sulfate gives a bitter or medicinal taste to water if it exceeds a concentration of 250 mg/l. This may make it unpleasant to drink the water. In the northern part of Borno State (northern Naganzai, eastern Mobbar, north eastern Gubio, south west Abadam, north west Kukawa LGAs) there is a zone where the Middle Chad Formation artesian aquifer groundwater has SO_4^{2-} concentrations above this recommended 'aesthetic' exceedance level. This same zone is also characterised by relatively high calcium (Ca^{2+}) concentrations. The zone is also situated north of the Gubio Basin and the Benue Axial Ridge in an area of relatively shallow crystalline basement. The shallow magnetic feature has a polygonal outline, which may indicate an uplifted horst fault block. If this zone was relatively elevated, then it may have been more likely to support shallow water environments with greater potential to accumulate evaporite minerals like gypsum ($CaSO_4 \cdot 2H_2O$). This would potentially explain the anomalously high sulfate and calcium concentrations in this area.

Elevated Temperature

Elevated temperature is a characteristic of the artesian groundwaters in Borno State. The groundwater temperature tends to increase with depth. Whilst temperature is not a direct hazard to human health, high groundwater temperature has driven the practice of cooling water by letting artesian bores discharge into large wetlands and ponds used for livestock watering. This has contributed to high rates of non-economic water losses and increased rate of decline of groundwater pressures over the last 50 years. The temperature of the Middle Chad Formation groundwater along a zone beneath and immediately to the north of Komadugu-Yobe River seems to be higher than the regional average. In terms of maximum groundwater temperatures, the deeper aquifers beneath the northern wards of Maiduguri city are the highest at around 49 to 50°C. Elevated temperatures can result in higher concentrations of certain ions in the water, which increases the risk that the groundwater could be hazardous to human health.

Elevated Fluoride

Elevated fluoride is found in various locations across the state, including sites in Maiduguri, Gubio and Dikwa. Fluoride risk increases with depth of drilling and one potential source of fluoride is peralkaline volcanism. Nearly 25 per cent of water bores constructed in the Lower Chad (or Continental Terminal Formation) aquifers were found to contain Fluoride concentrations at levels above the WHO limit (Bura et al., 2018). The occurrence of dental fluorosis in schoolchildren and adults in North East Nigeria had been reported as far back as the 1950's (Wilson, 1954). Idon and Enabulele (2018) confirmed that dental fluorosis has a high prevalence among dental patients from the northeastern region, high enough that they recommend it should be seen as a condition of public health significance.

Driving factors

Uncapped Free Flowing Artesian Bores

The uncontrolled discharge of groundwater from artesian free flow wells from the 1950's up to today from the whole Middle Chad Formation has resulted in regional declines in groundwater levels. Those living on the edges of the basin are generally experiencing the most serious rates of groundwater level decline. Rates of decline as high as 0.8 to 1.0 m/yr over the period 1960 to 2012 have been observed in some locations (9279; 9109; 3042; 3077; 9219). Falling groundwater levels result in higher capital cost and / or higher operating costs of groundwater supplies and in a worst case scenario, particularly around the edge of the basin, it can result in village hand water wells going dry for part or all of the year (e.g .8086; 10002; 8035). There are signs from our analysis that in some areas there was also a significant transfer of water from the artesian system to the water table aquifer as a result of infiltration via earth ponds, canals and dams used for stock watering. This was particularly prevalent in the high yield artesian zone east of the Benue Axial Ridge.

Diversion of Flood Waters from Aquifer Recharge Zones

Floods and flood inundation play an important role in groundwater recharge. Due to competing demands for water supply, large surface water supply projects have been implemented that divert water away from the major natural recharge zones of the Middle Chad Formation. An inadvertent outcome of these projects is that significant diversions of flood waters away from key natural wetlands and floodplains has resulted in a reduction in groundwater recharge. From preliminary assessment conducted by the Consultant, an example of this is the threat to the Bama Ridge sand barrier aquifer by the diversion of Ngadda River into the Alau Dam, resulting in less recharge. This is in addition to other threats on the sand barrier from increased pumping (due to urban population growth and increased number of drilled wells in the urban and peri-urban areas of Maiduguri) and regional declines in Middle Chad Formation artesian groundwater pressures, which is locally hydraulically connected via the Bama Ridge Fault.

Urban Development

There is a global trend towards ever increasing levels of urbanization. The ongoing conflict centred on Borno state is resulting in phenomenally high rates of forced migration for rural and regional areas to the capital Maiduguri and the major towns. In 2006 the Borno State capital city of Maiduguri had an estimated population of 540,000. Today Maiduguri Metropolitan Council (MMC) has an estimated population of over 2 million, making it now home to more than 40 percent of the population of Borno state. This is resulting in increased pressure upon the water supply systems across the city, and the water resources upon which these systems depend. As a result the single biggest user of groundwater in Borno State today is the combined capital city of Maiduguri and there is locally intensive exploitation and over-draft of the Upper Chad water table aquifer across Maiduguri City. In addition there is locally intensive pollution of the Upper Chad Formation water table aquifer beneath Maiduguri City and other major urban centres. This is largely due to the lack of adequate environmental sanitation infrastructure and related services. Shallow groundwater beneath urban areas is more vulnerable to pollution from human activities than shallow groundwater in regional and remote areas. There are various risk factors that will determine the probability of shallow groundwater pollution in urban areas. These include: (a) depth to water table; (b) permeability of the unsaturated zone; (c) population density; (d) duration of settlement; (e) total rainfall, rainfall intensity and susceptibility to flood inundation; (f) design, operation & maintenance of toilets and wastewater management systems.

Well Integrity Issues

More than 30 petroleum exploration wells have been drilled in the artesian zone since the 1970's. As these exploration wells targeted the Cretaceous Age basins beneath the sediments of Cenozoic Age Chad Basin, the petroleum explorationists drilled through the artesian groundwater water systems of the Middle and Lower Chad (or Continental Terminal) Formation aquifers. It is worth noting that Nigeria's oil and gas industry does have a history of failure in respect of environmental compliance (Agbonifo, 2016; Chuks-Ezike, 2018) meaning that it cannot be ruled out that some of these oil and gas exploration wells may not have been correctly decommissioned. Bura et al., 2018 undertook one of the few surveys of groundwater salinity of the Upper Chad Formation. Although not spatially comprehensive, that survey confirmed the presence of a higher salinity zone between Gajiram and Baga. Whilst this may be a natural expression, it is also a possibility that it could be evidence of a contaminant plume associated with incorrectly decommissioned oil and gas exploration wells. If not decommissioned correctly, oil and gas exploration wells can create a legacy of enhanced vertical connectivity between the 'underlying' higher pressure artesian aquifer systems and the 'overlying' lower pressure water table aquifers. Further, sub-artesian drilled wells are commonly constructed without a bentonite seal in the annulus which means that water flows from the Middle Chad to the Upper Chad aquifer are not prevented.

Modernisation of Water Bore Drilling & Groundwater Pumping Systems

The humanitarian crisis has resulted in a major modernisation of the fleet of water bore drilling rigs in North East Nigeria, especially in Borno State. It has led to the successful introduction and widespread roll out of solar groundwater pumping technologies. The medium to long term risk to groundwater users, especially those living on the edge of the artesian basin, is that when peace is restored, and modern irrigation systems were to be developed, then it would only take 200 unlicensed private irrigation bores pumping at a rate of 50 ML per year (i.e. 5 hectare irrigated with 10 ML per annum) to reach an annual water withdrawal equal to approximately 10,000 megalitres (ML), which is about the rate of peak artesian free flow discharge that occurred during the 1960's. This example of private irrigation water supply for only 1000 hectares out of a total area of 3,000,000 hectares potentially available above the artesian basin in Borno State shows that while intensified groundwater developments will bring many important economic and social benefits, if future development is not accompanied by water resources management and monitoring activities, then it will likely exacerbate some of water users' current problems with the quality and quantity of the groundwater resources.

GROUNDWATER MONITORING STRATEGY

Background

The groundwater monitoring strategy is designed to address the key groundwater issues identified and will need to be updated to incorporate future areas of concern. It is essential that the North East Nigeria Groundwater Surveillance Project be planned and implemented in line with the current, as well as the emerging, legal policy frameworks, national programmes, guidelines, and institutional mandates relating to water resources issues in Nigeria.

Nigeria's federal parliament is working to establish a Water Resources Act to establish a national regulatory framework for the water resources sector. The objective of the proposed national regulatory framework is to provide for the equitable and sustainable development, management, use and conservation of Nigeria's surface water and groundwater resources.

The proposed functions and powers of the different water resources management organizations are described in detail in the Draft Bill. At the National Sector Wide level, the Bill states that the Minister shall, through the NIHSA, establish and maintain national monitoring systems on water resources and that individual States within the Federation have the power to independently legislate some aspects of water resources management.

The Draft Bill states that for each Hydrological Area of Nigeria, a Catchment Management Office (CMO) will be established. The CMO shall be part of the operational structure of a future National Water Commission (the Commission). The purpose of a Catchment Management Office shall be to implement the regulations and policies of the Commission in accordance with the National Water Bill at the Hydrological Basin Level.

The NIHSA along with other designated agencies will support the CMO to establish and maintain catchment level information systems (CIS) on water resources. These CIS shall provide for the collection of appropriate data and information necessary to assess, among other matters-

a. the quantity of water in the various water sources;
b. the status of groundwater aquifers;
c. the quality of water resources and state of the aquatic environment;
d. the use of water resources, including a register of water use authorizations for irrigation, municipal and industrial use and other uses;
e. the extent and quality of coverage of water supply and sanitation services; and
f. compliance with water resource quality objectives.

There is often overlap between the monitoring of the water resource, and its use, and the monitoring of the water supply service. The Federal Ministry of Water Resources Draft Water Bill (FMWR, 2016) clearly states that "extent and quality of coverage of water supply and sanitation services" should be a category included in the Catchment Information System (CIS) data model. Making groundwater monitoring an integral part of WASH service provision and making WASH functionality an integral part of water resources monitoring is a sound strategy to pool resources for mutual benefit.

It is worthy to note that the efforts to develop information systems are legislatively supported by Section 112 of the Draft Water Bill that establishes water sector institutions shall make water resources information, especially as it relates to mitigating and / or adapting to either natural or man-made disaster, available to the public.

The different LGA Councils, INGOs, consultant hydrogeologists and water bore drilling companies are holding valuable records of previously drilled water bores. It is imperative that these records are digitally archived into a geospatial database and made publicly available. The process has commenced with master's students from the University of Maiduguri and further involvement of NIHSA and other agency staff proficient in GIS systems is proposed to keep momentum on the further development and uptake of the project GIS, and also on future data integration and visualisation activities. Further, for the success of the GIS / Catchment Information System there needs to be a Data Standard developed and consistently promoted to all generators of data.

To get the desired geographical coverage (monitoring density) it is envisaged that a multi-prong approach should be implemented, combining a primary groundwater monitoring program, comprising the deployment of automatic groundwater data loggers and meteorological stations; manual monthly monitoring circuits undertaken by LGA Council staff; hydrogeological information and groundwater measurement reporting by water supply agencies (government, non-government and private sector) as part of their general activities; along with problem- or opportunity-oriented "*secondary networks*".

Groundwater Monitoring Information Systems

Underlying many of the failures in water bore drilling campaigns is the lack of well-organized hydrogeological information and groundwater measurement data accessible via carefully curated and well managed spatial information systems. The GIS developed in this Project is already reducing groundwater exploration and management risk due to the ease of analysis and interpretation that is now possible. The full details outlined in the Draft Bill are that the information systems should include -

- line charts (e.g. for Water level, Temperature and EC data from new data loggers),
- column charts (for Rainfall records),
- drilling and well construction details,
- geological logs,
- geophysical logs,
- piper diagram based on major ion chemistry,
- line charts for pump test results.
- the quantity of water in the various water sources;
- the status of groundwater aquifers;
- the quality of water resources and state of the aquatic environment;
- the use of water resources, including a register of water use authorizations for irrigation, municipal and industrial use and other uses;
- the extent and quality of coverage of water supply and sanitation services; and
- compliance with water resource quality objectives.

Primary Monitoring Program

Automated Monitoring Activities - due to the current security situation, the decision was taken to install groundwater monitoring instruments in built up areas where AAH or other members of the WASH Cluster have permanent operational presence. The 6 chosen centres to establish initial hydro-meteorological hubs are:

- Maiduguri Hub
- Monguno Hub
- Damasak Hub
- Potiskum Hub
- Damboa Hub
- Bama Hub

Within the centre of, or nearby to these 6 townships, AAH and NIHSA teams will establish groundwater and meteorological monitoring equipment. In the short term NGO offices will be essential to operating and maintaining the monitoring network because they can guarantee reliable internet, electricity, secure premises and necessary computing and IT support staff. We have recommended the use of the Solinst 3001 LTC data logger, which measures water level, temperature and electrical conductivity (EC).

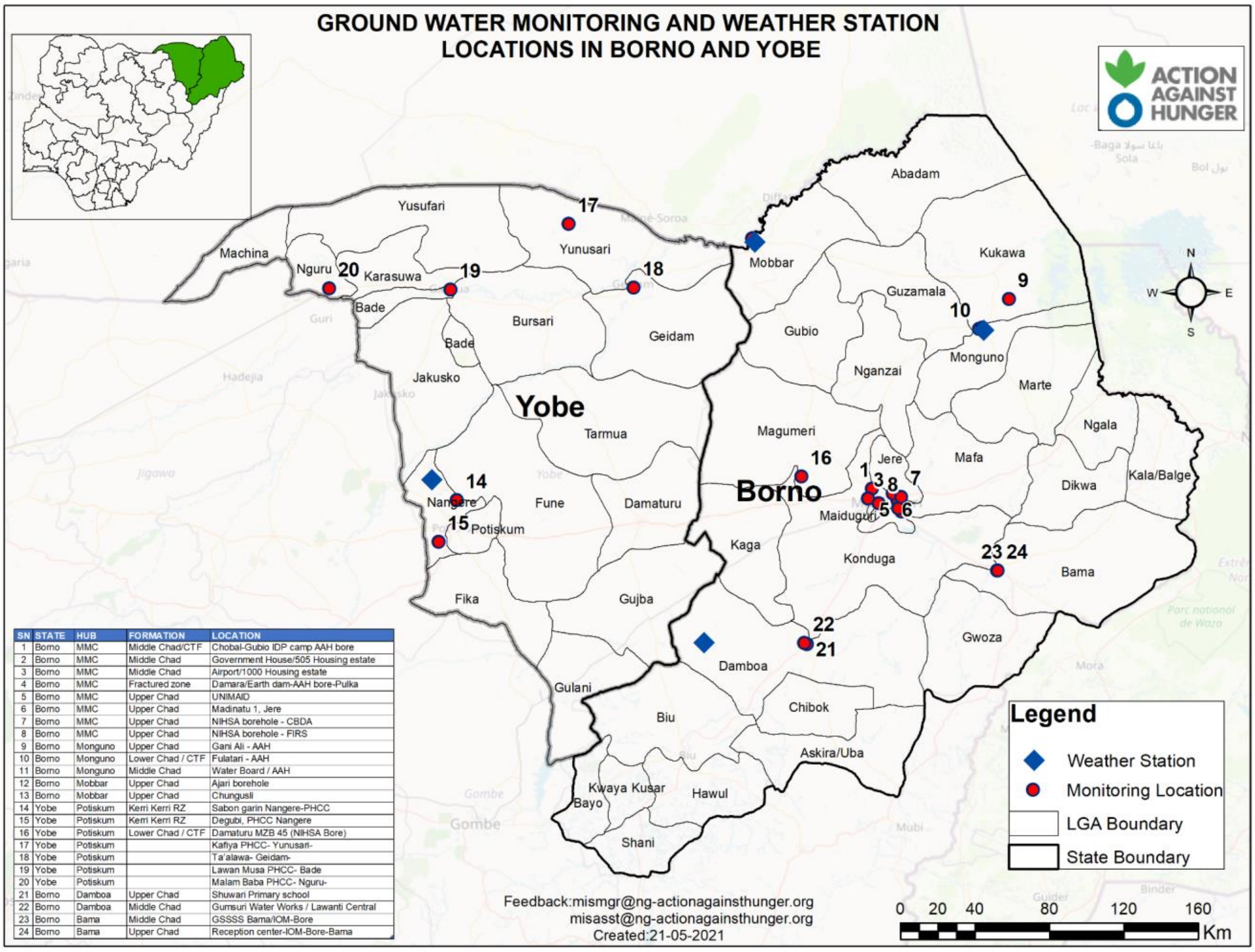
The instruments should be programmed to take a measurement every hour. In the first quarter, sites should be visited monthly to download data, maintain the transducers and collect static water level measurements. After the first quarter, data should be downloaded every 3 months. Whenever data is downloaded the SWL and EC should be measured and recorded. In the second year, it will be sufficient to download the data 2 times per year. At the end of the 2nd year, the frequency of data collection should be reviewed and all the performance measures for each of the instruments should be calibrated. Noting that the data frequently require corrections for factors such as barometric pressure, instrument drift, cable slippage or stretch, particular care needs to be taken with management of data from the field to the loading into the final information system. The expectation is that in the short term, AAH project staff will lead the work to download and transmit data. In the longer term, there needs to be a strategy to transfer responsibility to institutional partners, either the NIHSA, UNIMAID or Local Government.

Together with the 3 Mercy Corps monitoring sites that have already been established in Gwoza/Pulka, Ngala and Dikwa in the east of Borno state, the total of 9 locations provide a good initial skeleton monitoring network. Further monitoring sites are being established by Solidarites International but at the writing, the author is awaiting confirmation of those locations.

Routine Monitoring as part of Water Supply Projects

A culture needs to be fostered that sees drilling a water bore, rehabilitating a well, confirming the safety of a water sources, or fixing a valve on a hand pump as a source of data and information that contributes to knowledge for better water resources management. There are six stages in water supply service provision, each with their own groundwater data collection and reporting opportunities.

1. Hydro Census / Resampling Water Points
2. Hydrogeophysical surveys to choose location and depth of drill site
3. New water bore drilling, well construction, testing and borehole completion reporting
4. Borehole Rehabilitation, including testing and downhole inspection
5. General Operation, Maintenance & Repair of water points; and
6. Water quality safety monitoring of water points.



SN	STATE	HUB	FORMATION	LOCATION
1	Borno	MMC	Middle Chad/CTF	Chobal-Gubio IDP camp AAH bore
2	Borno	MMC	Middle Chad	Government House/505 Housing estate
3	Borno	MMC	Middle Chad	Airport/1000 Housing estate
4	Borno	MMC	Fractured zone	Damara/Earth dam-AAH bore-Pulka
5	Borno	MMC	Upper Chad	UNIMAID
6	Borno	MMC	Upper Chad	Madinatu 1, Jere
7	Borno	MMC	Upper Chad	NIHSA borehole - CBDA
8	Borno	MMC	Upper Chad	NIHSA borehole - FIRS
9	Borno	Monguno	Upper Chad	Gani Ali - AAH
10	Borno	Monguno	Lower Chad / CTF	Fulatari - AAH
11	Borno	Monguno	Middle Chad	Water Board / AAH
12	Borno	Mobbar	Upper Chad	Ajari borehole
13	Borno	Mobbar	Upper Chad	Chungusli
14	Yobe	Potiskum	Kerri Kerri RZ	Sabon garin Nangere-PHCC
15	Yobe	Potiskum	Kerri Kerri RZ	Degubi, PHCC Nangere
16	Yobe	Potiskum	Lower Chad / CTF	Damaturu MZB 45 (NIHSA Bore)
17	Yobe	Potiskum		Kafiya PHCC- Yunusari-
18	Yobe	Potiskum		Ta'alawa- Geidam-
19	Yobe	Potiskum		Lawan Musa PHCC- Bade
20	Yobe	Potiskum		Malam Baba PHCC- Nguru-
21	Borno	Damboa	Upper Chad	Shuwari Primary school
22	Borno	Damboa	Middle Chad	Gumsuri Water Works / Lawanti Central
23	Borno	Bama	Middle Chad	GSSSS Bama/IOM-Bore
24	Borno	Bama	Upper Chad	Reception center-IOM-Bore-Bama

Figure 14: Groundwater monitoring and weather station locations in Borno and Yobe

Implementers of water supply projects should design and build water supply infrastructure so that routine measurements of groundwater levels can be taken via a "*Dipper Pipe*" (see Figure 17). This would be consistent with the Code of Practice for Water Well Construction in Nigeria, (NWRI, 2010) that requires the inclusion of an access point for groundwater monitoring probes to be inserted.

In cases of water bore rehabilitation, it would be preferable for organizations to conduct downhole camera and wireline gamma ray logging surveys. This will generate accurate information about the depth of the well screens as well as a useful approximation of the stratigraphy. However, in rehabilitation cases where a prior borehole completion report exists, there is less need for this additional procedure.

Resampling Earlier Groundwater Monitoring Points

The Consultant proposes that the fieldwork starts with re-sampling original points from earlier monitoring activities. It is proposed that this step be conducted by the WASH Cluster, University of Maiduguri and LGA council teams. This includes 116 water points, comprising 35 drilled wells (mostly Middle Chad) and 81 hand dug village wells based on the Carmalt & Tibbitts (1968) monthly groundwater level monitoring between 1963 and 1968, and 33 of the oldest Middle Chad Formation drilled wells originally described in Barber (1965) for which standing water level measurements in 2007 and 2012 were recorded in Adamu et al., 2013. The first step is to determine if any of these hand dug wells or drilled bores are still reachable, functional and accessible. Those water points that meet these criteria will be some of the best monitoring sites to prioritise for a rapid baseline survey of water levels and chemistry. The standing water level data for these water points have been reproduced in Annex 1. Also already loaded into the Project GIS there is the major ion chemical analysis, geological logs and borehole construction details for most of these 33 bores used in the Adamu et al., 2013 study.

Hydrocensus

The Partnership for Expanded WASH (PE-WASH) is the national flagship 'Target Program' for the water supply and sanitation sector in Nigeria. The States and local government authorities are required - under the terms of the PE-WASH to carry out comprehensive baseline surveys (or Hydrocensus) of current access to WASH infrastructure. With the assistance of the Federal Ministry of Water Resources, most States undertook a hydrocensus of water points in 2015.

Due to the conflict, the hydrocensus in Borno was much more limited than elsewhere. The results of the previous hydrocensus were published to the Water Point Data Exchange platform and have been incorporated into the Project GIS developed by the Consultants. An observation of the results of the earlier hydrocensus was that there was a lot of incorrect reporting by enumerators and that a lot of very valuable and easy to acquire information about water infrastructure and water resources was not collected. This demonstrates the need for far greater attention to training, and quality assurance of the work, of local agents responsible for water point functionality and groundwater monitoring activities than has been the case until now. The first step to complete a hydrocensus is to digitally archive historical water bore records which is currently underway. A second step is to interpret remotely sensed satellite images which is already part of the plan for GIS development. The third is to work with LGA Council teams to carry out field measurements to confirm what has been determined from the 1st two tasks and to fill remaining gaps. The WASH Cluster can promote a cooperation between the LGA Department of Public Works (Water Superintendent) and the LGA Department of Health to implement a survey of water quality, starting with all the major urban areas. The first priority is water points in the urban and peri urban areas of LGA main towns and any easily accessible nearby villages. Following the successful completion of the water point census for the main urban centre of the LGA, the next phases should be: (a) smaller settlements / villages; and (b) remote location water points. The hydrocensus would include a series of data collection and verification steps that includes: Borehole registration / Differential GPS location (latitude, longitude, elevation above sea level) / Photograph(s) of Water Point / Water Point Functionality / Functionality Measure Categorisation / Future Monitoring Point Potential / Access Issues for Routine Monitoring / Water Quality Measurements / EC / Temperature / pH / Fluoride / Nitrate / Turbidity / Coliform Forming Units (CFUS) / Water Level Measurements / Establish a Measuring Point (MP) / Total Well Depth Measurement Using a Weighted Tape (below measuring point) and SWL below Measuring Point.

Manual Monitoring

Whilst manual monitoring might seem old fashioned, it has certain benefits that modern automatic technologies do not provide. Manual monitoring demands regular practice and only through practice can some of the basic 'common sense' judgement and related skills of taking measurements and documenting results be acquired. Promoting the manual collection of groundwater measurements by different actors will contribute to the development of broader skills, knowledge, appreciation and ultimately understanding of the value of this type of scientific data. This is fundamental to building a culture of monitoring. The LGA level staff, from either or both the Department of Public Works and Department of Health, should be supported with equipment, training and funds to carry out a program of monthly groundwater measurements. This should be initially for 12 months, with the possibility of extension if the work is carried out satisfactorily. The selection of monthly monitoring points should be informed by the results of an initial hydrocensus, assessment of accessibility of original monitoring points (considered to be a priority) and bearing in mind safety and accessibility considerations. The usefulness of manual monitoring is demonstrated by the fact that 60 monthly manual measurements taken correctly over a period of 5 years will provide a credible foundation for characterising hydrogeological response patterns sufficient to calibrate a numerical groundwater model.

Fluoride Surveillance

As part of the PE-WASH, the members of the WASH Cluster, Rural Water Service (RuWASSA), City water corporation, and various units under the department of health should be coordinating their testing of fluoride concentration in different sources of drinking water and groundwater. Based on the results, detailed fluoride maps should be available to the public and water points containing F- in excess of the national health ministry guideline limits should be labeled. If there is no alternative nearby water source without elevated F- levels, then such communities should be prioritised in the district water investment plans for new water supply. Often (but not necessarily always) this will mean a shift from deep drilled bores to shallower water table groundwater sources.

Secondary Monitoring Program

To complement the primary monitoring program, it is envisaged that the Technical Working Group will research, plan, design and implement additional research problems- or development opportunity-oriented local studies and “secondary monitoring networks”. The Consultant considers the key issues in this program to be –

Maiduguri City-Wide Groundwater Monitoring Network

Current groundwater sources for Greater Maiduguri are known to be declining, both in terms of quality and quantity. Due to the intensity of groundwater development, the high risk of water borne disease outbreaks (e.g. cholera), and the critical economic and security function of the city within the region, additional financial and technical assistance to establish a more comprehensive groundwater monitoring network in and around Maiduguri City is justified.

Middle Chad and Lower Chad Recharge Mechanism

The new analysis by the Consultants has placed a particular emphasis on understanding recharge mechanisms for the system. Zones of potentially significant concentrated riverine recharge to the main artesian aquifer systems include-

a) Ngadda River ‘*connected groundwater systems*’ between Alau Dam and Jere Food Bowl (Borno State)

b) Komadougou-Yobe River ‘*connected groundwater systems*’ between Damasak, Gumsa and Gashua (Yobe and Borno States).

c) Komadougou-Gana River ‘*connected groundwater systems*’ between the Gamawa Road and the Kano-Kari Road (Bauchi State).

d) Unconformity between the Kerri Formation and the Precambrian Basement along the upper reaches of Upper Komadougou-Gana Rivers.

e) Mountain block recharge zones along major river courses in the far south west of the Chad Basin (e.g. block faulted Bima Sandstone outcrop along Gongola River).

f) Cretaceous sedimentary basin mountain block recharge via the Biu Volcanic Plateau, combining natural recharge and primary mantle water exsolution recharge.

Alau Dam Surface Water Diversion

The costs of Alau Dam, measured in terms of water lost via evaporation or re-directed away from users of the Bama Ridge sand barrier aquifer and the underlying Middle Chad Formation artesian aquifer, is potentially out of balance with the benefits of the scheme. The Alau Dam project needs to be subject to more detailed meteorological, hydrological, geophysical and geochemical surveys and monitoring activities aimed at understanding the fluxes into and out of the Dam.

Links between Artesian Pressure Loss and Lake Chad Level Declines

The links between artesian groundwater pressure losses and the drying out of the Lake Chad wetlands has not been studied to date, which could make it an interesting subject for future research through a combination of groundwater monitoring and numerical groundwater modelling simulation.

Mapping Groundwater Basin Extent

Currently the member states of the Scheduled Hydrological Area 8 (HA-VIII) are Bauchi, Borno, Gombe, Jigawa, Kano, Yobe While the boundary shows surface water catchment divides, the groundwater catchment area for HA-VIII is larger than the surface water catchment area and includes parts of Plateau and Adamawa States. To scientifically ascertain the extent of the groundwater basin, it will be necessary to undertake further research and install long term groundwater monitoring instruments.

Leaking Oil & Gas Exploration Wells

There is the possibility that some of the petroleum exploration wells drilled since the 1970's may not have been decommissioned to the highest industry standards. While there is no clear evidence of this, from a groundwater monitoring perspective it would be prudent to carry out an official audit of these wells through a combination of independent desktop review of borehole completion reports held by the Nigerian National Petroleum Corporation and with field truthing of i) the original drill pads to check for any signs of leakage and ii) to sample the water quality and depth of wells to check for possible signs of unintended aquifer interconnectivity.

Upper Chad Formation Hydrostratigraphy

The Upper Chad Formation Aquifer is made of many different overlapping geo-hydrological elements. To think of it as a single aquifer would be wrong. To improve the management of the Upper Chad Formation system of aquifers, NiHSA experts have identified that far more work needs to go into building a better hydrostratigraphic model of the material above the main regional aquitard.

Comprehensively survey the Lower Chad Formation beneath Borno & Yobe States

There is evidence that the sustainable resource development potential of the Tertiary age aquifers, taking in the full thickness of the Middle Chad Formation and the largely undeveloped Lower Chad Formation (also known as the Kerri Kerri Formation or Continental Terminal Formation), has not been comprehensively assessed. The lack of high quality groundwater data and detailed hydrogeological information about the lower sections of the Tertiary formations reflects the fact that the original comprehensive survey carried out in the

1950's and 1960's by the USGS-GSN investigators (with USAID funding) did not have the technical capacity or the economic incentive / imperative to investigate below the highly productive Middle Chad Formation. Since that time until today, some fifty years later, the overwhelming focus of water supply projects has focused on the Middle Chad Formation. This is despite the fact that all indications have been that water levels are in decline. Actions to try and develop the full extent of the groundwater resources contained within the Tertiary Formations of the Chad Basin in Nigeria is now technically feasible as well as being socially and economically justifiable. Whilst the ongoing conflict is a barrier to undertaking a comprehensive survey aimed at comprehensively evaluated the deeper sections of the Tertiary Basin, it could be equally argued that unless the international community along with State and Federal governments commit resources to a program aimed at sustainably developing the deeper resources, then water scarcity problems will only increase and peace in the region will remain forever out of reach.. To move the process forward, members of the WASH Cluster should coordinate with one another to secure funding that includes deep wells (drilled to bedrock) in all the key settlements across the areas where the Continental Terminal formation is thought to be located. This is likely going to require a commitment by the WASH Cluster to bring in at least one additional purpose-built drilling rig with requisite capacity to reach the required depths. We recommend an initial phase of 10 deep wells drilled to the base of the Tertiary, which will be geologically and geophysically logged, screened & constructed, long duration pump tested, chemically analysed, continuously monitored (EC, SWL, Temp), and if successful, then developed and operated as the major bulk water source for a reticulated urban water service in each of the targeted townships. Once the Lower Chad is much better characterised (based on this proposed deep groundwater reconnaissance drilling and monitoring program) it will be possible to properly evaluate the water resource development options and formulate integrated water resources management measures that could be implemented to achieve sustainability.

Test Groundwater Development Potential of Bima Sandstone

Despite the significant challenges around drought and water scarcity in Borno State, there have been no attempts to assess the groundwater development potential of Bima Sandstone in the Damboa basin, where it is likely to be a confined artesian aquifer within the feasible range of less than 800 metres drilling depth.

Monitoring Equipment

The Consultant proposes a survey of all organizations currently implementing groundwater supply, both implementing agencies and contractors, to determine the local availability of various types of groundwater monitoring equipment and to assess the adequacy of the current supply and equipment sharing agreements or hire rates to further determine the merits of adding equipment. An easily accessible registry of equipment should be shared amongst WASH Cluster members. In order to fulfil the requirement of a monitoring system, the Consultant proposes the following minimum equipment required -

Automatic hydro-meteorological monitoring instruments

With the financial assistance of USAID Bureau of Humanitarian Assistance, and skilled technical assistance of AAH, the NIHSA regional office for Hydrological Area VIII has completed a program of work to install a network of 20 downhole data loggers and 5 meteorological stations across various parts of Borno and Yobe States. For the groundwater monitoring instrument the decision was taken to go with Solinist, which is a Canadian manufacturer. Solinst was identified as the better manufacturer for both ACF-Nigeria and Solidarites

International to adopt under the current phase of groundwater surveillance activities in N.E. Nigeria because of (a) available telemetry solutions (b) value for money and (c) consistency with other monitoring projects in the local area.

General use equipment for groundwater measurements

- Android Phone (with MWater App Installed)
- EC Meter
- Temperature Meter
- pH Meter
- Nitrate Meter
- Fluoride Meter
- Standing Water Level Meter
- End of Hole Meter
- SWL Measuring Device for artesian wells

Downhole Camera and Wireline Logging Surveys

Our observation is that borehole completion reports are often absent, incomplete or have been lost. Consequently many drilled wells have no information about the geology or the well construction. The WASH Cluster should make it a policy to deploy downhole camera surveys on a routine basis to verify the quality of water bore construction either upon completion of a drilling project or ahead of making a decision whether to rehabilitate an existing drilled well. For new bore drilling and well rehabilitation projects, wireline gamma logging instruments are very effective for logging even where there is steel and cement casing. Based on downhole geophysical surveys carried out by the oil and gas industry in Borno State, it is clear that both Gamma and Sonic downhole geophysical logging generates very valuable data that can be used to improve the current interpretation of the Hydrostratigraphy. We propose that downhole surveys should be mandatory for all water bores drilled greater than 100 metres depth.

Differential GPS Instrument(s)

The precise elevation of a groundwater point is critical information to support groundwater resource assessment, especially the mapping of groundwater flow directions and groundwater boundary conditions. A differential GPS survey of all water points is proposed as part of the hydrocensus to greatly improve the future value of all groundwater level measurements.

MWater Platform Mobile Application

The MWater Application is a system for real time water point functionality tracking. MWater is currently being used by several members of the WASH Cluster to collect, manage and share water point data. It is a mobile phone / android supported application used to collect data in the field and also a platform for the analysis, visualisation and reporting of survey data. If all WASH sector actors involved in developing and managing groundwater points in North East Nigeria (and even nationwide) could adopt the MWater application, then this would help to solve a critical bottleneck to groundwater monitoring information management. MWater assigns a unique identification number that is centrally stored and universally accessible, making it possible to locate, verify and manage the unique identity of water points at different stages of planning, development and use.

GRID3 Project

Also on the issue of geo-location identification issues, it is also recommended that the information system incorporate the settlement ID system utilized in the GRID3 programmes (The Geo-Referenced Infrastructure and Demographic Data for Development) which has been adopted by the Minister for Planning and Investment and is part of a bigger global initiative which aims to improve access to data for decision making. The GRID3 Nigeria project works across all states in Nigeria to collect accurate, complete, and geospatially referenced data relevant to a variety of sectors.

Future initiatives

Develop Hydrological Area VII Resources Strategy and Plan

Part IX of the Water Resource Bill (2020) deals with Water Resources Planning and Management. Particularly relevant to the feasibility of the Project concerns the formulation of Hydrological Area Resources Strategy and Plans. A Hydrological Area Resources Strategy will prescribe principles, objectives, procedures and institutional arrangements for management, protection, use, development, conservation, control and administration of the water resources within its Hydrological Area of Interest. This must include: (a) classification of each water resource within its basin; (b) determining water resource quality objectives; (c) setting out principles for allocating water; and (d) defining mechanisms for stakeholder participation.

There needs to be a hydrogeological research and groundwater survey plan for Hydrological Area VIII. Implementation of the plan should quantify key components of the system and test elements of the regional scale conceptualisation. The research plan needs to take account of the research going on in the other countries that make up the Lake Chad Basin. The WASH Cluster members need to make a more conscious effort to harmonize at least some resources for water supply activities with a centrally directed and scientifically rigorous program of hydrogeological research and groundwater survey. This will help to ensure information gaps are filled with high quality data and that parameter assumptions used in numerical models are robust and defensible. The Technical Working Group should work to provide the strategic high level oversight to planning water bore drilling as it relates to filling gaps in scientific knowledge and promoting collaboration between water supply practitioners and water resources researchers.

Numerical Groundwater Model Development

The results of numerical groundwater modelling should inform continuous improvements in monitoring and resource assessment. To this end, there is sufficient hydrogeological information available from the original USGS-GSN study completed during the 1950’s and 1960’s to start numerical model development immediately.

Technical Collaboration with National Petroleum Corporation

To improve the structural and hydrostratigraphic model, fault block data created for petroleum exploration can be utilized for groundwater management. The first step to managing the risks of faults or tapping into the benefits of faults, is mapping them accurately. Once there is an accurate fault block model, it can be compared with geological logs, water chemistry analysis, standing water level trends, to start developing predictive models that then drive groundwater exploration and groundwater resource development planning decisions. A more accurate fault block geometry model will help to identify prospective traps, especially in the Tertiary age Continental Terminal Aquifer (known locally as the Lower Chad or Kerri Kerri Formations). This will help to target exploration efforts and reduce risk associated with deep drilling.

Once an ancient buried shoreline trend is confirmed, then other villages along the same trendline of the buried shoreline can be targeted for rural water supply with far reduced risk. There is also opportunity to make use of potential field geophysics. The Consultants have concerns with the georeferencing of the depth to magnetic basement model image used in the GIS. The lack of certainty means that currently, interpreted basement structures could be out by many hundreds of metres or more. Data should be independently re-processed and imaged by suitably qualified experts in potential field geophysics.

Addressing Human Health Risks associated with Unsafe Groundwater

There are a range of potential water quality hazards associated with the different aquifers occurring in Borno, Yobe and Adamawa States. To better manage the human health risks will require investment in water quality sample collection, monitoring, measurement and information management activities. Intake of fluoride (F-) in water (at a concentration range of 1.0–1.2 mg/L) strengthens tooth enamel, which helps to prevent dental cavities. Unfortunately, above 1.5 mg/L fluoride can cause a condition known as dental fluorosis. Other known effects of chronic exposure to fluoride in drinking water include skeletal fluorosis (F- > 10 mg/L), neurological manifestations such as lowering of the intelligence quotient (IQ) (F- > 2 mg/L), gastrointestinal tract (GIT) dyspeptic symptoms (F- > 3.2 mg/L), and urinary tract malfunctioning and renal symptoms (F- > 8 mg/L). Among all these, dental fluorosis is the most common unwanted effect of chronic exposure to fluoride. It is therefore considered a valuable early indicator of excessive fluoride exposure in a population. The occurrence of dental fluorosis in schoolchildren and adults in North East Nigeria had been reported as far back as the 1950's (Wilson, 1954). Idon and Enabulele (2018) confirmed that dental fluorosis has a high prevalence among dental patients from the northeastern region, high enough that they recommend it should be seen as a condition of public health significance. As part of the PE-WASH, the members of the WASH Cluster, Rural Water Service (RuWASSA), City water corporation, and various units under the department of health should be coordinating their testing of fluoride concentration in different sources of drinking water and groundwater. Based on the results, detailed fluoride maps should be available to the public and water points containing F^- in excess of the national health ministry guideline limits should be labeled. If there is no alternative nearby water source without elevated F^- levels, then such communities should be prioritised in the district water investment plans for new water supply. Often (but not necessarily always) this will mean a shift from deep drilled bores to shallower water table groundwater sources. Implementing groundwater monitoring systems and processes efficiently, and ensuring the effective uptake and application of monitoring results, especially as it relates to potential human health of poor water quality, will greatly benefit from greater cooperation with the Ministry of Health and its various State and Local Authority level units.

Establishing a Water Fund

To restore the artesian aquifer system, it is proposed that consideration should be given to the establishment of a Water Fund as proposed by The Nature Conservancy for North East Nigeria Hydrological Area VIII that could be used to organise stakeholders and mobilize resources for groundwater catchment scale restoration activities. Developing the knowledge base upon which to plan and measure the effectiveness of policy measures and infrastructure investments is fundamental to securing funding for nature based solutions which may be a feasible approach to improve long term resilience of water resources in Borno State.

Auditing

Funding guidelines from Government and Donors need to be strict about the need to collect and submit all relevant data from water supply projects. Improved auditing of project financial statements, reported water supply infrastructure, and the presence of drilling, borehole construction and water testing data will be encouraged.

Information, Education & Communication

Awareness of groundwater and project results can be communicated widely, including through education systems, mass media, and key political decision making forums. In Nigeria, information about groundwater resources is intended to be available to the public. Elected officials can be encouraged to communicate the findings and recommendations of the activities completed to date and / or planned for the future. In the case of any natural or human-caused hazard relating to water resources the commitment to sharing that information is clearly stated in the Draft Water Bill (FMWR, 2016). From the analysis undertaken during the current study, there are a number of clear breaches of these criteria which the public should be informed about. Mass media should be used as a platform to communicate results of public health and environmental sustainability monitoring and survey activities. It is also proposed to work with the Department of Education in Borno State to develop tailored 'local content inspired' curriculum about hydrogeology and groundwater management for Middle School and High School level STEM (Science, technology, engineering, and mathematics students

INSTITUTIONAL ISSUES

Alignment with Existing Initiatives

GIS Ongoing Support / GIS Development

Over the course of the project over 500,000 points of interest have been collected, with data collectors being trained in the use of mobile data collection technology. To achieve the full benefits available from the GIS ongoing support should be provided to the users in addition to ongoing development of the GIS functionality. This will require high level support from within government and the Consultant.

Partnership for Expanded WASH

The Partnership for Expanded WASH (PE-WASH) is the national flagship '*Target Program*' for the water supply and sanitation sector in Nigeria. At the state level, it is directed by the Ministry of Water Resources or State Water Regulatory Board. The States and Local government authorities are required - under the terms of the PE-WASH to carry out comprehensive baseline surveys of current access to WASH infrastructure and to implement a continuous system of functionality monitoring and reporting. Water supply service providers are supposed to work under the various guidelines and strategies set out in the nationally accredited Partnership for Expanded WASH (PE-WASH) Framework. This includes guidelines for water point functionality; water use; hydrogeological information; and groundwater measurement monitoring data related to the changing quality and quantity of groundwater resources upon which water supply systems depend upon. To strengthen hydrogeological information management and groundwater monitoring as part of the PE-WASH, the Federal Water Minister through the NIHSA has issued a directive formally requesting all individuals and organizations implementing groundwater supply projects, including the RuWASSA and the non-government organization members of the WASH Clusters to submit borehole completion reports in accordance with the National Code of Practice for Water Well Construction. In North East Nigeria, the main organizations implementing water supply projects under the umbrella of the PE-WASH are the State Rural Water Services (RuWASSA), the Local Government Area Department of Public Works and a large number of international humanitarian and relief organizations including UN agencies and INGOs. These organizations are all potential major users of groundwater information and they are all major creators of groundwater information. As the Federal Minister responsible for achieving national goals on water resources management is also responsible for clean drinking water supply and sanitation, we see no obstacles to forging a coherent and unified hydro-meteorological monitoring and reporting strategy for North East Nigeria that is fully inclusive of water resources and water supply and fulfils the objective to meet the universal provision of safe drinking water for people and livestock.

Decentralise Groundwater Management

The Government of Nigeria recognises that management, (and therefore monitoring) of water needs to be decentralised to the most local government unit possible. Furthermore, water user participation in planning and management should be maximised. To support decentralisation of water management in Nigeria, the Draft Water Bill (FMWR, 2016) proposes that for each of the 8 national Hydrological Areas, a Catchment Management Office (CMO) will be established. The National Draft Water Bill calls upon State Parliaments to legislate independent State Water Regulatory Boards (SWRBs) with powers to monitor and regulate water resources development, including the licensing of stock, domestic and small scale irrigation wells.

To enable effective decentralisation of water different water supply planning and management functions, higher administrative levels need to have the means to verify LGA level activities are undertaken to specification and / or proposals submitted are warranted.

The Nigerian Constitution (Fourth Schedule) makes clear that it is the role of the Local Government to make recommendations and submit proposals to the State commission on economic planning (or any similar body) regarding the establishment, maintenance and regulation of public conveniences (e.g. like shared water points) and the provision and maintenance of refuse disposal (e.g. control of unsanitary wastewater through proper operation of drainage works). Under the Nigerian Constitution, LGA Council has the power to introduce taxes and fees related to the reasonable upkeep and maintenance of such public water & sanitation services. LGA Council is also responsible for naming of roads and streets and numbering of houses within the local jurisdiction. Therefore it makes sense that the LGA Council is also responsible to identify all public and private water points. The PE-WASH Guidelines require the State Government and Local Authorities to carry out comprehensive baseline surveys of current access to WASH infrastructure and to implement a continuous system of functionality monitoring and reporting. The expectation is that this will contribute to better coordination and prioritization of investment in new water supply facilities, rehabilitation of existing water supplies, and to ensure routine maintenance and prompt repair in cases of service failures.

We recognise that at different stages in delivery of water supply services, service providers have different groundwater information needs and each stage is a potential opportunity for water supply service providers to generate groundwater information. Local Government Councils are responsible to secure funding (and account for the use of all funds) to cover the cost of construction, operation and maintenance of public infrastructure conveniences, including public water points and wastewater drainage. Practical aspects of training and capacity building in the use of equipment and necessary protocols and quality assurance standards for RuWASSA, INGO, LGA and any contractors needs to be coordinated through a dedicated effort. To empower LGAs to conduct more water supply and water resources management monitoring and regulatory functions of the State, they will require an investment in equipment, training, salaries and operating expenses. LGA level staff can commence with conducting the proposed hydrocensus from which LGA level staff should be able to gain the confidence to implement routine monitoring in accordance with specified guidelines and technical standards.

Technical Working Group (TWG)

The establishment of the Technical Working Group during this project is greatly aiding collaboration amongst the WASH Cluster across the conflict areas within Borno, Yobe and Adamawa States. The Consultant proposes that TWG also develop long term groundwater policy and planning questions that require a far greater scientific evidence base; a 3 year groundwater priority research program outline; and a 1 year detailed activity plan to further develop, field test and finalise outputs from this project.

Enforcement of Existing Standards and Protocols

The Draft Bill states that NIHSA 'shall take a leading role in the development of guidelines prescribing: (a) procedures, standards and methods for monitoring; and (b) the nature, type, time period and format of data to be submitted'. The National Standards that have been developed are highly relevant to the implementation of groundwater surveillance activities in North East Nigeria:

- NIGERIAN INDUSTRIAL STANDARD NCP 027: 2010 Code of Practice for Water Well Construction ICS 23.040.10
- NIGERIAN INDUSTRIAL STANDARD NIS 554: 2007 Standard for Drinking Water Quality ICS 13.060.20

Borehole Completion Reporting

The WASH Cluster has developed a Borehole Completion Report template for member organizations to complete and submit in triplicate when carrying out new drilling. This process can be replaced by MWater in the future and it will be important to ensure all data participants have good internet connectivity, software and devices.

Code of Practice for Water Well Construction

The National Code of Practice for Water Well Construction provides clear instructions for hydrogeological information and groundwater measurement reporting standards for anyone involved in groundwater supply development in North East Nigeria. It should continue to be the foundation of the approach to reporting on drilling and water bore construction activities. In accordance with the Code we recommend that all members of the WASH Cluster (including the RuWASSA) collect more geophysical data to select optimum drilling sites. If targeting the artesian zone, carry out a downhole geophysical survey and use the results as the basis for the design of the well. Other activities include the important need to add a mandatory bentonite seal when installing any deep bores and include an access point where to insert and lower a groundwater probe. Further effort should be made to cap and tap all artesian free flowing wells and decommission and replace deep bores that were incorrectly constructed in the artesian zone. Geological logs need to be as accurate and detailed as possible and the decision to end a hole should be based on interpretation of the drill chips. WASH Cluster members should realize the desirability of including full site supervision by a qualified geologist / hydrogeologist during drilling. Samples for each metre should be collected into a 'chip tray' that should be correctly numbered with the Bore ID registered to MWater. The Ministry of Water Resources needs to establish and maintain a facility for the storage of geological chips from drilling. These initiatives are especially important in view of the growth in drilling rigs and capacity evidenced at the Borno state government Ministry of Water Resources Facebook account showing the RuWassa procurement in recent years of at least 12 modern drilling rigs with water tankers and 3 booster air compressors. This has significantly increased the RuWASSA capacity to implement rural water supply projects across Borno State. As an example of the capacity of RuWASSA in Borno State, up to 2017 the Borno State MOWR reported the following achievements: Kaga LGA (n=15); Gubio LGA (n=5); Magumeri LGA (n=7); Konduga LGA (n=32); Jere LGA (n=25); Dikwa LGA (n=6); Ngala LGA (n=5); Mafa LGA (n=8); Nganzai LGA (n=3); Mobbar LGA (n=3); Bama LGA (n=6); MMC (n=32); Kukawa LGA (n=2). In addition, across the southern Borno Senatorial zone 113 boreholes were installed across the 9 local government areas in that zone.

Draft Bill Recommendations for Stock and Domestic Bore Licensing

According to the Water Use & License Regulations (FMWR, 2016) the Federal Minister of Water Resources shall have the responsibility and authority to license activities deemed to be affecting the water sources. Notably, this ministerial authority does not include stock, domestic and small-scale irrigation water bore drilling activities. Part V of the Water Resources Bill (2020) deals with Water Licensing, which includes regulations on groundwater abstraction and drilling of boreholes, issuance of drillers' licences, and drilling permits. According to the Draft Bill, access to groundwater for household consumption, stock watering, and personal irrigation (not for commercial irrigation) - from a water source to which the public has free access - is considered to be an inalienable human right. In such circumstances, water users should be permitted to drill bores and / or abstract groundwater without a license. Any licensing of such activities will be at the discretion of the State Government. Authority over water bore drilling and groundwater abstraction can be assigned to a State Water Regulatory Body duly constituted and possessing such capabilities to carry out such functions subject to national guidelines. This situation is resulting in a very large amount of valuable hydrogeological information and groundwater measurement data from stock and domestic bores simply being lost. The expectation of the

Federal Ministry of Water Resources is that individual State Governments will legislate their own State Water Regulatory Board (SWRB) with powers to monitor and regulate water resources development. The appropriate authority should make approval of all drilled wells (manual and mechanical) contingent upon a permit / license. It should be a future condition for the granting of all water bore licenses that the owner submit borehole completion reports to the legislated body.

Recurrent Funding for Water Resources Monitoring

Each LGA Council, along with partners they cooperate with to implement water supply projects, needs to be empowered and incentivised to collect and submit water point functionality, hydrogeological survey, and groundwater measurement data. The State Houses of Assembly should make provisions for statutory allocation of public revenue to local government councils for the purposes of implementing water resources and water point functionality data collection activities as set out in Draft Water Bill. It may be appropriate that a suitable fraction of the PE-WASH national budget is allocated to integrated water supply and water resources monitoring by a dedicated LGA Council Water Superintendent. There is also the option under Part XIII of the Draft Water Bill that deals with the WATER SUPPLY, SANITATION AND HYGIENE (WASH) FUND. The Fund shall be administered by the Minister responsible for Water Resources through a transparent and accountable framework. The Minister shall ensure that there is strong analytical, technical, policy and regulatory capacity for project appraisal and advisory functions available to the Fund at all times. It therefore also appears appropriate for the Federal Ministry of Water Resources to draw from the WASH Fund to pay for the costs associated with monitoring activities at the local level.

WASH CLUSTER (TECHNICAL WORKING GROUP) ACTIONS

Since 2009, Borno, Adamawa and Yobe states (the BAY States) of the North East region of Nigeria, have attracted massive financial and technical assistance for the provision of groundwater supplies to internally displaced persons. A lot of this assistance has been directed at urban and peri urban areas, which is where the great majority of internally displaced persons are currently settled.

Implementation of the water supply projects in the North East is being coordinated through the Emergency WASH Cluster (the WASH Cluster), which is led by the Borno State Ministry of Water Resources (MoWR).

This section sets out key recommendations to the WASH Cluster members, which have emerged from the feasibility study phase of the North East Nigeria Groundwater Surveillance Project, for key actions they should take, as part of current future water supply projects and programmes, to address the growing concerns about the sustainability of current approaches to groundwater resource development and management in North East Nigeria.

The recommendations aim to build upon and elaborate some of the items detailed in the Terms of Reference for the WASH Sector - Water Supply Technical Working Group (WTWG). It includes a recommendation to establish a sub-working group under the WTWG specifically tasked with providing technical leadership on the cross cutting issues of groundwater management, monitoring & information systems.

What we recognised most through the course of conducting the feasibility study is that groundwater monitoring & information systems are the lifeblood of groundwater resource development, protection and management decisions. Groundwater monitoring & information systems help to detect and diagnose problems, track changes, and reduce risks for investments leading to overall improvements in sustainability and impact.

The biggest generators of groundwater data are not national or state groundwater monitoring programs, rather they are the organizations implementing water supply projects. Far too much valuable groundwater data is getting lost, or is simply not being collected. This situation must stop! Thankfully there is still time for the WASH Cluster to take the lead in charting a new and better course for groundwater monitoring over the coming period, which will build a positive legacy out of the current crisis, benefiting future generations wishing to make the best management decisions regarding groundwater resources development plans now and into the future.

In order to have a strong evidence base for groundwater resource management decisions, it is vital that, in addition to the official network of groundwater monitoring instruments maintained by government agencies, all actors involved in the provision of water supply services:

- Collect groundwater measurements and document hydrological observations during the course of their work.
- Submit the collected data and information to regulators in a consistent format based on standardised guidelines and reporting frameworks.

In turn, the regulators need to be accountable for the work of consolidating the data into highly functional decision support oriented information systems, to be made available to anyone.

If the WASH Cluster commits greater resources and pays closer attention to ensuring the accurate collection, timely submission and widespread dissemination (sharing) of groundwater data and information, this will have transformative benefits across the value chain for water supply service provision and water resources management. To make the necessary changes, there needs to be stronger oversight to ensure the INGO and UN members of the WASH Cluster and the various government, as well as private bore drill rig operators, contracted to INGO and UN-managed water supply projects, are adhering to National Standards for water quality and water bore drilling.

To oversee and quality assure the long term work of the WASH Cluster in the field of groundwater management, monitoring and information, it is critical that the WASH Cluster itself support the emergence and continued work of competent “duty-bearing” water resources management professionals, especially within government, with the requisite skills and knowledge to use data from monitoring systems to: inform regulatory and planning decisions; develop environmental monitoring trigger levels; define areas of concern where to intensify monitoring or undertake targeted investigations and surveys; and to be acting as a focal point able to energize a coordinated sector approach to the challenge.

To help meet the need for greater professionalisation of objective water resources management decision making, Phase 1 of the North East Nigeria Groundwater Surveillance Project has supported the establishment of a Sub Technical Working Group on Groundwater Management, Monitoring & Information Systems. The sub-technical working group on groundwater management, monitoring and information systems, chaired by the Nigerian Hydrological Services Agency, will take the lead in driving forward the various recommendations for WASH Cluster members arising from the feasibility study.

Collect Data

The first step must be the completion of a comprehensive water point census that will establish the unique identity of all existing water points. Beyond the census, what will be needed is a system of continuous (or routine reporting) of groundwater conditions alongside monitoring of functionality of water points that is able to capture groundwater measurements through the entire cycle of water supply service provision.

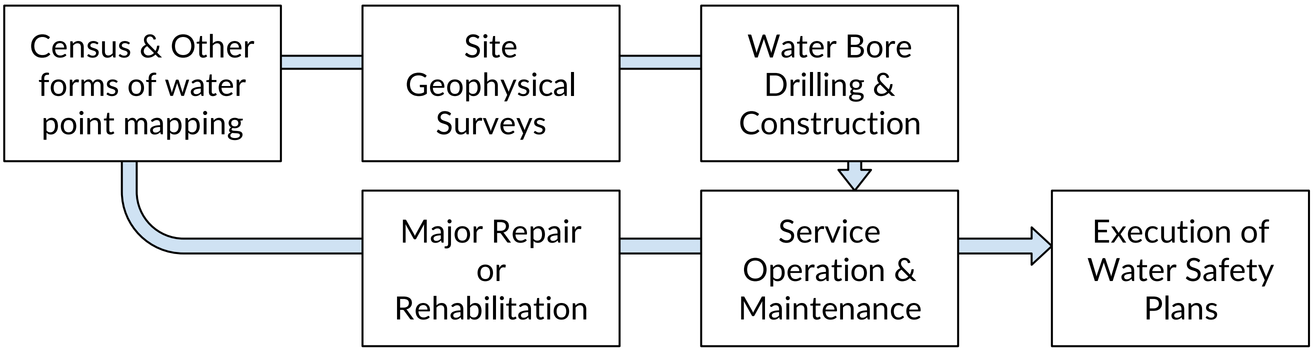


Figure 15: Stages in water supply service provision when groundwater measurements should be taken (Source: Author).

Complete updated water point census for BAY states

WASH Cluster is to support the RuWASSA and the Local Government Authorities to undertake a comprehensive census of water points across the BAY states. This is actually a requirement for any State wishing to secure funding through the Nigerian Federal Ministry of Water Resources led Partnership for Expanded WASH (PE-WASH). Borno State has still not satisfactorily completed its census. For Yobe State, the most recent census data from 2015 has been uploaded to the Water Point Data Exchange (WPDx) platform. The authors reviewed the results of the 2015 census and found evidence of inaccurate and incomplete reporting. Also, many water points were probably not recorded. For future water point census, there needs to be a far stronger emphasis on capturing hydrogeological information and groundwater measurement data wherever possible. Enumerators should have equipment, relevant training, as well as designated space in survey forms, to effectively enable and promote the observation, measurement and documentation of (a) water quality field parameters, (b) standing water level (SWL) from accessible open wells / boreholes, and (c) situation of wastewater management around water points. To help with census planning and promote comprehensive coverage, it is recommended that time series satellite imagery be used to geo-locate water points in the more remote areas, away from major centres.

Leverage project financial resources to get better groundwater data

Make payments to service providers conditional on compliance with reporting guidelines

To improve groundwater surveillance in North East Nigeria, WASH Cluster members should use their project financial resources as a leverage to ensure that different service providers (i.e. exploration geophysicists, water bore drilling companies, drill site geologists / hydrogeologists, water quality testing laboratories) engaged in the planning, construction and / or rehabilitation of water points are meeting established guidelines and standard operating procedures.

Limit drilling contracts to licensed drilling companies

WASH Cluster members need to lead the sector in making eligibility for drilling contracts conditional on having a State-issued license. Until the State Government has successfully introduced its own State-level system of regulation and licensing of water bore drillers, the alternative national water bore drilling accreditation offered by the National Water Resources Institute based in Kaduna should be accepted.

Qualified Geologist / Hydrogeologist to supervise all water bore drilling activities

Compared to the original USGS-GSN Studies carried out in the 1950's and 1960's, many of the geological logs presented in borehole completion reports submitted by members of the WASH Cluster, including those submitted by RuWASSA, have been of much lower quality. WASH Cluster members implementing water supply projects need to take steps to improve the quality of geological logging and other types of documentation as part of borehole completion reporting requirements. To this end, WASH Cluster members should make it a condition of water bore drilling contracts that a certified geologist is to be onsite, during the course drilling through to well installation, and responsible for all hydrogeological and groundwater reporting and final decision making about well design and supervision and sign off on final construction.

Resample historical water points

Resampling / Remeasuring historical water points that were used in previous studies is one of the most effective ways by which long term changes in groundwater conditions can be evaluated most rapidly. Through closer cooperation between WASH Cluster member organizations, the State RuWASSA and investigators from the University of Maiduguri, along with the Nigerian government military (in case of remote sites), a coordinated plan should be drawn up and subsequently funded by the WASH Cluster so that old monitoring points can be tested and a long term plan for monitoring drawn up based on the accessibility of sites and efficiency in the allocation of monitoring resources. Given that there is virtually no monitoring data for the past decade, this resampling exercise will work to concretize the policy advocacy messaging of the WASH Cluster more effectively than alternative approaches.

Infill hydro-meteorological monitoring network

To meet the information needs of water resources management, WASH Cluster members should advocate to donors the need for greater investment in groundwater and meteorological monitoring instruments across the BAY States. Donors should be encouraged to include funding for dedicated groundwater monitoring piezometers. The sustainability and impact of investments in new hydro-meteorological monitoring instruments should be argued based on the demonstrated performance of the coordinated activities of other WASH Cluster members working under the umbrella of the NiHSA. Demonstrating the functionality of the monitoring systems by way of a website with comprehensive and up to date data will be important to making a compelling argument. The siting of new monitoring points should be coordinated / planned through the Sub Technical Working Group on Groundwater Management, Monitoring & Information System. Focus should be on in-filling the regional network of monitoring hubs, as well as intensifying monitoring in areas of high risk from groundwater conditions.

Increase the use of downhole geophysical survey methods

To improve the quality and accuracy of hydrogeological data, downhole wireline geophysical logging should be made standard practice by all WASH Cluster members, both when drilling and constructing new wells and also when rehabilitating old wells for which there is no geological logs available. For new wells, the downhole survey should include a caliper tool, which is used to measure the variation in borehole diameter. Having accurate information about borehole diameter is necessary to estimate the volume of material required to back fill the annulus of the well, which is essential information to estimate the point at which bentonite pellets should be added. In terms of other geophysical tools, priority should probably be given to the gamma ray method. In the geological setting of Borno and Yobe states, gamma ray logs provide fairly clear signals to differentiate formation with contrasting hydraulic properties. Additionally, the gamma ray method performs well when surveying geology of already constructed wells. This will be important in the case of inferring the geology when rehabilitating an existing well.

Make the use of bentonite seals compulsory

Many boreholes screened in the Middle Chad formation have been constructed without the use of a bentonite seal. Gravel like material is reportedly being used to fill around the annulus of the well. Without a bentonite seal, there is a risk that water can flow from the Middle Chad to the Upper Chad formation (or vice versa depending on the head difference between the formations). One possible concern is that this may contribute to faster rates of decline in Middle Chad Formation pressures. It may also result in chemical mixing between the aquifer formations. For drilled wells screened in the Upper Chad Formation, correctly located bentonite seals will help to reduce the risk of surface sources of pollution. Bentonite seals are also very important, especially in the case of wells being used for groundwater monitoring purposes because they work to ensure that groundwater measurements can be attributed to a specific formation and that the result is not a mixture of 2 or more formations. For these reasons, we recommend that the use of bentonite seals be made compulsory on all new water bore drilled and constructed by members of the WASH Cluster.

Commit greater project funding to exploration geophysical surveys

The Partnership for Expanded WASH (PE-WASH) stipulates that all new water bores must be planned based on the results of a geophysical survey. Whilst this regulation is being widely followed, the value of the current approach to geophysical surveys has room for improvement. Often, it seems that the depth of drilling is being prescribed based on the results of a single geophysical vertical profile. As a result, some drilled wells have been stopped at a pre-planned depth, even when the drilling bit was in the middle of a productive aquifer formation. The practice has resulted in at least some bores constructed by WASH Cluster members having lower yields and higher rates of drawdown compared with what could have been possible if the driller and / or supervising geologist had autonomy to continue drilling (and screening) the total aquifer thickness. Also, to choose the best drill location, it would be better practice to complete two transects of no fewer than 10 vertical soundings each so as to identify the thickest and most hydraulically permeable formations. These transects should be oriented at approximately right angles to the trends of the historical shorelines and paleo valleys. It would also be good for members of the WASH Cluster to support the introduction and systematic evaluation of alternative hydrogeophysical methods, as the current options offered by local geophysical service providers is very limited.

Require contractors to upload Borehole Completion Reports via an online form

As part of this general contractual obligation, make it a condition that drilling contractors submit borehole completion report data into an online database reporting system of the Ministry of Water Resources at State Level (operated and maintained with the financial and technical assistance of the WASH Cluster). By establishing such a database and data entry portal for contractors to use, this will relieve the current burden upon the staff of WASH Cluster member organisations, including the MOWR and RuWASSA, who seem overburdened with the task of transcribing paper-based borehole completion reports into a format compatible with a geospatial database.

Reconnaissance survey of the Lower Chad Formation beneath Borno & Yobe States

Members of the WASH Cluster should coordinate with one another to secure funding that includes deep wells (drilled to bedrock) in all the key settlements across the areas where the Continental Terminal formation is thought to be located. This is likely going to require a commitment by the WASH Cluster to bring in at least one additional purpose-built drilling rig with requisite capacity to reach the required depths (750 metres). We recommend an initial phase of 10 deep wells drilled to the base of the Tertiary. Each of the holes will be geologically and geophysically logged, screened & constructed, long duration pump tested, chemically analysed, continuously monitored (EC, SWL, Temp), and if successful, then developed and operated as the major bulk water source for a reticulated urban water service in each of the targeted townships. Once the Lower Chad is much better characterised (based on this proposed deep groundwater reconnaissance drilling and monitoring program) it will be possible to properly evaluate the water resource development options and formulate integrated water resources management measures that could be implemented to achieve sustainability.

Capacity building and quality assurance mechanisms

To improve hydrogeological fieldwork will include developing detailed groundwater measurement & sampling procedures, providing leadership on the development and training in the use of groundwater monitoring guidelines (including many of the points raised previously regarding drilling and well construction standards) and routine groundwater monitoring during different stages of water supply service provision (e.g. Standard rules, nomenclature and abbreviations for completing geological logs).

Develop and implement systems for uniquely identifying water points

To successfully build up a groundwater database and information system, it is vital that everyone involved in groundwater monitoring data collection has the means to determine the unique identity (and the associated unique identification number) of any water point through time. The best way to overcome the current challenge associated with identifying a water point is to mainstream the adoption and use of a standard mobile-device service for uploading, storing and sharing field monitoring data (e.g. MWater, WPDx, ArcGIS Survey123. eagle.io). So far, many of the members of the WASH Cluster are yet to adopt any such mobile data entry tools and then in the case of those organizations that are using such tools, they are not all using the same one. When registering a water point, or updating information about a water point, into any of these mobile-device enabled systems, enumerators should upload as many photos from different angles and perspectives as possible. To complement a mobile-device system of identification, all newly constructed and rehabilitated drilled water points should be fitted with a metal plate with an inscription that includes essential (minimum) technical information about the water point.

Equip and train project officers (both in-house and partner authorities)

In addition to professional services companies, WASH Cluster members should take greater steps to invest in their own staff and the staff of local authorities (especially the department of public works and the department of health) so that they have access to correctly maintained and calibrated instruments and equipment (e.g. standing water level meters, field level water quality monitoring devices), and are trained in the relevant skills, that make them able to confidently and competently carry out various groundwater monitoring and reporting activities accurately and efficiently within the general course of their works. This includes the ability to be able to critically evaluate the quality of work undertaken by professional service companies and to hold them accountable.

Figure 16: Example of water point identification plate

Support a process of certification for drilling contractors

As the affected States work to enshrine such licensing requirements / standards into law, the WASH Cluster through the newly established Water Supply Sub Technical Working Group on Groundwater Management, Monitoring & Information Systems take the lead in develop interim standards, review past performance, offer trainings, and work towards MOWR certification and benchmarking of existing and upcoming contractors. The training and licensing of drillers and the training and licensing of geologists (see below) should be developed in a coordinated manner. For the accreditation of drillers and geologists working on WASH Cluster water supply projects in North East Nigeria, the content of the training and testing modules should be built upon existing National Guideline Standards for Water Bore Drilling. In theory, accreditation of water bore drillers is supposed to be the responsibility of the NWRI in Kaduna. Therefore, the water supply technical working group should try to develop and deliver local training and certification of drillers in a way that is aligned with NWRI approach.

Develop Groundwater Quality Sampling & Testing Guidelines

The Nigerian Code of Practice for Borehole Drilling includes a number of annexes with forms containing a pro forma Groundwater Sampling Form (Appendix H) and pro forma Water Quality Analysis Reports (Appendix I.1, I.2 and I.3). The prescribed parameters, units of measure, and maximum permissible levels are based on the Nigerian Standard for Drinking Water Quality NIS 554: 2007 (NSDWQ). Neither the code of practice for borehole drilling nor the standard for drinking water quality provide detailed guidance and standard operating procedures for water quality sample collection through to delivery at laboratories. This is a current gap in both the national guidelines and in the guidelines for the WASH Cluster in North East Nigeria. There is scope to improve the water quality monitoring aspects of the water supply programming of the WASH Cluster members by working on the development and roll out of groundwater quality sampling and testing guidelines.

This should be a task to be led by the Sub Technical Working Group on Groundwater Management, Monitoring & Information Systems. A good starting point to inform the development of local QA/QC standards for water quality work of the WASH Cluster is available from the International Waters Learning Exchange & Resource Network.

Address weaknesses in water quality laboratory testing capabilities

According to the 2018 Report On Certification Of Drinking Water Testing Laboratories In 20 Unicef Supported States In Nigeria, the situation of laboratory accreditation standards is very poor. Widespread problems with the majority of laboratories include: poorly equipped with obsolete analytical instruments; no active calibration standards; no standard operating procedures (SOPs); overall limited knowledge of water quality testing among staff. The authors of the certification exercise go as far as to conclude that water quality data previously generated may not have been reliable and accurate. This included a total of 6 water quality testing laboratories in Borno and Yobe states that were evaluated. Given this situation, it may be a better investment for the WASH Cluster to pool resources and purchase better quality field level monitoring equipment and just focus on critically important water quality parameters rather than send samples to laboratories who are producing unreliable data. To better understand the levels of inaccuracy in laboratory data, the WASH Cluster members should be integrating various QA/QC tests into the water quality sampling and testing protocols and the results should be shared amongst members to help identify the most competent laboratory service(s).

Fit water points with Dipper Pipes

After pumps are installed, drilled wells are closed under a concrete block. Consequently, there is no point of access to monitor groundwater levels. For the current project, NIHSA and AAH needed to remove and replace some of these concrete blocks in order to install permanent downhole loggers. Whilst this is acceptable in the case of installing a permanent instrument, it is not a feasible approach in the case of taking manual routine

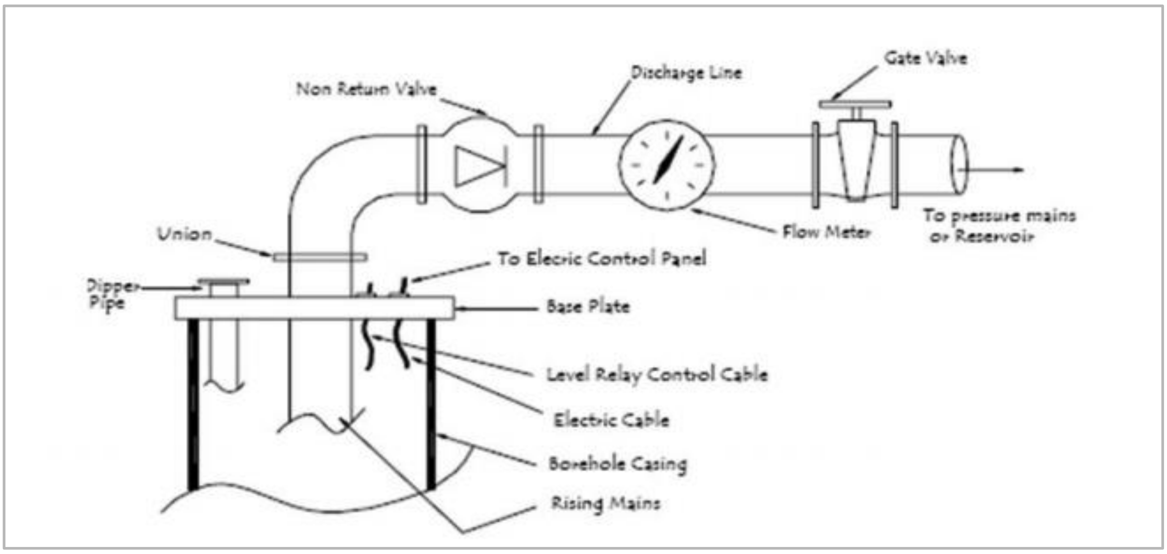


Figure 17: Illustration of a well head with dipper pipe to allow the deployment of groundwater monitoring probes (Source: Code of Practice for Water Well Construction in Nigeria, National Water Resources Institute, 2010)

monthly measurements as part of monitoring circuit by local authorities, or in the case of ad-hoc measurements by WASH Cluster staff when conducting functionality census or water safety monitoring. Therefore, it is recommended that the WASH Cluster make it a requirement that dipper access pipes are included in the design and final construction of water points proposed by contractors (both for new wells and rehabilitated wells).

Managing Data

Build, Operate & Maintain Groundwater Database and Information System

Select Cloud-Hosted Platform go link data collection to data management

The WASH Cluster Water Supply Sub Technical Working Group on Groundwater Management, Monitoring & Information Systems should carry out further study to propose the most suitable platform for universal cloud-hosted mobile device technology for universal adoption by all sector actors involved in the creation of both water point functionality and groundwater resource data and information. As a priority, the working group should evaluate the suitability of the mWater platform uploading, managing, visualising and sharing groundwater data.

Fund the work of a database manager to manage Project GIS

There should be continuous development, maintenance and sharing of Project GIS developed by the Consultant. The WASH Cluster should fund the work of a geospatial database manager to run QA/QC, perform various analytics, and generate a range of reports / alerts matched to different needs of data users. Over time, the goal of the database manager should be to achieve increasing levels of automation through the power of machine based learning algorithms.

Archive existing groundwater data and hydrogeological information to Project GIS

To be led by the database manager, and with the support of the University of Maiduguri Department of Geology, carry out the work of manually registering and transcribing all existing water bore records from the WASH Cluster members and other key WASH sector stakeholders, including the RuWASSA and private water bore drilling companies, into a standardised geospatial database.

Re-process, image and depth model existing airborne geophysical data

The currently available airborne magnetic survey data should be reprocessed, imaged and depth modelled by international experts from the oil and gas industry. Better information on igneous intrusions, depth to basement, and basement faults, which can be elicited in part from potential field geophysical survey data like magnetics, when integrated with more traditional hydrogeological information and groundwater data will aid exploration efforts - especially exploration for deeper groundwater basin systems or groundwater in the bedrock areas.

Using Data

Publish groundwater monitoring data online

To promote the use of various types of groundwater monitoring data, and to enhance the communication and advocacy potential of monitoring data, the WASH Cluster should invest in the development of a streamlined website where the data can be explored by way of trend lines, maps, tabulations that highlight various exceedance cases around either water quality, water levels, as well as water point functionality.

Review Nearby Geological Logs

When planning and implementing water bore drilling activities, the historical geological logs, which have now been uploaded into the GIS, should be studied carefully to understand the stratigraphic associations and patterns. To illustrate the practical value of reviewing nearby geological logs, consider the example shown in Figure 18. It shows geological logs for 3 boreholes drilled by USGS-GSN. Bores 3078 and 3079 were less than 330 metres depth, both terminating in a blue-grey clay layer whereas bore 3076 situated 25 km further east, intersected a better medium to coarse sand horizon below 330 metres. The Middle Chad Formation zonation maps developed by Miller et al (1968) define the area to the west as low-yield, when they may simply be a reflection of the fact that drilling was shallower than actually required.

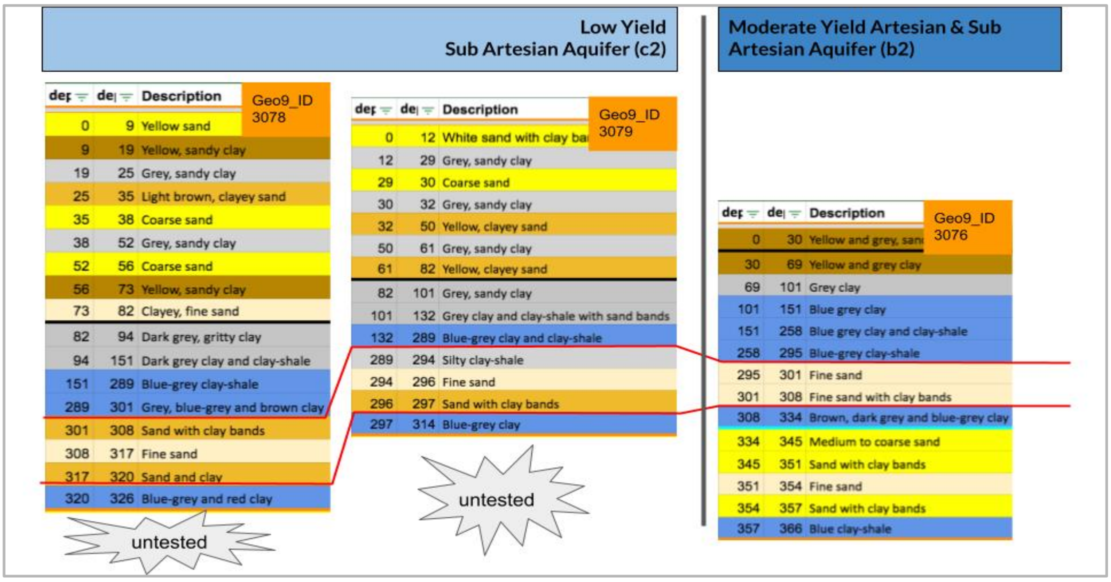


Figure 18: Comparison of geological logs

Oversight of WASH Cluster Performance

Improve the capture, storage and sharing of groundwater data: Provide oversight to ensure that whenever the opportunity to gather groundwater measurements, or record hydrogeological information presents itself (e.g. water bore drilling, repair and / or rehabilitation of water points, routine maintenance activities, functionality monitoring, etc.) members of the WASH Cluster are doing this and that the groundwater monitoring data being submitted is comparable to total water supply work programs these organizations report completing.

LGA Council Groundwater Monitoring Plans

To make a contribution to the development of the Hydrological Area VII Resources Strategy and Plan, WASH Cluster members should work with individual LGA Council to undertake their own research and analysis to devise their LGA level hydrological and meteorological monitoring plans, detailing the key sites where they propose to install any permanent instruments, reference sites where to undertake routine monitoring (monthly, quarterly, bi-annually or annually), their monitoring equipment and training needs, organizational plan for monitoring, annual budget and consumables, etc. The data and information systems on groundwater conditions so far assembled, and continuing to grow, should be made accessible to LGA Council teams (especially from the Department of Public Works and the Department of Health) through workshops and training so they can be supported to carry out their own planning to the greatest extent possible. Planning by LGA Councils should be integrated with training and equipping LGA Councils on groundwater monitoring skills.

CONCLUSIONS

At a basic level, effective water resources management requires a clear separation of power between those involved in the implementation of water resource developments and those responsible for the regulation of water resource developments. Until now, the weighting in Nigeria has been heavy on implementation and light on regulation. The Nigerian Federal Government, through the Federal Ministry of Water Resources is working to strengthen the regulation of water resources development, including monitoring activities, through the introduction of a Bill for a national level Water Resources Regulatory Framework. Whilst some very good national standards have been developed such as standards on water quality and water bore drilling, enforcement of these standards has not been effective. Even many of the international NGOs and UN agencies are not managing to comply with these national standards within their programs.

Whenever the opportunity to gather groundwater measurements, or record hydrogeological information presents itself (e.g. water bore drilling, repair and / or rehabilitation of water points, routine maintenance activities, functionality monitoring, etc.) there needs to be capacity to take measurements and a clear chain of command for where those measurements are to be submitted to, and in what format they are reported in.

One promising solution being tested is the MWater platform. Action Against Hunger, Yobe RuWASSA and a number of WASH sector actors implementing projects in North East Nigeria have been successfully using the MWater platform to collect, store and share monitoring data and information about water points and water supply systems. At the present time, these WASH Cluster partners are primarily using the tool to collect and share information about infrastructure, but the MWater tools may be adapted to seamlessly incorporate future water resources data collection activities as well.

INGO and LGA Council teams working on implementation of groundwater supply projects in Borno and Yobe state would benefit from additional equipment and training to improve the quality of their hydrogeological fieldwork and groundwater monitoring activities. To meet the information needs of water resources management in North East Nigeria Hydrological Area VIII, the required investment in hydro-meteorological monitoring activities greatly exceeds the current commitments. In future phases, there needs to be greater attention to funding for the drilling and construction of dedicated groundwater monitoring piezometers. Alternatively, there needs to be far stronger coordination of efforts by the various PE-WASH implementing partners so that monitoring instruments can be factored into the technical design and budgeting discussions with donors when new water bores are being planned for installation.

If States want to develop new knowledge or information tools that can be used to improve groundwater resources development and management, then they will need to take greater individual responsibility for the archive management and quality assured curatorship of their hydrogeological information and groundwater measurement data.

The Consultant has compiled hydrogeological information and groundwater measurement data for Borno and Yobe States from different sources. This data is accessible to the WASH Cluster members via a Geographical Information System (GIS) project. Priority has been given to information and data from the major scientific surveys previously carried out. There is still much more hydrogeological information and groundwater measurement data that exists which should be added to the GIS.

Based on literature review, and independent analysis of the data using the newly built Geographical Information System, the authors have come up with a revised interpretation of the hydrogeological setting and pattern of change of groundwater conditions over time. This has been undertaken to identify and better understand the environmental, social and economic problems associated with groundwater development and any major gaps in current hydrogeological knowledge that need to be filled as a priority. Based on preliminary analysis of the multiple layers in the GIS and work in developing the appropriate groundwater monitoring plan for this project, the Consultant identified a number of key research themes for future stakeholder consultation, consensus building and investigation. This includes further investigations of the Bama Ridge sand barrier aquifer; dam building and irrigation development (e.g. Kano River Irrigation Scheme - KRIS; and Hadejia Valley Irrigation Scheme - HVIS) along the Hadeja and Jammara tributaries of the Komadougou-Yobe River; flow of the Ngadda River into, and impact of Alau Dam on Jere Bowl; deep test well drilling of the Consultant's hypothesis (based on the depth to magnetic basement model (Goni et al., 2014) that the artesian basin may extend west of the Bama Ridge into parts of Yobe State; groundwater and land use in a zone spanning parts of Magumeri, Gubio, Naganzi, Guzamala, Monguno and Kukawa LGAs in Borno State; deep exploration targets in the Gubio Sub-Basin and feasibility of water supply for Maiduguri City and the Jere Food Bowl; determining local to regional scale hydrogeological setting of floodplains and wetlands; development opportunities of the Upper Chad Formation water table aquifer system at a regional scale, and obtaining a better understanding of Basin recharge and hydrodynamics including the extent of groundwater resources in the underlying cretaceous sedimentary basins and fractured crystalline basement and its probable contribution to the currently used artesian system.

The roles and responsibilities for various partners and stakeholders for groundwater monitoring and information management need to be better defined and there needs to be greater commitment of resources for technical equipment, training and operating expenses. While it is the responsibility of the NIHSA to install and maintain a national hydrological monitoring network for Nigeria, including a sub-network of dedicated groundwater observation wells, we have found that the NIHSA cannot meet the demand for groundwater information alone. The aquifer systems are too complex; the past, present and future rates of groundwater exploitation too intensive; and the largely remote and often insecure nature of the operating environment too challenging for a relatively fledgling Federal organization with a small office in Maiduguri to effectively monitor on its own. NIHSA needs to have strong and effective alliances with the PE-Wash strategic partners committed to following common monitoring guidelines and to ensure the monitoring strategy meets the objectives of as many participants as possible.

PROJECT RECOMMENDATIONS

The following recommendations have been complied as a result of the extensive work undertaken to date by the Consultant and the TWG. They have been prioritised in order of importance and all will build upon the success to date and lead to improved future outcomes for the nation and its people.

1) **Data**
   a) **Ensure Systematic Collection of Measurement and Monitoring data**: Whenever the opportunity to gather groundwater measurements, or record hydrogeological information presents itself (e.g., water bore drilling, repair and / or rehabilitation of water points, routine maintenance activities, functionality monitoring, etc) ensure data and results are captured and shared with relevant State Ministry of Water departments.
   b) **Adapt MWATER Platform for easy use in the field:** WASH Cluster and partners to work with the MWater tool and adapt it to incorporate future water resources data collection activities. ACF have concluded there should be clear instruction from the Ministry of Water Resources of Borno State for all members of the WASH Cluster to adopt the MWater platform for registering water points. WASH Cluster members should be encouraged to advocate to relevant State and Federal bodies that the new practices and technologies be implemented.
   c) **Improve hydrogeological fieldwork**: Provision of additional equipment and training to improve the quality of their hydrogeological fieldwork and groundwater monitoring activities for INGO and LGA Council teams. It should also become a requirement that a hydrogeologist be present on site to undertake logging of geological data and supervise the design and construction phases.
   d) **Digitise and Share Records:** Continue with compilation of archival drilling records, digitisation and incorporation into GIS. This will require a concerted effort and commitment by all parties involved in drilling and exploration works
2) **Ensure Standards are respected:** Ensure INGO and UN agencies are complying with National Standards for water quality and water bore drilling.
3) **Expand TWG participation and membership**: investigate expanding the TWG activities across all States of North East Nigeria, to involve other State RuWaSSA's and consider the inclusion of other water industry participants to enable greater cooperation and efficiency. For example, it is conceivable that more collaborative projects and PPP's will be required for the development of Nigeria's future water management and these initiatives would benefit greatly from coordination of data and activities in the TWG.
4) **Investigate key research themes:** Based on the preliminary analysis of the GIS and developing the groundwater monitoring plan for this project, the Consultant identified at least six research themes for future stakeholder consultation, consensus building and investigation.
5) **Improving GIS Update methodology:** Use satellite imagery to geo-locate water points, digitization of the 1:1,000,000 Scale Geological Map and increased exchange with the MWater platform. Investigate implementing a regular update cycle of all information, systems and new user training.
6) **Expand hydro-meteorological monitoring**: To meet the future information needs of water resources management in North East Nigeria Hydrological Area VIII, expand the process into wider areas.
7) Consideration should be given to the re-invigoration of historical system for collection of meteorological data that applied before the conflict (i.e., schools collecting rain water data)
8) **Ongoing independent auditing of all processes:** an ongoing independent auditing process should be implemented to ensure all processes from field work, data collection, uploading and analysis are occurring

9) effectively and in line with the required Standards. This should also include the design, construction and operations of new wells.
10) NIHSA to coordinate expanded use of GIS: Based on the experience gained from the project, the Consultant specialists to support further expansion and use of the GIS with NIHSA and all stakeholders. Initial discussions with project participants support the aim to build on the momentum the project has already achieved. The recommendation includes continuing discussions with NIHSA on further developing the GIS, making it available on-line in real time, to provide improved access in areas of poor internet connections, and to expand its availability to other users / groups / organisations. NIHSA has been identified by project participants as suitable organisation to take the lead and develop the GIS as an example of government support and leadership. Based on experience and background, ACF has recommended that the Ministry of Water Resources of Borno State support their desire to have the Consultant to act and manage the hub to the WASH Cluster for hydrogeological information and groundwater measurement data systems development and management moving forward.
11) Consideration should be given to longer term objectives and initiatives for Groundwater Management which could include:
    a) Develop Hydrological Area VIII Resources Strategy and Plan
    b) Numerical Groundwater Model Development
    c) Technical Collaboration with National Petroleum Corporation
    d) Addressing Human Health Risks associated with Unsafe Groundwater
    e) Establishing a Water Fund for the city of Maiduguri
    f) Auditing
    g) Information, Education & Communication

REFERENCES & LITERATURE SOURCES

These literature sources and references have been identified and sourced by the Consultant in the course of the project. As part of the long term development of Knowledge Management Systems, the Consultants have collected many useful references relating to hydrogeology and groundwater in North East Nigeria and the portion of the Chad Basin. These are listed in full here as reference and we anticipate this central list of resources to develop over time and be included in a future data online portal.

Abubakar, M.B., 2014. Petroleum Potentials of the Nigerian Benue Trough and Anambra Basin: A Regional Synthesis. Natural Resources, 2014, 5, 25-58.

Adamu, S., Allamin, M., Sani, A., and Joseph, M.V., 2013. Evidence of Drawdown Cone in Chad Formation of Chad Basin of Northeastern Nigeria. Research Journal in Engineering and Applied Sciences 2(3)230-237.

Adefila, S.F., 1975. Decline in the Pressure of the Middle Aquifer of the Chad Formation in Parts of the South Eastern Niger and North Eastern Nigeria. J. Mining and Geology, 12: 23-26.

Agbo, J.U. and Goni, I.B., 1995. A review of the Geology and Sedimentology of the Bama Ridge in parts of North East Nigeria. Faculty Research Journal of Science, University of Maiduguri, Vol.2 PP. 11-30

Agbonifo, P.E., 2016. Risk Management and Regulatory Failure in the Oil and Gas Industry in Nigeria: Reflections on the Impact of Environmental Degradation in the Niger Delta Region. Journal of Sustainable Development; Vol. 9, No. 4; 2016.

Akanji, A.O., Sanuade, O.A., Osinowo, O.O., Okafor, O., 2020. Interpretation of High Resolution Aeromagnetic Data for Hydrocarbon Exploration in Bornu Basin, Northeastern, Nigeria. ANNALS OF GEOPHYSICS, 63, 2, GM222, 2020; doi:10.4401/ag-8064

Aitchison, P.J., Bawden, M.G., Carroll, D.M., Glover, P.E., Klinkenberg, K., de Leeuw, P.N., and Tuley, P., 1972. The Land Resources of North East Nigeria Volume 1 - The Environment. Foreign and Commonwealth Office Overseas Development Administration

Armitage, S.J., Bristow, C.S. and Drake, N.A., 2015. West African monsoon dynamics inferred from abrupt fluctuations of Lake Mega-Chad. In: Proceedings of the National Academy of Sciences, June 2015

Babagana, A., Dungus, B., Bello, S.A., and Kolo, B.S., 2015. Problems and prospects of Alau dam construction in alau community, konduga local government area, Borno state, Nigeria. European Scientific Journal July 2015 edition vol.11, No.20 ISSN: 1857 – 7881 (Print) e - ISSN 1857- 7431. pp. 194 - 207.

Bakari and Akunna, 2013 impact of anthropogenic and natural sources of contamination on the groundwater quality of the Upper unconfined aquifer system of the Chad Basin around Maiduguri.

Bakari, A., 2014. Hydrochemical assessment of groundwater quality in the Chad Basin around Maiduguri, Nigeria. Journal of Geology and Mining Research. Vol. 6(1), pp. 1-12, January, 2014

Bako, M., Adetola, B.A., and Umaru, A.F.M., 1998. The Chad Basin Aquifers: New evidence from seismic reflection sections and wireline logs. Water Resources Journal of NAH Vol 9.

Barber, D.F.M., 1965. Pressure Water in the Chad Formation of Bornu and Dikwa Emirates, North-Eastern Nigeria. Geological Survey of Nigeria Bulletin No. 35.

Barber, W., Dousse, B., 1965. Rise in the water-table in parts of Potiskum area. Bomu state. Further observations. Geol. Surv. Niger. 9, 1-21.

Barber, W.M., and Jones, D.R., 1960. Geology and Hydrology of Maiduguri. Records of Geological Survey, Borno State Province.

Bouchez, C., Goncalves, J., Deschamps, P., Vallet-Coulomb, C., Hamelin, B., Doumnang, J-C., Sylvestre, F., 2016. Hydrological, chemical, and isotopic budgets of Lake Chad: A quantitative assessment of evaporation, transpiration and infiltration fluxes. Hydrology and Earth System Sciences 20(4): 1599-1619.

Bouchez, C., Deschamps, P., Goncalves, J., Hamelin, B., Nour, A.M., Vallet-Coulomb, C., and Sylvestre, F., 2019. Water transit time and active recharge in the Sahel inferred by bomb-produced 36Cl. Scientific Reports | (2019) 9:7465.

Bukar, S., Bukar, M., and Adams, F.D.,2020. Syn-rift Fluvio-lacustrine Depositional System Of The Cretaceous Bima Formation In The Gongola Sub – Basin, Northern Benue Trough, NE Nigeria. International Journal of Research -GRANTHAALAYAH, 8(9), 54-62. https://doi.org/10.29121/granthaalayah.v8.i9.2020.1327

Bura, B. and Goni, I.B., 2012. Tracing the factors influencing occurrence of fluoride in groundwater of the Middle zone aquifer in Borno State, NE Nigeria. Journal of Mining and Geology, Vol. 48. Pp. 177 – 184.

Bura, B., Goni, I. B., Sheriff, B.M. and Gazali, A. K., 2018. Occurrence and distribution of fluoride in groundwater of Chad Formation aquifers in Borno State, Nigeria. International Journal of Hydrology. Vol. 2 (4). 528-537.

Burke, K., 1976. The Chad Basin: An active intra-continental basin. Tectonophysics

Volume 36, Issues 1–3, 24 November 1976, Pages 197-206.

Candela et al., 2014 groundwater modeling with limited data sets: at the Chari-Logone area (Lake Chad Basin, Chad).

Carmalt & Tibbetts, 1969. “Water Levels and Artesian Pressures in the Chad Basin of North Eastern Nigeria, 1963-68”. USGS Open File Report 72-61.

Carter J.D., and Barber W., 1958. The Rise in the Water Table in Parts of Potiskum Division, Borno Province. Records of the Geological Survey of Nigeria

Carter, J.D., Barber, W., Tait, E.A and Jones, G.P., 1963. The Geology of parts of Adamawa, Bauchi and Bornu Provinces of North-Eastern Nigeria. Explanation of 1:250,000 Sheets Nos. 25, 36 and 47. Ministry of Mines and Power Geological Survey of Nigeria Bulletin No. 30.

Carter, R., 1994. The groundwater hydrology of the Manga Grasslands, northeast Nigeria: importance to agricultural development strategy of the area. In: Quarterly Journal of Engineering Geology and Hydrogeology volume 27.

Chuks-Ezike, C.I., 2018. Environmental crime liability of the Nigerian government in its oil pollution menace. Environmental Risk Assessment and Remediation (2018) Volume 2, Issue 2.

Colchester, F.E., Marais, H.G., Thomson, P., Hope, R., and Clifton, D.A., 2017. Accidental infrastructure for groundwater monitoring in Africa. Environmental Modelling & Software Volume 91, May 2017, Pages 241-250.

Consulint, 1979. Maiduguri water supply: Hydrogeological report Vol.1 Hydrogeology and future exploitation of groundwater.

Cratchley, C.R., Louis, P., and Ajakaiye, D.E., 1984. Geophysical and geological evidence for the Benue-Chad Basin Cretaceous rift valley system and its tectonic implications. Journal of African Earth Sciences, Vol. 2, No.2. pp. 141 to 150.

C. Deniel, P. M. Vincent, A. Beauvilain & A. Gourgaud, 2015. The Cenozoic volcanic province of Tibesti (Sahara of Chad): major units, chronology, and structural features. Bulletin of Volcanology volume 77, Article number: 74 (2015)

Dibal, H.U., Dajilak, W.N., Lekmang, I.C., Nimze, L.W., and Yenne, E.Y., 2017. Seasonal Variation in Fluoride Content in Groundwaters of Langtang Area, Northcentral Nigeria. Contemp.Trends.Geosci., 6(1),2017,11-27.

Du Preeze, J.W., and Barber, W., 1965. The distribution and chemical quality of groundwater in northern Nigeria. Federal Ministry of Mines and Power, Lagos (Nigeria)

Durand, A., 1982. Oscillations of Lake Chad over the past 50,000 years: New data and new hypothesis. Palaeogeogr. Palaeoclimatol. Palaeoecol. 39: 37-53.

Déruelle B, Ngounouno I, Demaiffe D (2007) The ‘Cameroon Hot Line’ (CHL): a unique example of active alkaline intraplate structure in both oceanic and continental

lithospheres. C R Geosci 339: 589–600

M.DescloitresaK.ChalikakisbA.LegchenkoaA.M.MoussacP.GenthondG.FavreaudM.Le CozdM.BoucheraM.Oïd. Investigation of groundwater resources in the Komadougou Yobe Valley (Lake Chad Basin, Niger) using MRS and TDEM methods. In: Journal of African Earth Sciences Volume 87, November 2013, Pages 71-85

Edmunds W.M., and Smedley, P.L., 2005. Fluoride in Natural Waters In: Selinus, O et al (Ed) Essential of Medical Geology, Springer. Pp 311 - 336

Edmunds, W.M., Fellman, E., and Goni, I.B., 1999. Lakes, groundwater and palaeohydrology in the Sahel of NE Nigeria: Evidence from hydrogeochemistry. J. Geol. Soc. 156(2):345-355.

Edmunds, W.M., Fellman, E., Goni I.B., McNeill, G., and Harknesss, D.D., 1997. Groundwater, paleoclimate and palaeo recharge in the SW Chad Basin. Borno State, Nigeria. In: Isotope techniques in the study of past and current environmental changes in the hydrosphere and the atmosphere. IAEA,Vienna

Edmunds, W.M., Fellman, E., Goni, I.B., and Prudhomme, C., 2002. Spatial and temporal distribution of groundwater recharge in northern Nigeria. Hydrogeology Journal (2002) 10:205–21.

Fairhead, J. D. and Green, C. M. 1989. Controls on rifting in Africa and the regional tectonic model for the Nigeria and Niger rift basins. Journal African Earth Sciences 8:231–249.

FAO. 2021. Evaluation of the FAO response to the crisis in the Lake Chad Basin 2015–2018. Programme Evaluation Series, 01/2021. Rome.

FMWR. 2000. "National Water Supply and Sanitation Policy." Federal Ministry of Water Resources (FMWR), Department of Water Supply and Quality Control, Abuja.

FMWR. 2003. "Water Resources Management Institutions in Nigeria: Institutional Mapping Report." Draft Report, Federal Ministry of WaterResources (FMWR), Abuja.

FMWR, 2012. The Project for Review and Update of Nigeria National Water Resources Master Plan Progress Report 2 - Summary.

FMWR, 2016a. Partnership for Expanded Water, Sanitation & Hygiene (PE-WASH) Programme Strategy 2016 - 2030.

FMRW, 2016b. Draft Water Bill Version 5.

Genthon, P., Hector, B., Luxereau, A., Descloitres, M., Abdou, H., Hinderer, J., and Bakalowicz, M., 2015. Groundwater recharge by Sahelian rivers—consequences for agricultural development: example from the lower Komadougou Yobe River (Eastern Niger, Lake Chad Basin). Environmental Earth Sciences. 74. 10.1007/s12665-015-4119-y.

Goes, B. J. M. & Zabudum, A. N. (1996, 1998 and 1999) Hydrology of the Hadejia-Jama 'are-Yobe River Basin: 1992-95, 1996-97, 1998-9. IUCN-Hadejia-Nguru Wetlands Conservation Project, Nigeria.

Goes, B.J.M., 1999. Estimate of shallow groundwater recharge in the Hadejia-Nguru Wetlands, semi-arid north-eastern Nigeria. Hydrogeology Journal 7, p. 294-304.

Goni, I.B., Kachalla, M., and Aji, M.M., 2000. Another look at the Piezometric Head Declines in the Middle Zone Aquifer of the Chad Formation in the South Western Chad Basin. Borno Journal of Geology. Vol.2. No.2: pp. 51-64

Goni, I.B., Nur, A., Mbusube, A.M., Yusuf, S.N., and Sheriff, B.M., 2016. Estimating the Sedimentary Thickness of the Bornu Basin Using Spectral Analyses of High Resolution Aeromagnetic Data. Journal of Mining and Geology Vol. 52(1) 2016. pp. 83 - 92.

Goni, I.B., Sheriff, B.M., Kolo, A.M., Ibrahim, M.B., 2019. Assessment of nitrate concentrations in the shallow groundwater aquifer of Maiduguri and environs, Northeastern Nigeria

Goni, I.B., Travi, Y., and Edmunds, W.M., 2005. Estimating groundwater recharge from modeling unsaturated zone using chloride profile on the Nigerian sector of the Chad Basin. Journal of Mining Geology Vol.41 No.1.

Griffin, D.L., 2006. The late Neogene Sahabi rivers of the Sahara and their climatic and environmental implications for the Chad Basin. Journal of the Geological Society, 163, pp. 905-921.

Halliday AN, Dickin AP, Fallick AE, Fitton JG (1988) Mantle dynamics: a Nd, Sr, Pb and O isotopic study of the Cameroon Line volcanic chain. J Petrol 29:181–211

Hamza, H., and Hamidu, I., 2011. Hydrocarbon resource potential of the Bornu Basin North Eastern Nigeria. Global Journal of Geological Science Vol. 10, No. 1 2012, pp. 71-84. ISSN 1596-6798.

Handa, R.K (1975): Geochemistry and genesis of fluoride-containing Groundwater in India, GW, 13, pp 275-281.

Hazell, J.R.T., and Barker, M., 1995. Evaluation of alluvial aquifers for small-scale irrigation in part of the southern Sahel, West Africa. Quarterly Journal of Engineering Geology and Hydrogeology, 28, S75-S90, 1 February 1995.

IAEA, 1972. International Atomic Energy Agency report to the Lake Chad Basin Commission analysis and interpretation of environmental isotope data

Idon, P.I., and Enabulele, J.E., 2018. Prevalence, severity, and request for treatment of dental fluorosis among adults in an endemic region of Northern Nigeria. European Journal of Dentistry, 2018 Apr-Jun; 12(2): 184–190.

IGRAC, 2008. Guideline on: Groundwater monitoring for general reference purposes. Report nr. GP 2008-1.

Ikusemoran, M., Alhaji, M. and Abdussalam, B., 2018. Geospatial Assessments of the Shrinking Lake Chad. Adamawa State University Journal of Scientific Research

ISSN: 2251-0702 (P) Volume 6 Number 1, April, 2018; Article no. ADSUJSR 0601026

Isiorho, S.A., and Matisof, G., 1990. Groundwater recharge from Lake Chad. Limnology and Oceanography Volume35, Issue4 June 1990. Pages 931-938

Isiorho, S.A., and Matisof, G., and Wehn, K.S., 1996. Seepage Relationships Between Lake Chad and the Chad Aquifers. Ground Water 34(5):819 - 826 · September 1996

Kiser, R. T., 1968, Chemical Quality of Water in Northern Nigeria, 1965-68: U.S. Geol. Survey open-file report, 41 p., 1

Konate, M., Ahmed, Y., and Harouna, M., 2019. Structural evolution of the Téfidet trough (East Aïr, Niger) in relation with the West African Cretaceous and Paleogene rifting and compression episodes. Comptes Rendus Geoscience Volume 351, Issue 5, June–July 2019, Pages 355-365

Lar, U.A., Dibal, H., and Schoeneich, K., 2014. Fluoride in groundwater in Nigeria: Origin and health impact. American Journal of Environmental Protection 2014; 3(6-2): 66-69

LCBC, 1973. Comprehensive study of the water resources of the Chad basin for development

Le Heron, D.P and Craig, J., 2008. First-order reconstructions of a Late Ordovician Saharan ice sheet. Journal of the Geological Society, 165, 19-29, 14 January 2008.

Lemoalle J., Bader J., Leblanc, M., and Sedick A., 2012. Recent changes in Lake Chad: Observations, simulations and management options (1973–2011) Global and Planetary Change. 2012;80–81:247–254. doi: 10.1016/j.gloplacha.2011.07.004.

Lopez, T., Antoine,R., Kerr, Y., Darrozes, J., Rabinowicz, M., Ramillien, G., Cazenave, A., and Genthon, P., 2016. Subsurface hydrology of the Lake Chad Basin from convection modelling and observations. Surveys in Geophysics, Springer Verlag, 37 (2), pp.471-502.

Luxereau, A., Genthon, P. & Ambouta Karimou, J.M., 2012. Fluctuations in the size of Lake Chad: consequences on the livelihoods of the riverain peoples in eastern Niger. Reg Environ Change 12, 507–521 (2012). https://doi.org/10.1007/s10113-011-0267-0

Maddaloni, F., Braitenberg, C., De Min, A., Schuster, M., Pivetta, T., and Morsut, F., 2020. Gravimetry and petrophysics of the Chad basin area: determining the depth of the basement and the implication for defining a scientific drilling site (ICDP-CHADRILL project).

Maduabuchi, C., Faye, S., and Maloszewski, P., 2006. Isotope evidence of palaeorecharge and palaeoclimate in the deep confined aquifers of the Chad Basin, NE Nigeria. Environment 370(1):467-479.

Maduabuchi, C., Maloszewski, P., Stichler, W., and Eduvie, M., Preliminary interpretation of environmental isotope data in the Chad Basin aquifers, NE Nigeria (IAEA-CN-104/P-12). In: Isotope Hydrology and Integrated Water Resources Management, Unedited Proceedings of International Symposium held in Vienna, 19–23 May 2003.

Mahamat Nour, A., Vallet-Coulomb, C., Bouchez, C., Ginot, P., Doumnang, J. C., Sylvestre, F., and Deschamps, P., 2020. Geochemistry of the Lake Chad Tributaries Under Strongly Varying Hydro-climatic Conditions. Aquatic Geochemistry volume 26, pages 3–29 (2020)

Mahmood, R., Jia, S., Mahmood, T., and Mehmood, A., 2020. Predicted and Projected Water Resources Changes in the Chari Catchment, the Lake Chad Basin, Africa. Journal of Hydrometeorology Volume 21, Issue 1

Mayomi, I., and Mohammed, J.A., 2014. A Decade Assessment of Maiduguri Urban Expansion (2002 - 2012): Geospatial Approach. Global Journal of Human Social Science. Retrieved 19 October 2019.

Mbowou, G.I.B., Lagmet, C., Nomade, S., Ngounouno, I., Durelle, B., and Ohnenstetter, D., 2012. Petrology of the Late Cretaceous peralkaline rhyolites (pantellerite

and comendite) from Lake Chad, Central Africa. Journal of Geosciences, 57 (2012), 127–141

Mémin, A., Ghienne, J-F., Hinderer, J., Roquin, C., and Schuster, M., 2020. The Hydro-Isostatic Rebound Related to Megalake Chad (Holocene, Africa): First Numerical Modelling and Significance for Paleo-Shorelines Elevation. Water 2020, 12(11), 3180

Miller, R.E., Johnston, R.H., Oluwu, J. A. I. and Uzoma, J. U., 1968. Ground-Water Hydrology of the Chad Basin in Bornu and Dikwa Emirates, Northeastern Nigeria, with Special Emphasis on the Flow Life of the Artesian System. Geological Survey Water Supply Paper 1757-1.

Nadar, K., and Nwozor, R., 2016. ICT enabled monitoring fosters greater accountability and improves WASH services in communities (Nigeria). 39th WEDC International Conference, Kumasi, Ghana, 2016 BRIEFING PAPER 2371

Ndehedehe, C., Agutu, N. O., Okwuashi, O., and Ferreira, V. G., 2016. Examined the relationship of El-Niño Southern Oscillation (ENSO) with rainfall, river discharge at Chari river, and Lake Chad water level at Kalomand and Kindjeria.

Ndubisi, O.L., 1990. Managing Groundwater Resources of the Lake Chad Basin in Nigeria. Proceedings of Natural Hydrology Symposium - Maiduguri. Pp 429 – 436.

Nigerian Industrial Standard NCP 027: 2010 Code of Practice for Water Well Construction ICS 23.040.10 Price group G © SON 2010 Approved by SON Governing Council STANDARDS ORGANISATION OF NIGERIA

Nkono, C., Liégeois, J-P., and Demaiffe, D., 2018. Relationships between structural lineaments and Cenozoic volcanism, Tibesti swell, Saharan metacraton. Journal of African Earth Sciences Volume 145, September 2018, Pages 274-283

Nkouathio, D.G., Kagou Dongmo, A., Bardintzeff, J.M. et al. Evolution of volcanism in graben and horst structures along the Cenozoic Cameroon Line (Africa): implications for tectonic evolution and mantle source composition. Miner Petrol 94, 287–303 (2008). https://doi.org/10.1007/s00710-008-0018-1

Odedede, O., and Adaikpoh, E.O., 2011. Sequence stratigraphic analysis of the Gombe Sandstone and lower Kerri–Kerri Formation exposed around Fika-Potiskum, Upper Benue Trough, Nigeria: A consideration for petroleum reservoir indicators. Indian Journal of Science and Technology Vol. 4 No. 5 (May 2011)

Offodile, M.E., 1972. Groundwater Level Fluctuation in the East Chad Basin of Nigeria. Min. Geol. Vol. 7. No. 1&2: 19-34.

Ola-Buraimo, A.O., Abdulganiyu, Y., 2017. Palynology and stratigraphy of the Upper Miocene Chad Formation, Bornu Basin, northeastern Nigeria. China University of Petroleum - Journal of Palaeogeography. Volume 6, Issue 2, April 2017, Pages 108-116

Olugboye, M.O., 1995. Groundwater Monitoring Network as an aid to averting some Ecological Disaster, the Case for Chad Basin Area. Water Resources, Vol. 6 No.1&2: 57-60.

Ostaficzuk, S. (1985): The impact of geology on the vanishing waters of the rivers of Maiduguri. Paper presented at an international conference on arid zone hydrology and water resources, Center for Arid zone studies, University of Maiduguri.

Oteze, G.E., and Fayose, S.A., 1988. Regional Development in the Hydrogeology of Chad Basin. Water Resources Journal, 1, 9-29.

Oteze, G.E., and Ogwude, G.N., 1989. Geodetic surveys in hydrogeological investigations. Water Resources, Vol.1. No.2. Pp. 106 – 110.

Raeburn, C. and Jones, B. 1934. The Chad Basin: geology and water supply. Bulletin Geological Survey Nigeria 15: 61 pp.

Robbins, N., Davies, J., Hankin, P., and Sauer, D., 2002. Groundwater and data – an African experience. In: Waterlines Vol. 21 No. 4 April 2002.

Salman, S.M.A, and Bradlow, D.D., 2006. Regulatory Frameworks for Water Resources Management: A Comparative Study. World Bank, Washington D.C.

Schoenich and Askira, 1990. Maps of thickness and effective porosity for each aquifer.

Scotese et al., 1999; Ordovician Glaciation

J. G. Shellnutt T.-Y. Lee P.-K. Torng C.-C. Yang Y.-H. Lee, 2016. Late Cretaceous intraplate silicic volcanic rocks from the Lake Chad region: An extension of the Cameroon volcanic line? Geochemistry, Geophysics & Geosystems - Volume17, Issue7. July 2016, Pages 2803-2824

Shettima, B., Kyari, A.M., Aji, M.M., and Adams, F.D., 2018. Storm and tide influenced depositional architecture of the Pliocene–Pleistocene Chad Formation, Chad Basin (Bornu Sub–basin) NE Nigeria: A mixed fluvial, deltaic, shoreface and lacustrine complex. Journal of African Earth Sciences. Volume 143, July 2018, Pages 309-320

Subba, R. and Devadas, D. (2003): Fluoride incidence in groundwater in a developing area of Guntur district, Andhra Pradesh India, J. Appl. Geochem 5, pp 94-100

Sulaiman, M.M., Shettima, J., Ndahi, K., Abdul, H., Baba, M.M., Ummate, I., and Hussein, K.,. 2019. Chronic kidney disease of unknown origin in Northern Yobe, Nigeria: Experience from a regional tertiary hospital in northeastern Nigeria. Borno Medical Journal July-December 2019 Vol. 16 Issue 2.

Suleiman, A. A., Magee, C., Jackson, C. A.-L. and Fraser, A. J. 2017. Igneous activity in the Bornu Basin, onshore NE Nigeria; implications for opening of the South Atlantic. Journal of the Geological Society, 174, 667-678, 7 March 2017.

Sutcliffe et al., 2000 Ordovician Glaciation

Sylvestre, F., Schuster, M., Vogel, H., Abdheramane, M., Ariztegui, D., Salzmann, U., Schwalb, A., Waldmann, N., and the ICDP CHADRILL Consortium, 2018. The Lake CHAd Deep DRILLing project (CHADRILL) – targeting ∼ 10 million years of environmental and climate change in Africa. Sci. Dril., 24, 71–78, 2018

Williams, M. (2019). Jebel Marra Volcano. In The Nile Basin: Quaternary Geology, Geomorphology and Prehistoric Environments (pp. 176-195). Cambridge: Cambridge University Press. doi:10.1017/9781316831885.014

Wilson, D.C., 1954. Fluorine content of some Nigerian waters. Nature. 1954;173:305.

WHO, 2011. Guidelines for drinking water quality (4th edn), World Health Organisation.

Yangoin, N.S., & Obajem, N.G., 2004. Depositional environments and reservoir properties of the Gombe Sandstone, Upper Benue Trough, Northeastern Nigeria. 40 Annual International Conference of Nigerian Mining and Geosciences Society, Nigeria

Yusuf, A.K., 2014. Hydrogeological Characterization of the Middle Zone Aquifer in the Nigerian Sector of the Chad Basin. An Unpublished PhD Thesis, University of Maiduguri, 146p.

Yusuf, A.K., 2015. Groundwater Resource Management Strategy in the Nigerian Sector of the Chad Basin. Journal of Natural Sciences Research. Vol.5, No.14, 2015

Yusuf, A.K., Goni I.B., and Hassan, M., 2014. The Declining Middle Zone Aquifer of the Southwestern Chad Basin in the Last Millenium. IOSR Journal of Applied Geology and Geophysics (IOSR – JAGG), Volume 2, Issue 2 Ver.1. Pp 67- 75.

Yusuf, S.N., Kasidi, S., Kuku, A.Y., Ibrahim, Y. and Peter, G.M., 2019. Interpretation of High Resolution Aeromagnetic Data over Potiskum and Environs, Northeastern Nigeria. Journal of Mining and Geology Vol. 55(2) 2019. pp. 139 - 146

Zaborski, P., Ugodulunwa, F., Idornigie, A., Nnabo, P., and Ibe, K., 1997. Stratigraphy and structure of the Cretaceous Gongola Basin, northeastern Nigeria. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine 21:153–185.

Zarma, A.A., 2016. Classification and Nomenclature of the Sandstones of the Bama Ridge, Bornu Sub Basin, North Eastern Nigeria. International Journal of Science and Research (IJSR) Volume 5 Issue 5, May 2016. pp. 935-946.

ANNEXES

This Annex to North East Nigeria Groundwater Surveillance Project Scoping Study is organized into three sections:

Annex 1: Long Term Monitoring of Middle Chad Formation Pressures

Long Term drawdown pattern for the Middle Chad Pressurised Aquifer, plotted as 2nd order polynomial curves, based on a compilation of measurements from 33 of the original USGS-GSN wells reported in Barber (1965) and re-measured in 2007 and 2012 as reported by Adamu et al., 2013

Annex 2: Monthly Monitoring 1963 to 1968 (Carmalt & Tibbitts, 1969)

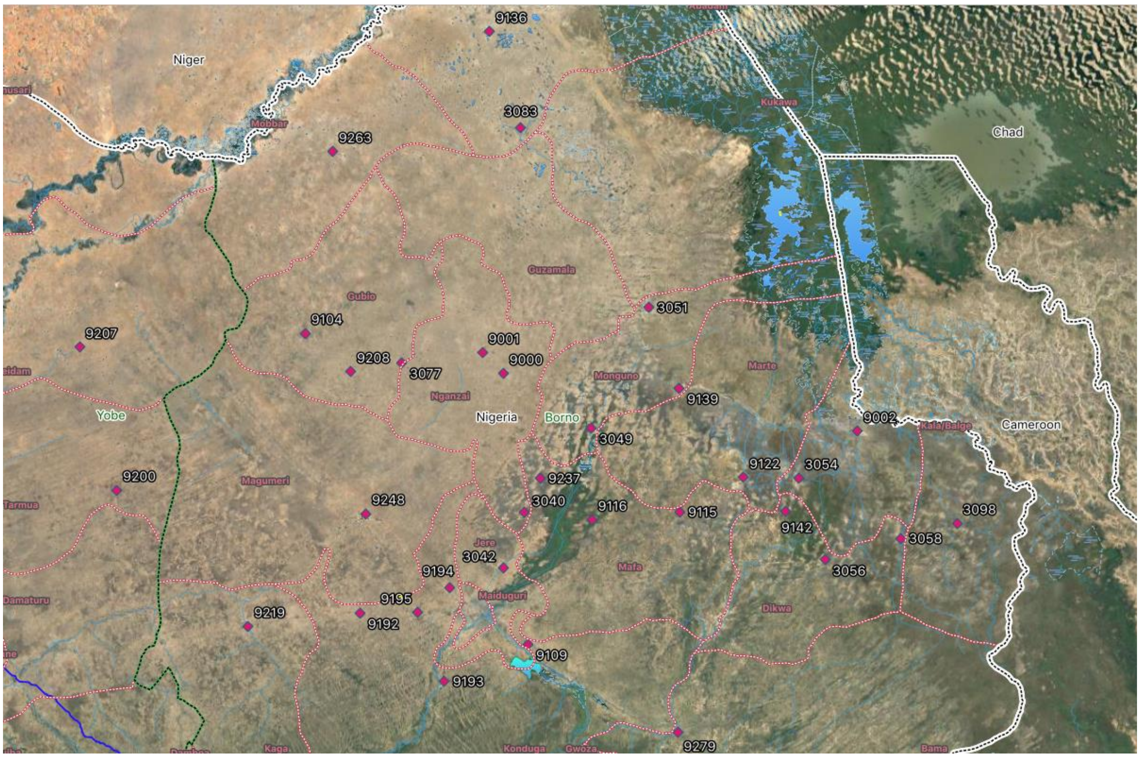
Monthly manual groundwater level measurements that were carried out at sites across Borno State during the period 1963 to 1968 by a team from the Geological Survey of Nigeria and the United States Geological Survey.

Annex 3: Maiduguri City Upper Chad Formation Hydrographs

High frequency monitoring (combination of manual dip meter and automatic data logger) of Upper Chad Formation groundwater levels in and around Maiduguri City carried out by the University of Maiduguri Department of Geology during the 1980's and 1990's (courtesy of Professor Ibrahim Baba Goni).

Annex 1 Long Term Monitoring of Middle Chad Formation Pressures

Location Map of Middle Chad Formation bores re-measured by Adamu et al., 2013

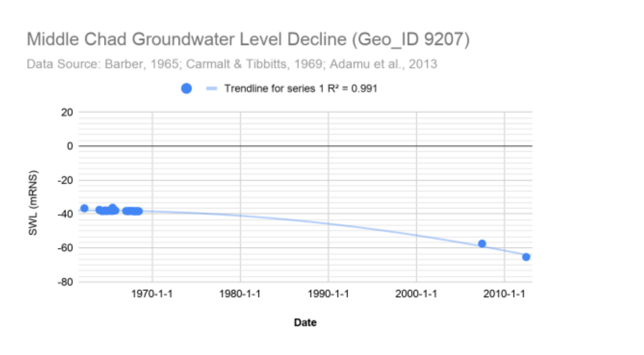


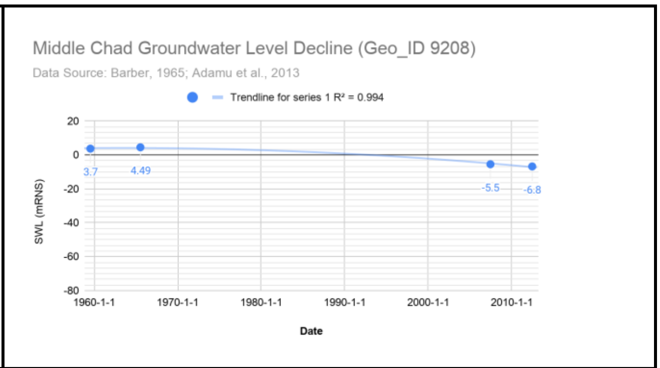
Details of Middle Chad Formation bores measured by Adamu et al., 2013

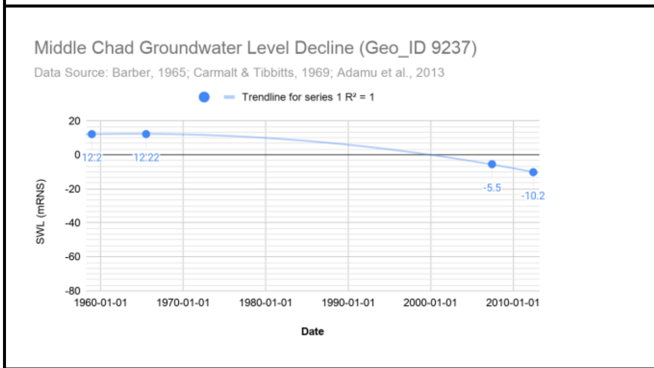
Geo_ID	GSN	Geology	Screen	HydroChem	Latitude	Longitude
9207	GSN 2722	Yes	Yes	No	12.561881	12.026747
9208	GSN 1987	Yes	Yes	No	12.495717	12.780485
9237	GSN 1846	Yes	Yes	No	12.206278	13.305391
9248	GSN 2511	Yes	Yes	No	12.110978	12.822492
9279	GSN 1629	Yes	No	No	11.51625	13.688083
9194	GSN 1832	Yes	Yes	No	11.910937	13.055447
9193	GSN 1647	Yes	Yes	No	11.655168	13.040124
9192	GSN 1555	Yes	Yes	No	11.841349	12.806192
9142	GSN 2084	Yes	Yes	Yes	12.117177	13.986782
9139	GSN 2704	Yes	Yes	Yes	12.451104	13.692923
9122	GSN 2405	Yes	Yes	Yes	12.208979	13.870723
9116	GSN 2708	Yes	Yes	Yes	12.094564	13.450221
9115	GSN 2707	Yes	Yes	Yes	12.115139	13.693593

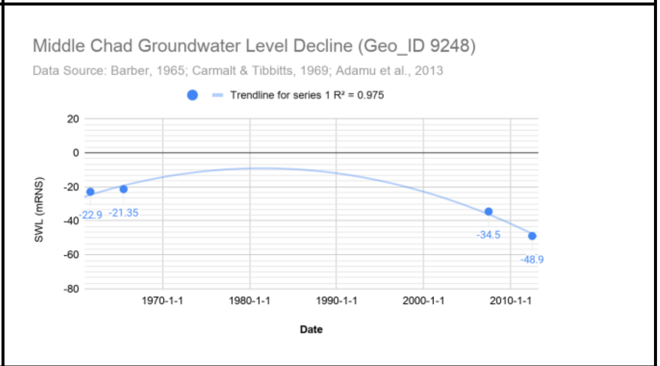
9109	GSN 2274	Yes	Yes	Yes	11.756552	13.273194
9002	GSN 1996	Yes	Yes	Yes	12.334292	14.187569
9001	GSN 1984	Yes	Yes	Yes	12.547325	13.146081
3040	GSN 1649	Yes	Yes	Yes	12.115254	13.262347
3042	GSN 1831	Yes	Yes	Yes	11.964427	13.204438
3049	GSN 1973	Yes	Yes	Yes	12.343216	13.448786
3051	GSN 1980	Yes	Yes	Yes	12.669233	13.607523
3054	GSN 1849	Yes	Yes	Yes	12.207053	14.024546
3056	GSN 2086	Yes	Yes	Yes	11.985633	14.096917
3058	GSN 2090	Yes	Yes	Yes	12.043485	14.306973
3077	GSN 1986	Yes	Yes	Yes	12.520235	12.922389
9000	GSN 1982	Yes	Yes	Yes	12.490759	13.204239
3098	GSN 2094	Yes	Yes	Yes	12.084578	14.463597
3058	GSN 2090	Yes	Yes	Yes	12.043485	14.306973
3056	GSN 2086	Yes	Yes	Yes	11.985633	14.096917
9136					13.415381	13.166175
9263					13.091136	12.730191
3083					13.155646	13.25272
9195					11.84264	12.96626
9104					12.59985	12.653701
9200					12.17477	12.130799
9219					11.804962	12.495356

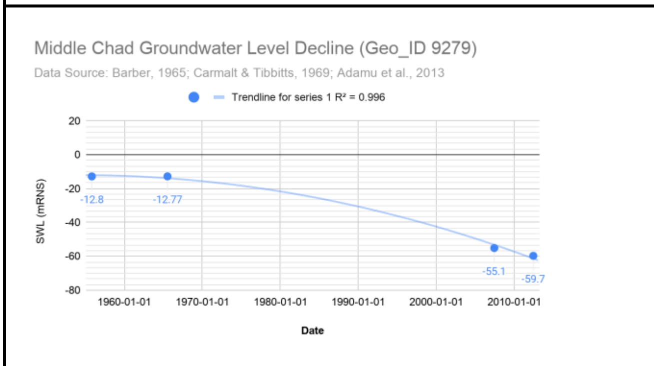
2nd Order Polynomial Curves of Middle Chad Formation groundwater level decline

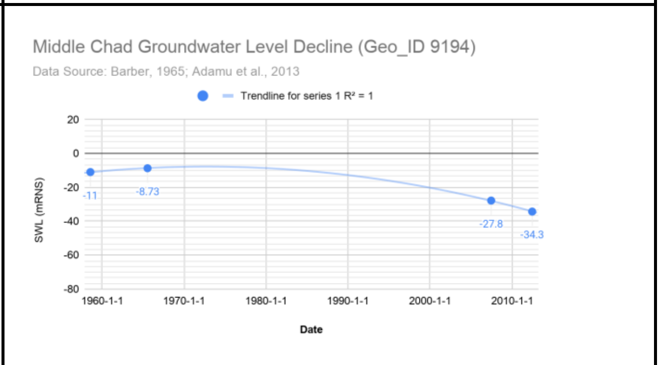


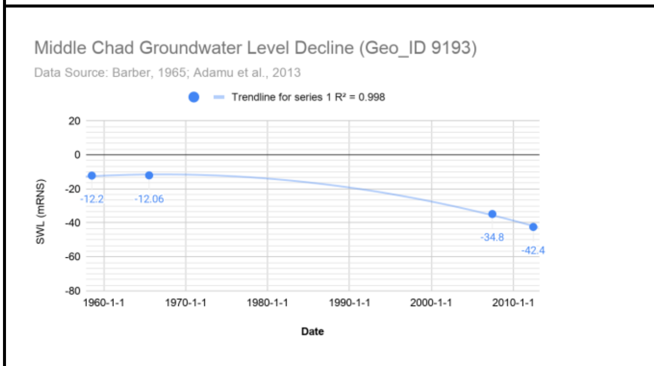


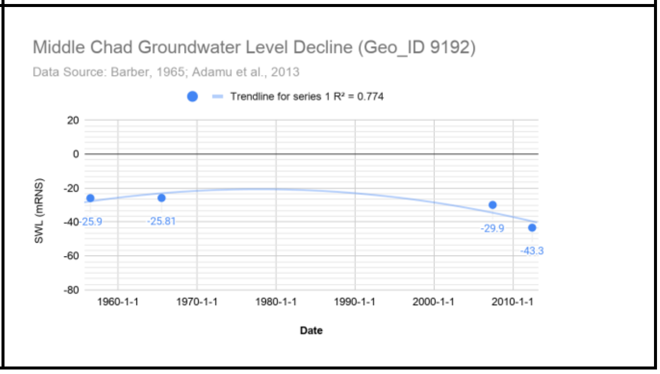


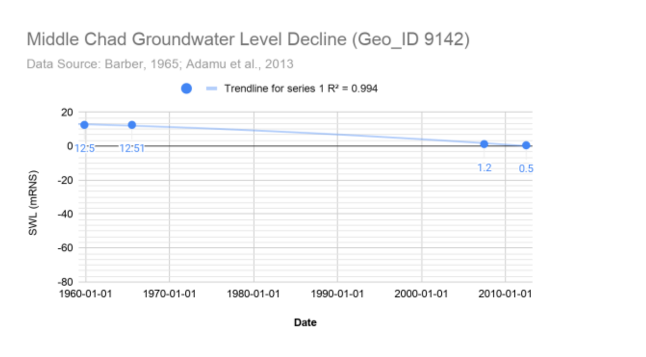


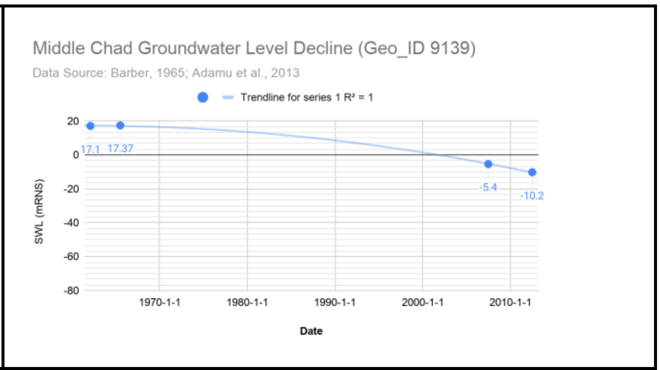


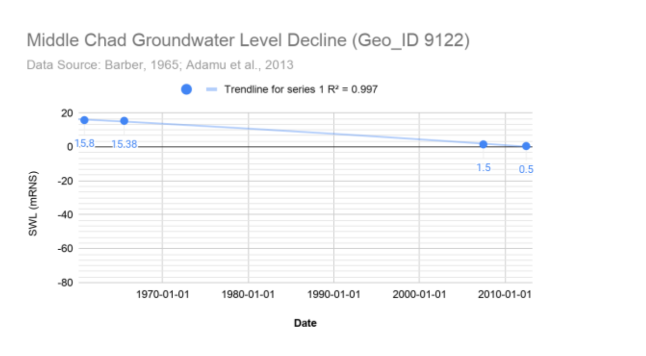


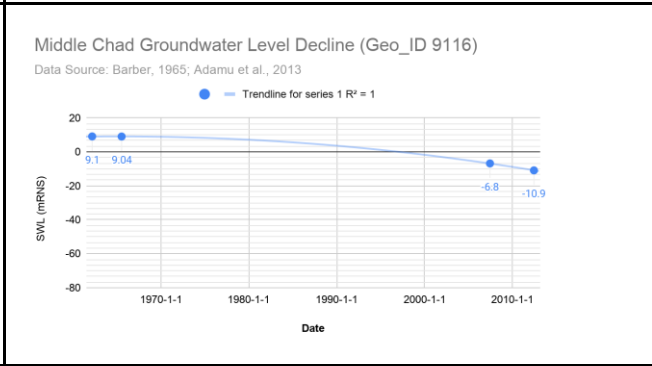


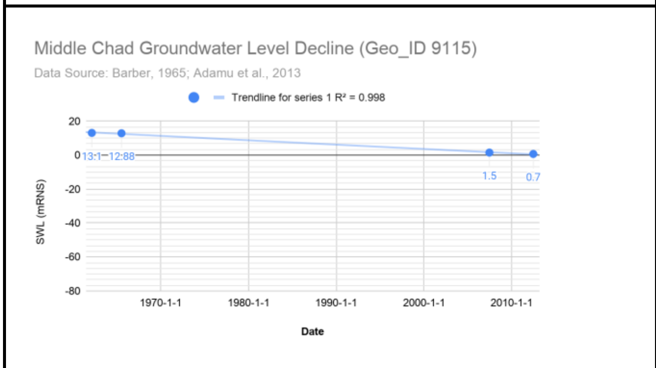


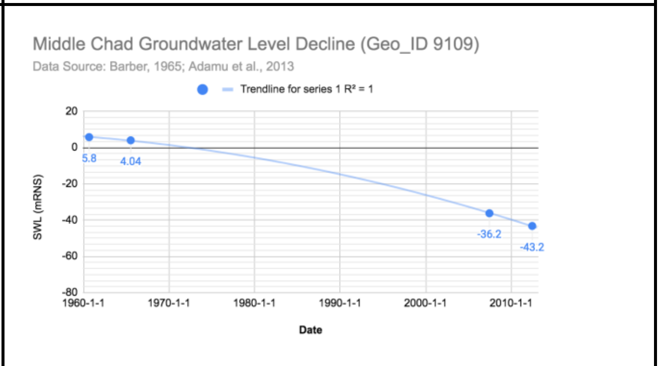

Middle Chad Groundwater Level Decline (Geo_ID 9142)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.994
SWL (mRNS)
20
0
-20
-40
-60
-80
12.5
12.51
1.2
0.5
1960-01-01
1970-01-01
1980-01-01
1990-01-01
2000-01-01
2010-01-01
Date

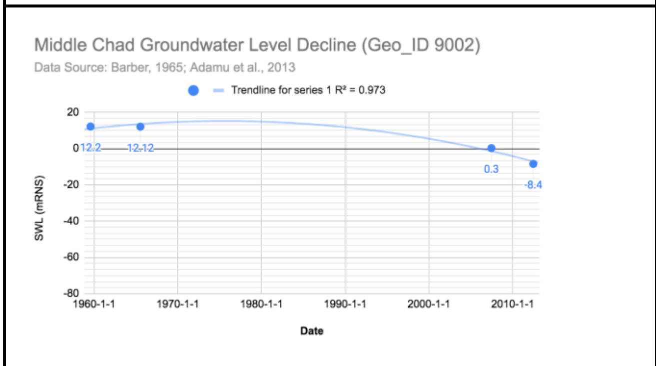

Middle Chad Groundwater Level Decline (Geo_ID 9139)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 1
SWL (mRNS)
20
0
-20
-40
-60
-80
17.1
17.37
-5.4
-10.2
1970-1-1
1980-1-1
1990-1-1
2000-1-1
2010-1-1
Date


Middle Chad Groundwater Level Decline (Geo_ID 9122)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.997
SWL (mRNS)
20
0
-20
-40
-60
-80
15.8
15.38
1.5
0.5
1970-01-01
1980-01-01
1990-01-01
2000-01-01
2010-01-01
Date


Middle Chad Groundwater Level Decline (Geo_ID 9116)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 1
SWL (mRNS)
20
0
-20
-40
-60
-80
9.1
9.04
-6.8
-10.9
1970-1-1
1980-1-1
1990-1-1
2000-1-1
2010-1-1
Date


Middle Chad Groundwater Level Decline (Geo_ID 9115)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.998
SWL (mRNS)
20
0
-20
-40
-60
-80
13.1
12.88
1.5
0.7
1970-1-1
1980-1-1
1990-1-1
2000-1-1
2010-1-1
Date


Middle Chad Groundwater Level Decline (Geo_ID 9109)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 1
SWL (mRNS)
20
0
-20
-40
-60
-80
5.8
4.04
-36.2
-43.2
1960-1-1
1970-1-1
1980-1-1
1990-1-1
2000-1-1
2010-1-1
Date


Middle Chad Groundwater Level Decline (Geo_ID 9002)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.973
SWL (mRNS)
20
0
-20
-40
-60
-80
12.2
12.12
0.3
-8.4
1960-1-1
1970-1-1
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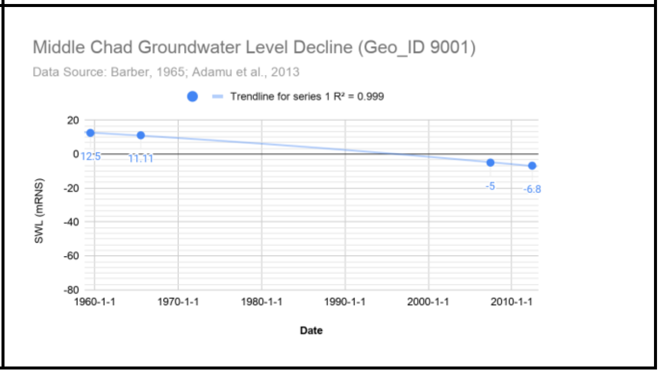
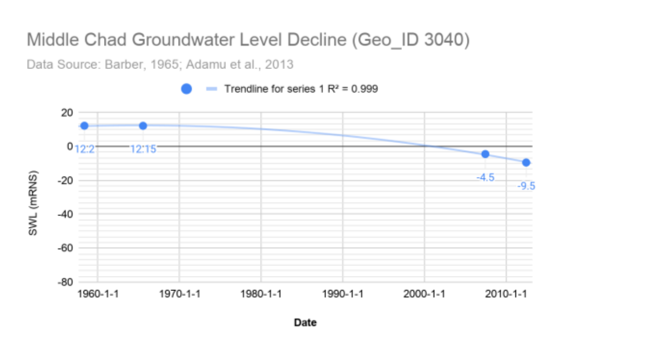
2010-1-1
Date


Middle Chad Groundwater Level Decline (Geo_ID 9001)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.999
SWL (mRNS)
20
0
-20
-40
-60
-80
12.5
11.11
-5
-6.8
1960-1-1
1970-1-1
1980-1-1
1990-1-1
2000-1-1
2010-1-1
Date


Middle Chad Groundwater Level Decline (Geo_ID 3040)
Data Source: Barber, 1965; Adamu et al., 2013
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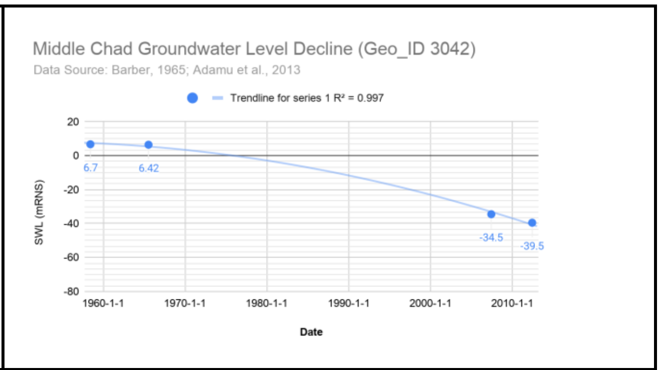
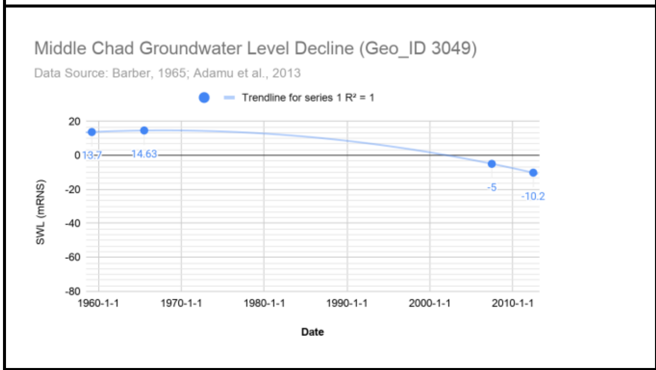
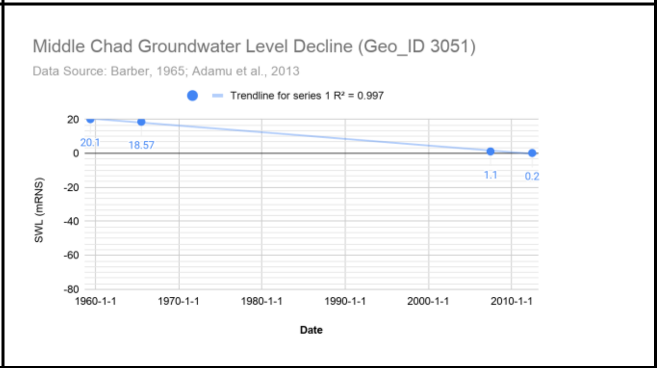
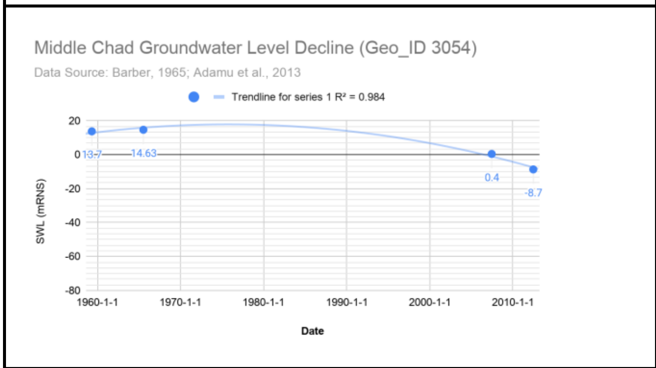
SWL (mRNS)
Date
12.2
12.15
-4.5
-9.5


Middle Chad Groundwater Level Decline (Geo_ID 3042)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.997
SWL (mRNS)
Date
6.7
6.42
-34.5
-39.5


Middle Chad Groundwater Level Decline (Geo_ID 3049)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 1
SWL (mRNS)
Date
13.7
14.63
-5
-10.2


Middle Chad Groundwater Level Decline (Geo_ID 3051)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.997
SWL (mRNS)
Date
20.1
18.57
1.1
0.2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Data Source: Barber, 1965; Adamu et al., 2013
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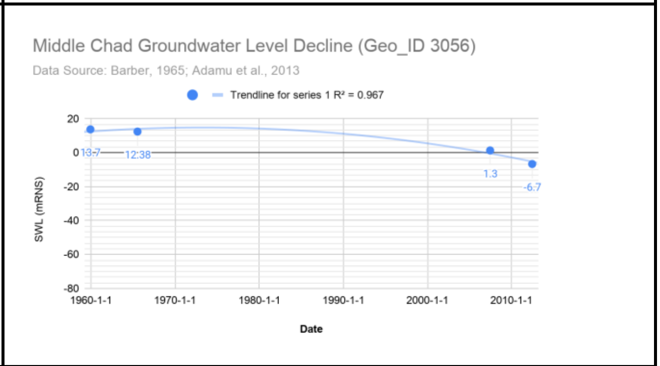
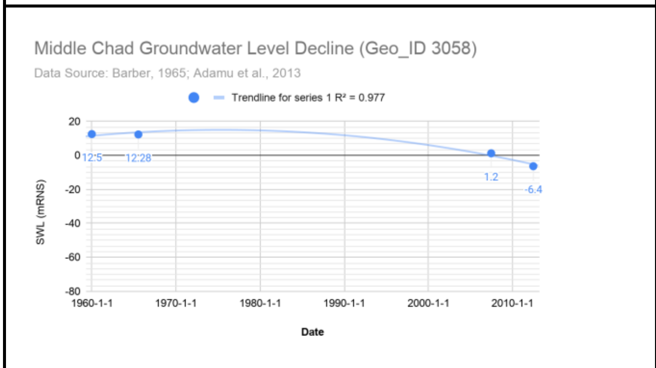
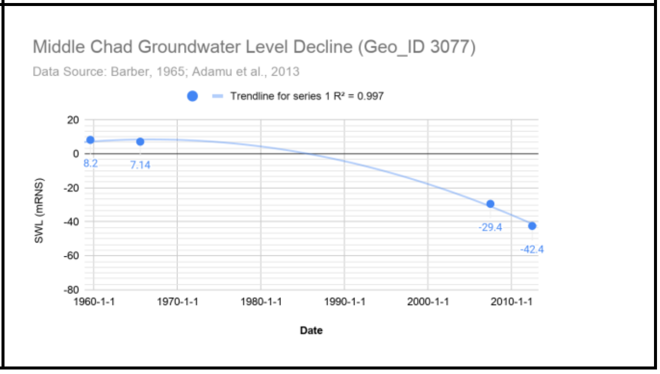
SWL (mRNS)
Date
13.7
14.63
0.4
-8.7


Middle Chad Groundwater Level Decline (Geo_ID 3056)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.967
SWL (mRNS)
Date
13.7
12.38
1.3
-6.7


Middle Chad Groundwater Level Decline (Geo_ID 3058)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.977
SWL (mRNS)
Date
12.5
12.28
1.2
-6.4


Middle Chad Groundwater Level Decline (Geo_ID 3077)
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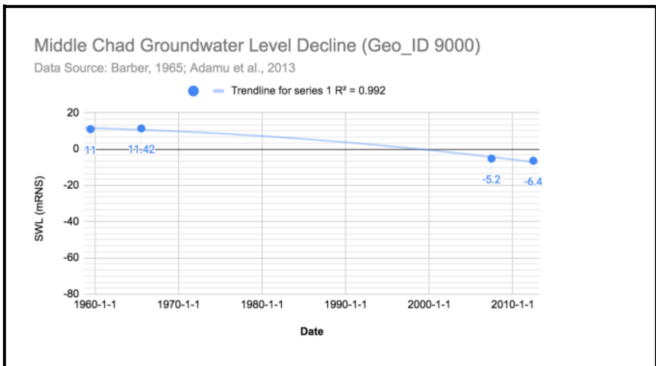
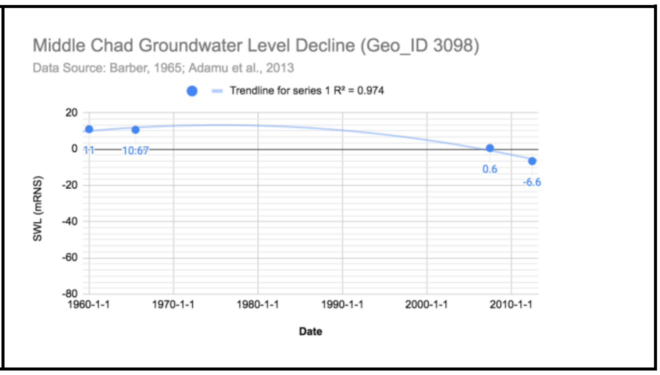
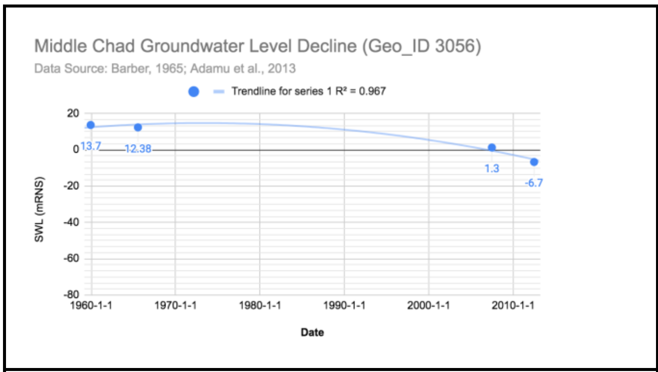
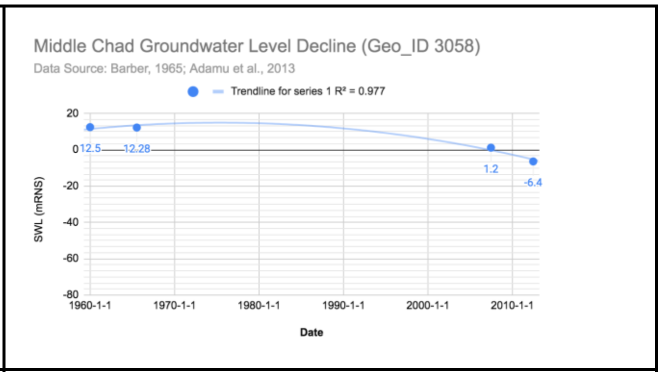
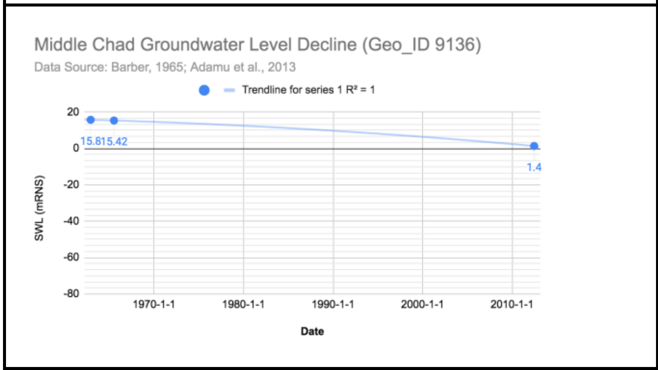
SWL (mRNS)
Date
8.2
7.14
-29.4
-42.4

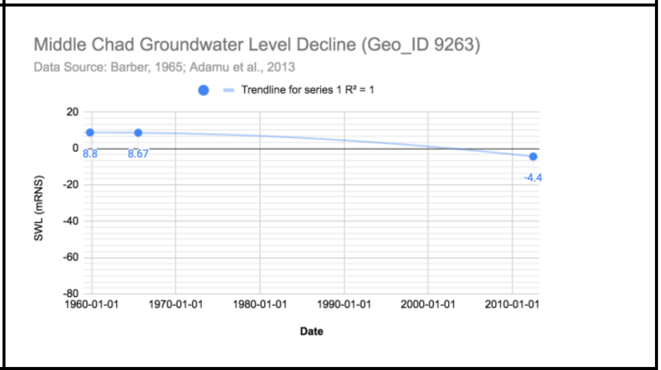

Middle Chad Groundwater Level Decline (Geo_ID 9000)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.992
SWL (mRNS)
Date
11
11.42
-5.2
-6.4

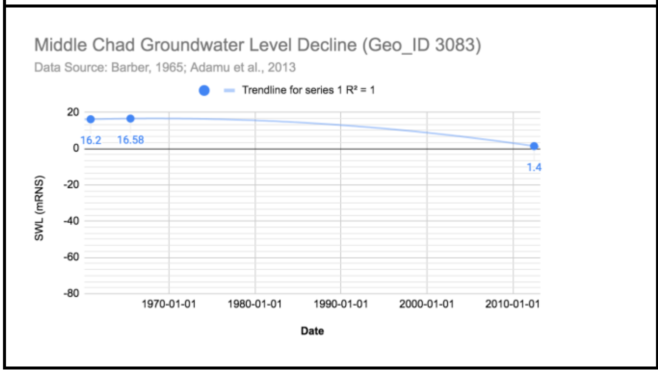

Middle Chad Groundwater Level Decline (Geo_ID 3098)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.974
SWL (mRNS)
Date
11
10.67
0.6
-6.6

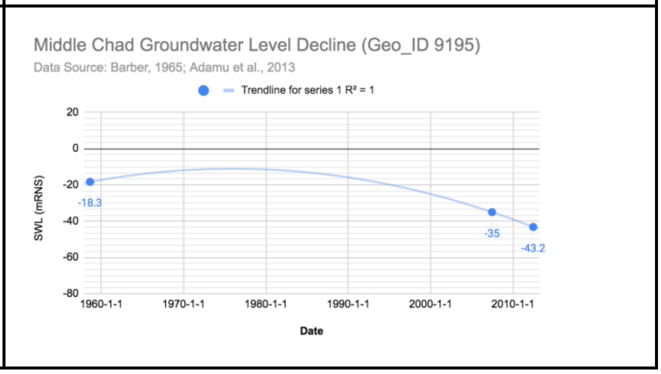

Middle Chad Groundwater Level Decline (Geo_ID 3056)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.967
SWL (mRNS)
20
0
-20
-40
-60
-80
13.7
12.38
1.3
-6.7
1960-1-1
1970-1-1
1980-1-1
1990-1-1
2000-1-1
2010-1-1
Date

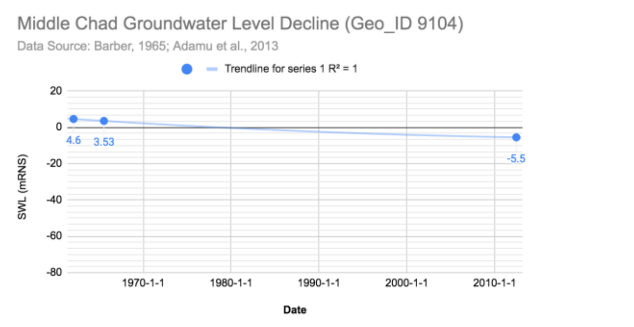

Middle Chad Groundwater Level Decline (Geo_ID 3058)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.977
SWL (mRNS)
20
0
-20
-40
-60
-80
12.5
12.28
1.2
-6.4
1960-1-1
1970-1-1
1980-1-1
1990-1-1
2000-1-1
2010-1-1
Date

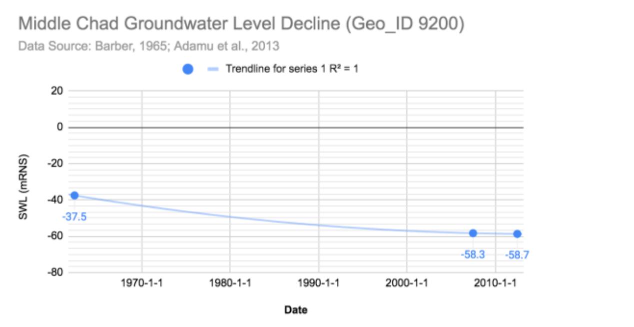

Middle Chad Groundwater Level Decline (Geo_ID 9136)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 1
SWL (mRNS)
20
0
-20
-40
-60
-80
15.815.42
1.4
1970-1-1
1980-1-1
1990-1-1
2000-1-1
2010-1-1
Date

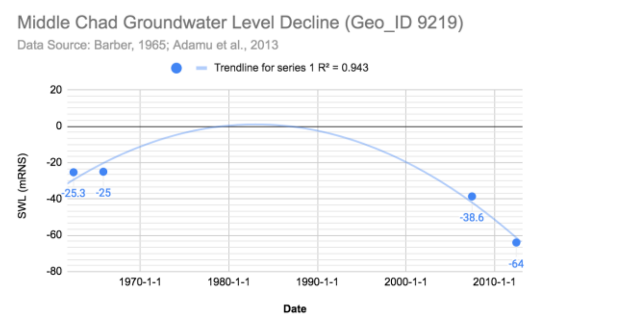

Middle Chad Groundwater Level Decline (Geo_ID 9263)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 1
SWL (mRNS)
20
0
-20
-40
-60
-80
8.8
8.67
-4.4
1960-01-01
1970-01-01
1980-01-01
1990-01-01
2000-01-01
2010-01-01
Date


Middle Chad Groundwater Level Decline (Geo_ID 3083)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 1
SWL (mRNS)
20
0
-20
-40
-60
-80
16.2
16.58
1.4
1970-01-01
1980-01-01
1990-01-01
2000-01-01
2010-01-01
Date

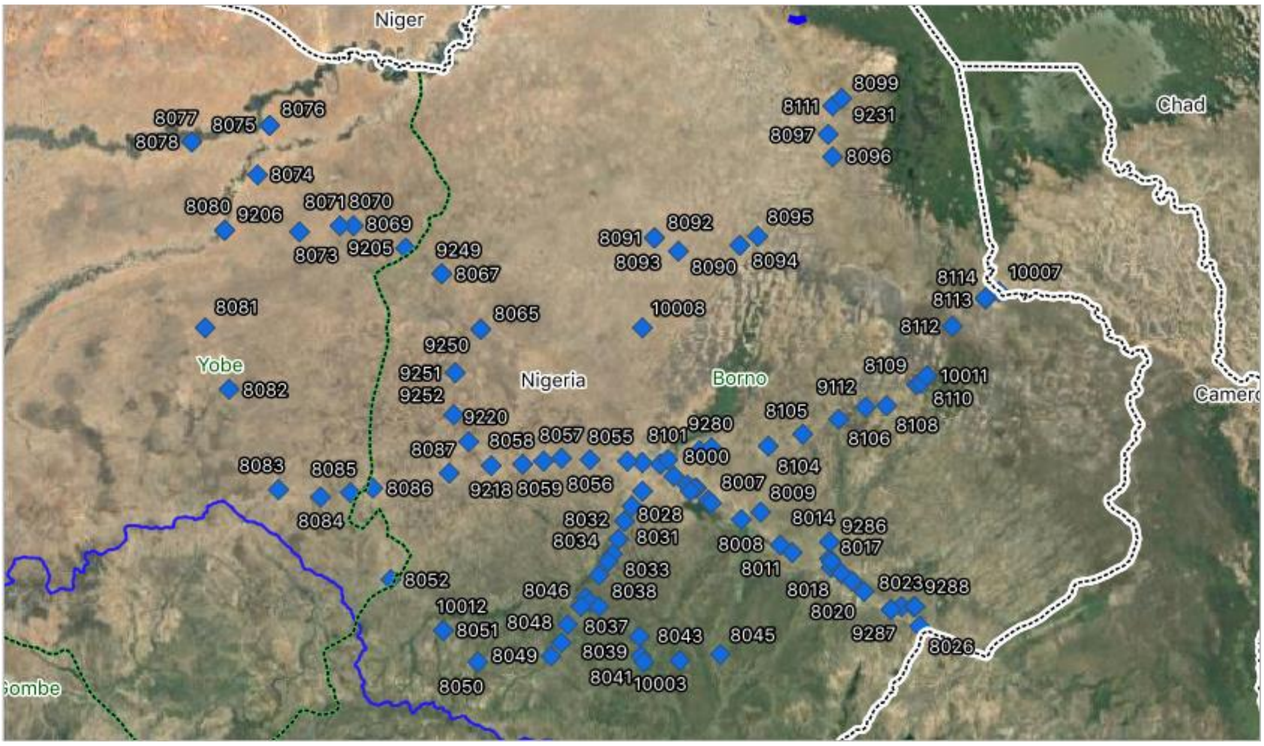

Middle Chad Groundwater Level Decline (Geo_ID 9195)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 1
SWL (mRNS)
20
0
-20
-40
-60
-80
-18.3
-35
-43.2
1960-1-1
1970-1-1
1980-1-1
1990-1-1
2000-1-1
2010-1-1
Date


Middle Chad Groundwater Level Decline (Geo_ID 9104)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 1
SWL (mRNS)
Date
4.6
3.53
-5.5
1970-1-1
1980-1-1
1990-1-1
2000-1-1
2010-1-1


Middle Chad Groundwater Level Decline (Geo_ID 9200)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 1
SWL (mRNS)
Date
-37.5
-58.3
-58.7
1970-1-1
1980-1-1
1990-1-1
2000-1-1
2010-1-1


Middle Chad Groundwater Level Decline (Geo_ID 9219)
Data Source: Barber, 1965; Adamu et al., 2013
Trendline for series 1 R² = 0.943
SWL (mRNS)
Date
-25.3
-25
-38.6
-64
1970-1-1
1980-1-1
1990-1-1
2000-1-1
2010-1-1

Annex 2 Monthly Monitoring 1963 to 1968 (Carmalt & Tibbitts, 1969)



Groundwater monitoring points measured by the USGS-GSN during the period 1963 to 1968 (after Carmalt & Tibbitts, 1969). Location numbers shown are based on Geo9 ID applied in the Project GIS.

Kauwa Run Monitoring Point Location Map

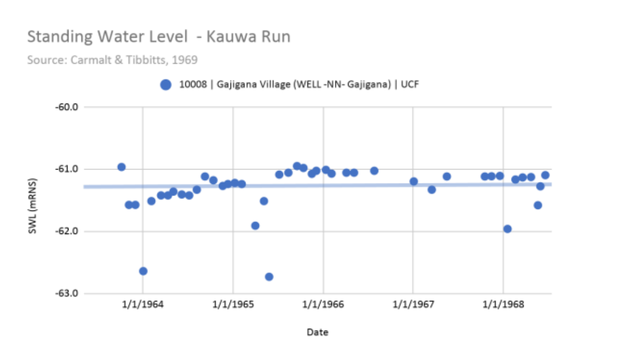
Location of Groundwater Level Monitoring Points included on the Kauwa Run.

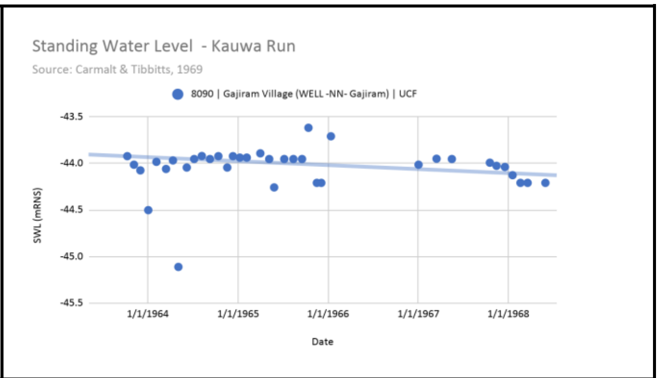
Kauwa Run Monitoring Location Details

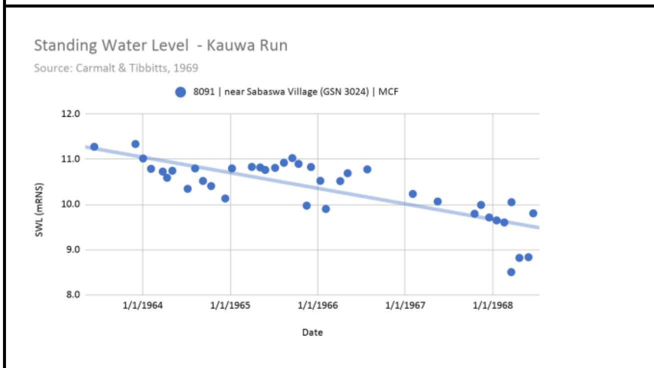
Geo9 ID	Well ID	Location Description
8090	Gajiram Village (WELL -NN-Gajiram)	ON MAIDUGURI-BAGA ROAD ABOUT 48.7 MILES FROM MAIDUGURI. WELL IS AT NORTH EDGE OF TOWN
8091	near Sabaswa Village (GSN 3024)	VILLAGE IS ABOUT 7.2 MILES NW OF GAJIRAM, BOREHOLE IS ABOUT 1 MILE SOUTH OF VILLAGE. BOREHOLE IS ABOUT 500 FT. NORTH OF CONCRETE SHELTER OVER GSN 3025 AND ABOUT 300 FT. NORTH OF GSN 3026.
8092	near Sabaswa Village (GSN 3026)	VILLAGE IS ABOUT 7.2 MILES NW OF GAJIRAM, BOREHOLE IS ABOUT 1 MILE SOUTH OF VILLAGE. BOREHOLE IS ABOUT 200 FT. NORTH OF CONCRETE SHELTER OVER GSN 3025 AND ABOUT 30-FT. SOUTH OF GSN 3024.
8093	near Sabaswa Village (GSN 3025)	VILLAGE IS ABOUT 7.2 MILES NW OF GAJIRAM, BOREHOLE IS ABOUT 1 MILE SOUTH OF VILLAGE. BOREHOLE IS ABOUT 500 FT. SOUTH OF GSN 3624 AND ABOUT 200 FT. SOUTH OF GSN 3026. A CONCRETE SHELTER ENCLOSES THE BOREHOLE AND A FOXBORO PRESSURE RECORDER
8094	Gudwari Village (WELL -NN-Gudwari)	ON OLD GAJIRAM-MONGONU TRACK ABOUT 15 MILES FROM GAJIRAM
8095	Furta Village (WELL -NN-Furta)	ON OLD GAJIRAM-MONGONU TRACK ABOUT 20 MILES FROM GAJIRAM
8096	Checheno Village (WELL -NN-Checheno)	ON MAIDUGURI-BAGA ROAD ABOUT 91.4 MILES FROM MAIDUGURI. WELL IS ABOUT 700 YARDS EAST OF ROAD
8097	Dogoshe Village (WELL -NN-Dogoshe)	ON MAIDUGURI-BAGA ROAD ABOUT 96.8 MILES FROM MAIDUGURI. VILLAGE IS ON EAST SIDE OF ROAD, AND WELL IS IN NORTH EAST CORNER OF VILLAGE

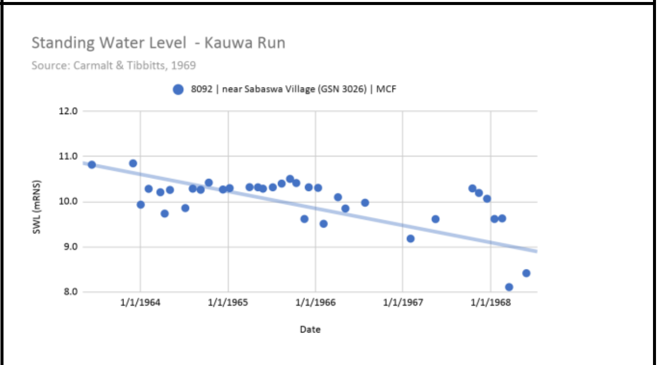
8099	near Kauwa Village (GSN 3020)	ON KAUWA-RAGA TRACK ABOUT 3.7 MILES FROM KAUWA VILLAGE, IN SIGHT OF NEW MAIDUGURI-BAGA ROAD. BOREHOLE IS ABOUT 500 FT. EAST OF SHELTER OVER GSN 3021
8111	Kauwa Village (WELL -NN-Kauwa)	VILLAGE IS ABOUT 1.8 MILES EAST OF ROUNDABOUT WHERE KUKAUWA SPUR JOINS MAIDUGURI-BAGA ROAD. WELL IS IN FRONT OF VILLAGE HEAD'S HOUSE
9231	near Kauwa Village (GSN 3021)	ON KAUWA-BAGA TRACK ABOUT 3.7 MILES FROM KAUWA VILLAGE, IN SIGHT OF NEW MAIDUGURI-BAGA ROAD. A CONCRETE SHELTER ENCLOSES THE BOREHOLE AND A FOXBORO PRESSURE RECORDER
10008	Gajigana Village (WELL -NN-Gajigana)	MAIDUGURI-BAGA ROAD ABOUT 30.6 MILES FROM MAIDUGURI. WELL IS AT THE WESTERN EDGE OF VILLAGE, ABOUT 500 FT. NORTH EAST OF NA SCHOOL AND 150 FT. EAST OF VILLAGE BOREHOLE

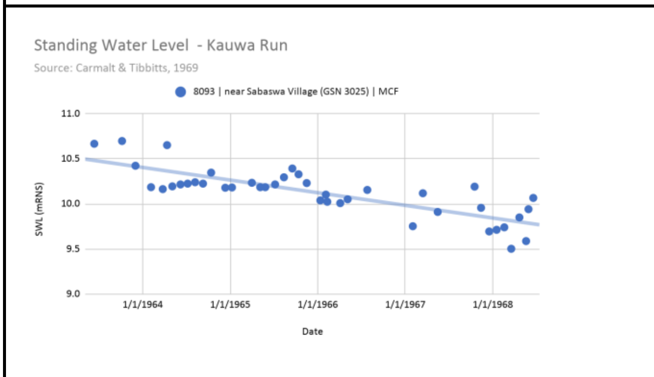
Kauwa Run Monthly Manual Measurement Hydrographs

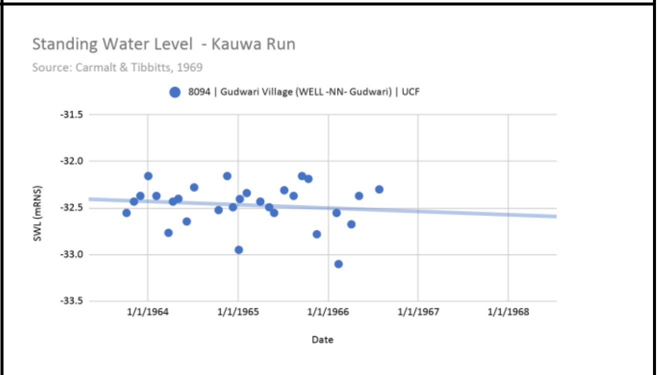


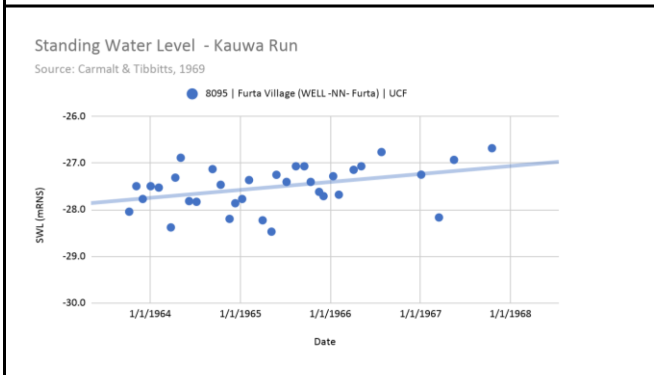


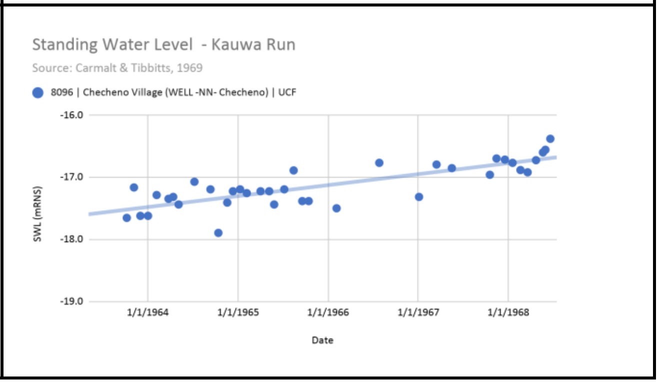


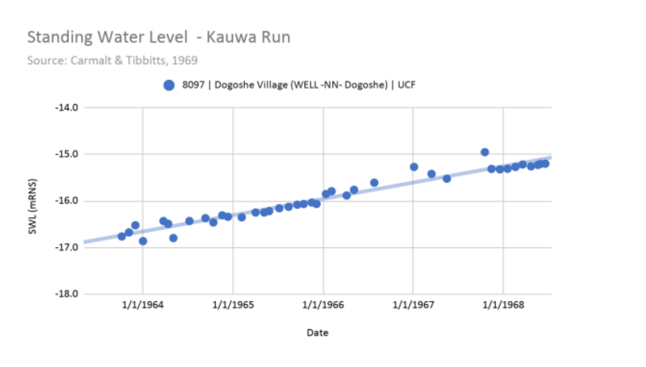


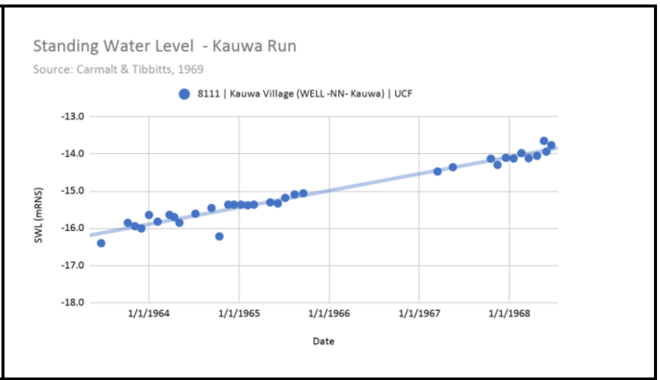


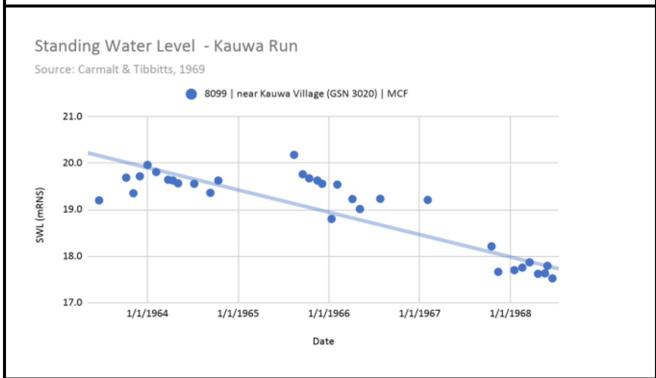


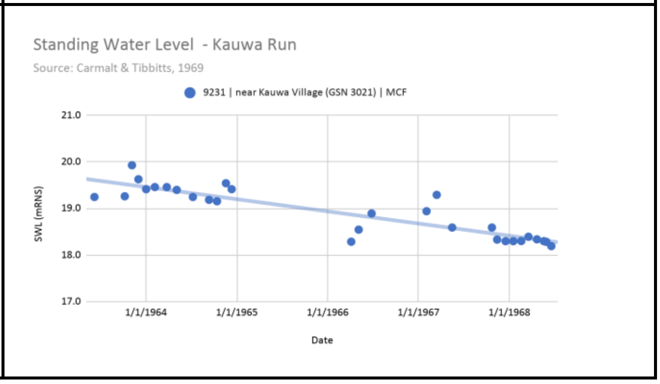




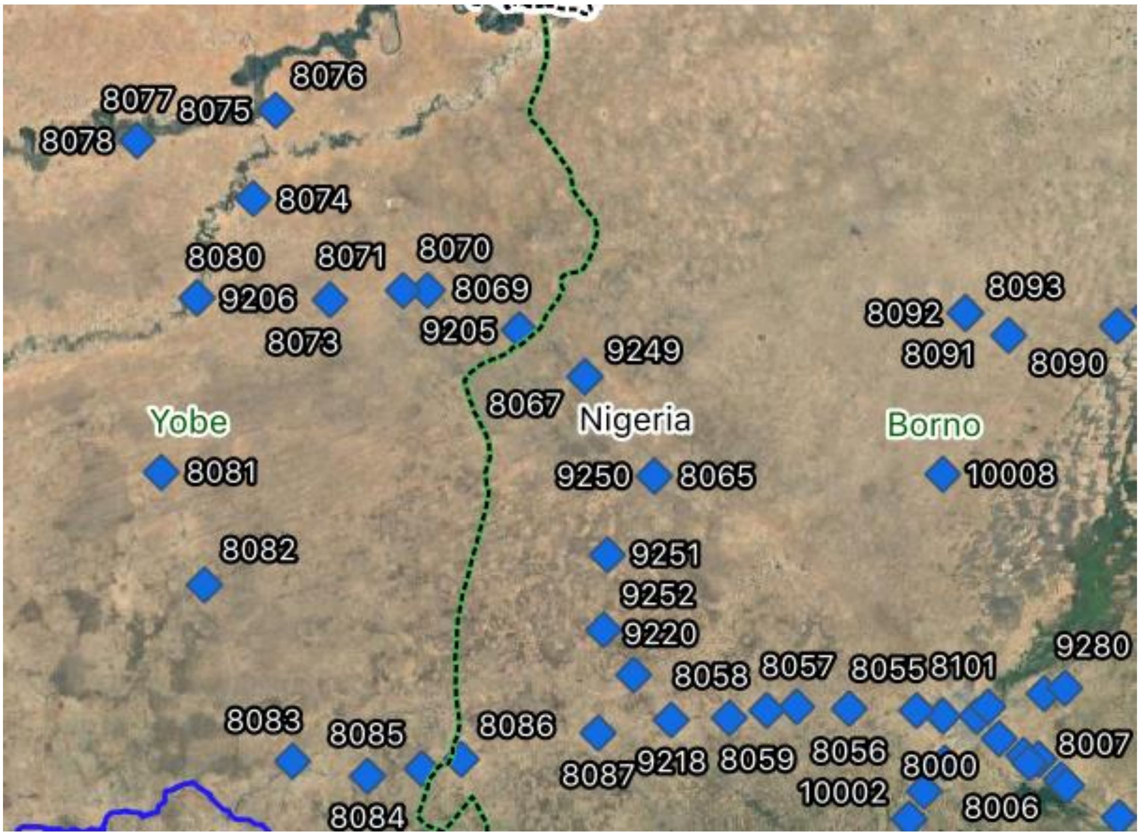

Standing Water Level - Kauwa Run
Source: Carmalt & Tibbitts, 1969
8097 | Dogoshe Village (WELL -NN- Dogoshe) | UCF
SWL (mRNS)
-14.0
-15.0
-16.0
-17.0
-18.0
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Kauwa Run
Source: Carmalt & Tibbitts, 1969
8111 | Kauwa Village (WELL -NN- Kauwa) | UCF
SWL (mRNS)
-13.0
-14.0
-15.0
-16.0
-17.0
-18.0
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Kauwa Run
Source: Carmalt & Tibbitts, 1969
8099 | near Kauwa Village (GSN 3020) | MCF
SWL (mRNS)
21.0
20.0
19.0
18.0
17.0
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Kauwa Run
Source: Carmalt & Tibbitts, 1969
9231 | near Kauwa Village (GSN 3021) | MCF
SWL (mRNS)
21.0
20.0
19.0
18.0
17.0
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

Geidam Run Monitoring Point Location Map



Location of Groundwater Level Monitoring Points included on the Geidam Run.

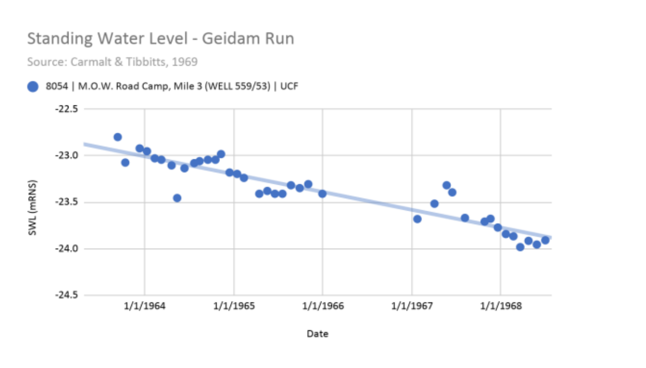
Geidam Run Monitoring Location Details

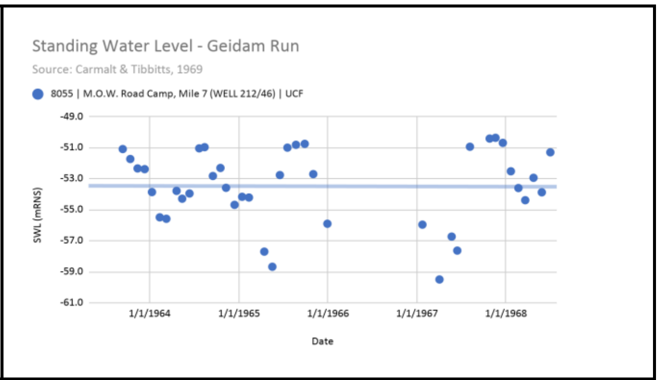
Geo9 ID	Well ID	Location Description
8054	M.O.W. Road Camp, Mile 3 (WELL 559/53)	ON MAIDUGURI-BENESHEIK ROAD ABOUT 1.5 MILES WEST OF MAIDUGURI POLICE STATION. WELL IS ABOUT 75 YARDS SOUTH OF THE ROAD
8055	M.O.W. Road Camp, Mile 7 (WELL 212/46)	ON MAIDUGURI-BENESHEIK ROAD ABOUT 6.1 MILES WEST OF MAIDUGURI POLICE STATION. WELL IS ABOUT 50 YARDS NORTH OF ROAD
8056	Auno Village (WELL BM-68)	ON MAIDUGURI-BENESHEIK ROAD ABOUT 14.0 MILES W OF MAIDUGURI POLICE STATION. WELL IS IN FRONT OF SCHOOL, ABOUT 100 YARDS NORTH OF ROAD
8057	Yanayaku Village (WELL 805/55)	MAIDUGURI-BENESHEIK ROAD ABOUT 17.2 MILES W OF MAIDUGURI POLICE STATION. WELL IS ABOUT 100 YARDS SOUTH OF ROAD
8058	Kasawa Village (GSN 3034)	ON MAIDUGURI-BENESHEIK ROAD ABOUT 24.6 MILES W OF MAIDUGURI POLICE STATION. BOREHOLE IS ABOUT 1/4 MILE E OF VILLAGE, ABOUT 200 FT. N OF ROAD. A CONCRETE SHELTER ENCLOSES THE BOREHOLE AND A STEVENS TYPE F WATER LEVEL RECORDER
8059	Lefa Village (WELL -NN- Lefa)	ON MAIDUGURI-BENESHEIK ROAD ABOUT 29.2 MILES W OF MAIDUGURI POLICE STATION. WELL IS AT EDGE OF VILLAGE, ABOUT 150 YARDS NORTH OF ROAD
9218	Mainok Village (WELL 209/1946)	MAIDUGURI-BENISHEIK ROAD ABOUT 35.2 MILES W OF MAIDUGURI POLICE STATION. WELL IS AT W EDGE OF TOWN, ABOUT I00 YARDS SOUTH OF ROAD
9220	Karagawaru Village (GSN 2737)	ON MAINOK-BORNU YESSU TRACK ABOUT 8 MILES FROM MAINOK. BOREHOLE IS ABOUT 200 YARDS SOUTH EAST OF TOWN

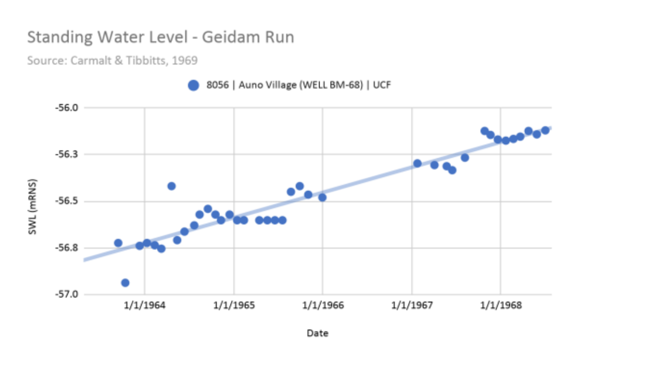
9252	Lowanti Village (GSN 2872)	MAINOK-BORNU YESSU TRACK ABOUT 15 MILES FROM MAINOK. BOREHOLE IS ABOUT 300 YARDS EAST OF TRACK AND 300 YARDS NORTH OF VILLAGE
9251	Kajidiri Village (GSN 2742)	ON MAINOK-BORNU YESSU TRACK ABOUT 26 MILES FROM MAINOK. BOREHOLE IS ABOUT 1/2 MILE SOUTH OF KAJIDIRI VILLAGE
9250	Bornu Yessu Village (GSN 2736)	ABOUT 50 MILES NW OF MAIDUGURI ON DIRECT MAIDUGURI-GEIDAM TRACK. BOREHOLE IS IN FIELD NE OF VILLAGE, ABOUT 100 FT. FROM CONCRETE WELL
8065	Bornu Yessu Village (WELL -NN- Bornu Yessu)	VILLAGE IS ABOUT 50 MILES NW OF MAIDUGURI ON DIRECT MAIDUGURI-GEIDAm TRACK. WELL IS IN FIELD NE OF VILLAGE
9249	Yasku Village (GSN 2703)	DIRECT MAIDUGURI-GEIDAM TRACK ABOUT 10.6 MILES NW OF BORNU YESSU. BOREHOLE IS ABOUT 200 FT. SOUTH OF TRACK AND 100 FT. WEST OF WELL
8067	Yasku Village (WELL -NN- Yasku)	DIRECT MAIDUGURI-GEIDAM TRACK ABOUT 10.6 MILES NW OF BORNU YESSU. WELL IS ON SOUTH SIDE OF TRACK, ABOUT 200 YARDS SOUTH OF VILLAGE
9205	Dana Village (GSN 2705)	DIRECT MAIDUGURI-GEIDAM TRACK ABOUT 23.9 MILES NW OF BORNU YESSU. BOREHOLE IS ABOUT 150 EAST OF TRACK AND 300 FT. WEST OF VILLAGE
8069	Dana Village (WELL -NN- Dana)	DIRECT MAIDUGURI-GEIDAM TRACK ABOUT 23.9 MILES NW OF BORNU YESSU,! WELL IS ABOUT 100 YARDS S OF ROAD IN FIELD WEST OF VILLAGE
8070	Lumusu Village (WELL -NN- Lumusu)	ON DIRECT mAIDUGuRI-GEIDAM TRACK ABOUT 36.1 MILES NW OF BORNU YESSU. WELL IS ABOUT 400 YARDS NORTH OF TRACK
8071	near Shilawa Village (WELL -NN- Near Shilawa)	WELL IS ABOUT 0.1 MILE SW OF DIRECT MAIDUGURI-GEIDAM TRACK AT A POINT ABOUT 37.3 MILES NW OF BORNU YESSU. THE TRACK CROSSES A SLIGHT RISE JUST EAST OF THE WELL
9207	Kusar Village (GSN 2722)	VILLAGE IS ABOUT 23 MILES SSE OF GEIDAM. BOREHOLE IS AT SOUTH EDGE OF MARKET AREA, SOUTH OF TOWN.
8073	Kusar Village (WELL -NN- Kusar)	VILLAGE IS ABOUT 23 MILES SSE OF GEIDAM. WELL IS AT WESTERN EDGE OF TOWN
8074	Bulama Village (WELL 394/51)	ON DIRECT MAIDUGURI-GEIDAM TRACK ABOUT 1/2 MILE SE OP JUNCTION WITH LANTEwA-GEIDAm TRACK. WELL IS ABOUT 50 YARDS SOUTH OF TRACK.
8075	Geidam Town (WELL 387/51)	GEIDAM IS A LARGE TOWN ABOUT 110 MILES NW OF MAIDUGURI. WELL IS IN LARGE OPEN AREA IN FRONT OF DISTRICT HEAD'S COMPOUND, AND JUST TO THE SW OF THE WATER TANK
8076	Geidam Town (GSN 2717)	GEIDAM IS A LARGE TOWN ABOUT 110 MILES NW OF MAIDUGURI. BOREHOLE IS IN LARGE OPEN AREA IN FRONT OF DISTRICT HEAD'S COMPOUND. BOREHOLE IS ABOUT HALFWAY BETWEEN THE TWO COVERS OF THE PRODUCTION BOREHOLE
8077	Belle Village (GSN 3166)	ON GEIDAM-GASHUA TRACK ABOUT 17 MILES w OF GEIDAM. BOREHOLE IS ABOUT 500 FT. S OF TRACK ABOUT 1/4 MILE E OF VILLAGE. A CONCRETE SHELTER ENCLOSES THE BOREHOLE AND A STEVENS TYPE F WATER LEVEL RECORDER
8078	Belle Village (WELL 392/51)	ON GEIDAM-GASHUA TRACK ABOUT 17 MILES W OF GEIDAM. WELL IS IN CENTER OF VILLAGE A FEW BLOCKS N OF TRACK
9206	Gumsa Village (GSN 2714)	ON GEIDAM-LANTEWA TRACK ABOUT 24.2 MILES S OF GEIDAM. BOREHOLE IS ABOUT 50 FT. EAST OF ROAD AND ABOUT 300 FT. NORTH OF VILLAGE
8080	Gumsa Village (WELL -NN- Gumsa)	ON GEIDAM-LANTEWA TRACK ABOUT 24.2 MILES S OF GEIDAM. WELL IS IN CENTER OF Village
8081	Lantewa Village (WELL -NN- Lantewa)	ON DAMATURU-GASHUA ROAD ABOUT 4C MILES N OF DAMATURU. WELL IS ABOUT IC' FT. E OF JUNCTION OF ROAD AND TRACK TO GEIDAM
8082	Kalalawa Village (WELL 534/53)	ON DAMATURU-GASHUA ROAD ABOUT 15.9 MILES N OF DAMATURU. WELL IS IN VILLAGE ABOUT 5C FT. E OF ROAD.
8083	Damaturu Village (WELL 173/1937)	DAMATURU-GASHUA ROAD ABOUT C.9 MILES N OF MAIDUGURI-KANO ROAD. WELL IS ABOUT 50 FT. E OF ROAD, NEAR THE DISPENSARY

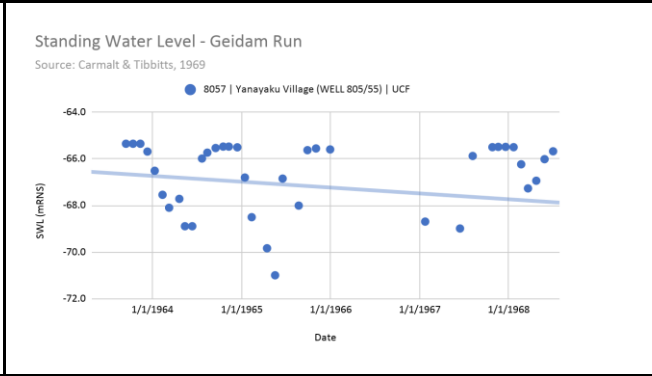
8084	M.O.W. Road Camp, Mile 674 (WELL 583/53)	ON MAIDUGURI-KAN0 ROAD ABOUT 73.5 MILES FROM mAIduGURI (OPPOSITE MILEPOST 74). WELL IS S OF ROAD ABOUT 75 YARDS, AT W SIDE of VILLAGE
8085	Kukaretta Village (WELL 692/54)	ON MAIDUGURI-KANO ROAD ABOUT 67.5 MILES FROM MAIDUGURI. WELL IS ABOUT 25 YARDS S OF ROAD IN W SECTION OF VILLAGE
8086	Ngamdu Village (WELL 859/57)	ON MAIDUGURI-KANO ROAD ABOUT 61.9 MILES FROM MAIDUGURI. WELL IS ABOUT 20 YARDS SOUTH OF ROAD AT WESTERN END OF VILLAGE
8087	Benesheik Village (WELL 172/1937)	MAIDUGURI-KANO ROAD ABOUT 45.1 MILES FROM MAIDUGURI. WELL IS IN SQUARE IN FRONT OF DISTRICT HEAD'S HOUSE
9219	Benesheik Village (GSN 2730)	ON MAIDUGURI-KANO ROAD ABOUT 45.5 MILES FROM MAIDUGURI. BOREHOLE IS ABOUT 100 YARDS S OF ROAD, AT W END OF VILLAGE

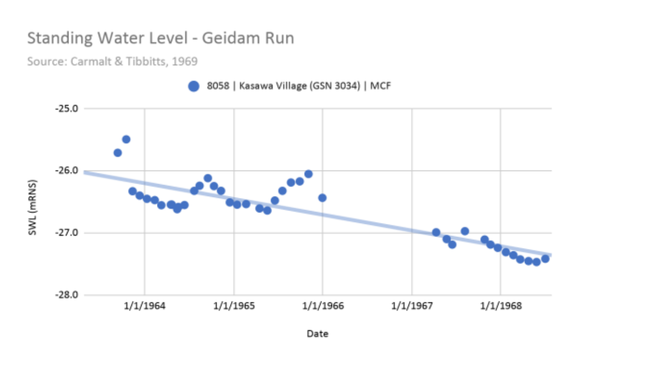
Geidam Run Monthly Manual Measurement Hydrographs

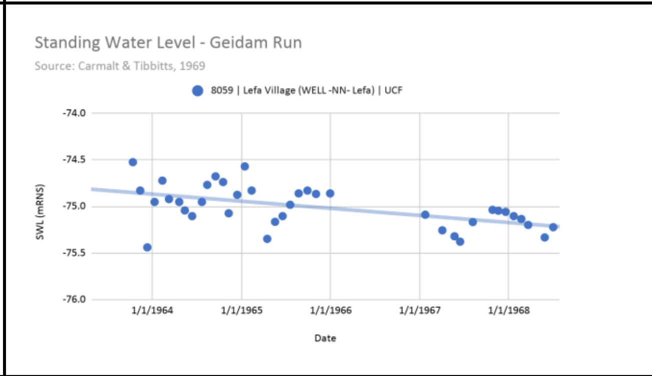


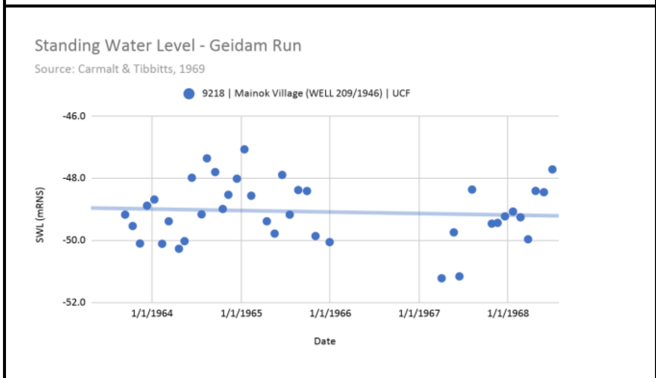


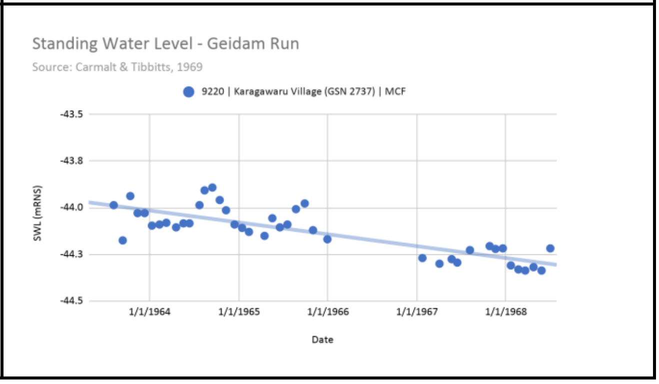


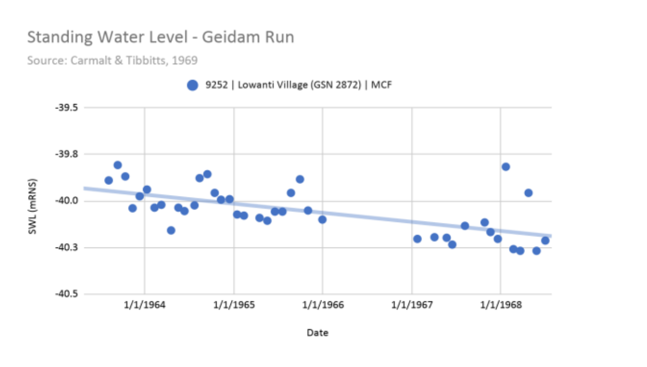


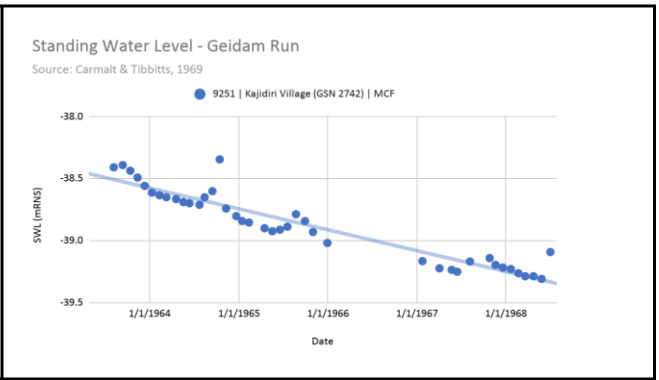


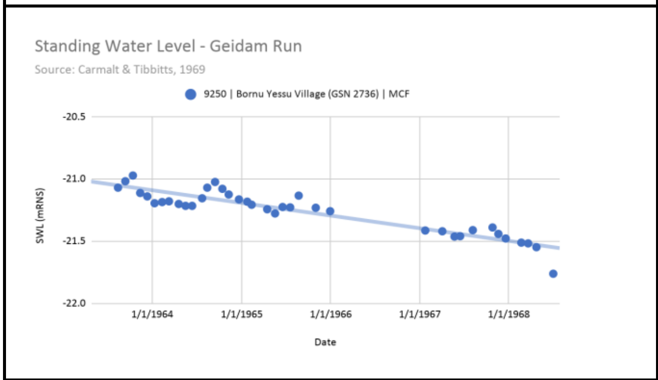


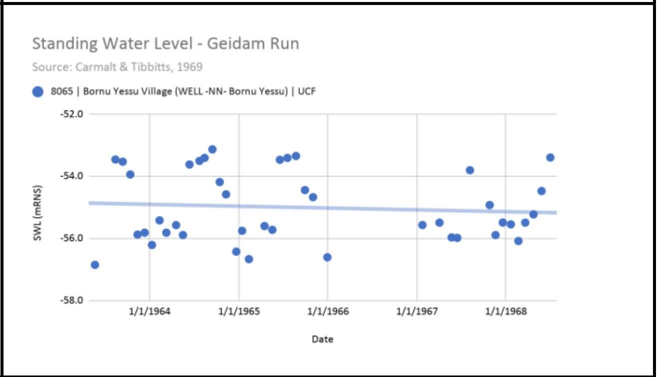


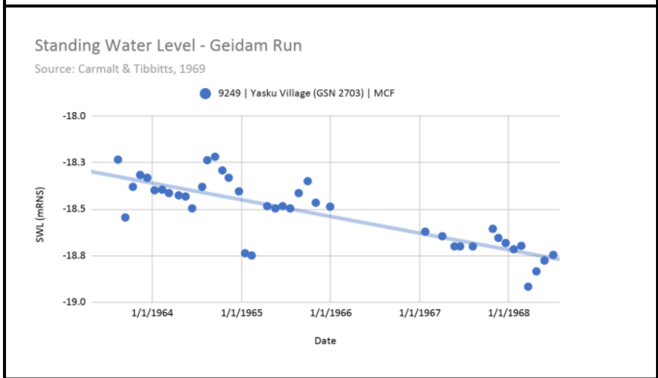


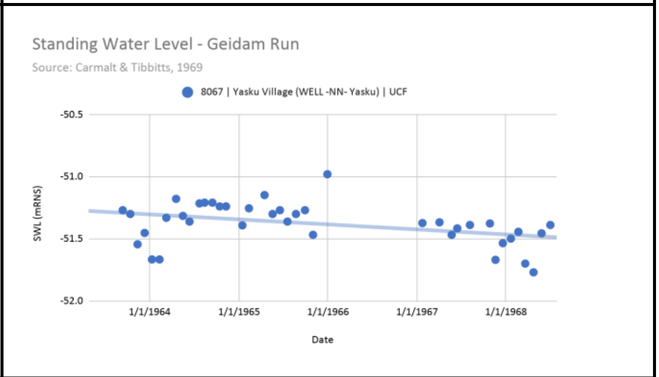

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
9252 | Lowanti Village (GSN 2872) | MCF
-39.5
-39.8
-40.0
-40.3
-40.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

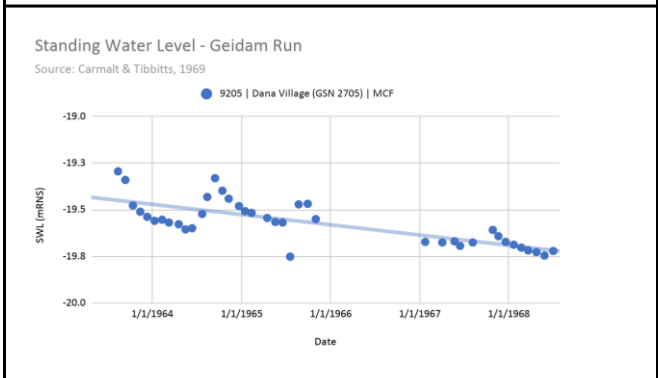

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
9251 | Kajidiri Village (GSN 2742) | MCF
-38.0
-38.5
-39.0
-39.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

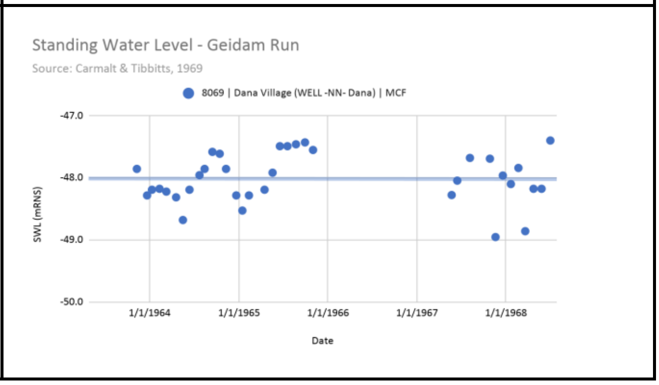

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
9250 | Bornu Yessu Village (GSN 2736) | MCF
-20.5
-21.0
-21.5
-22.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

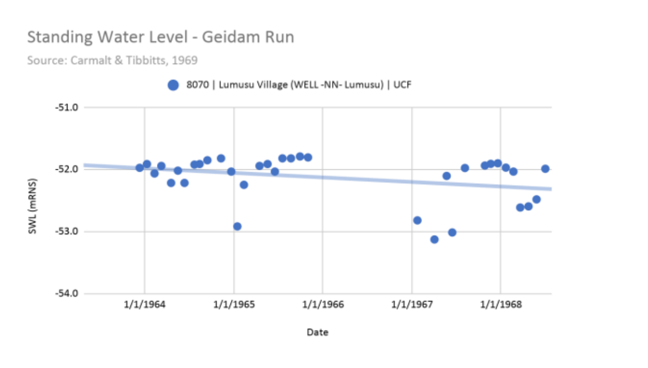

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8065 | Bornu Yessu Village (WELL -NN- Bornu Yessu) | UCF
-52.0
-54.0
-56.0
-58.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

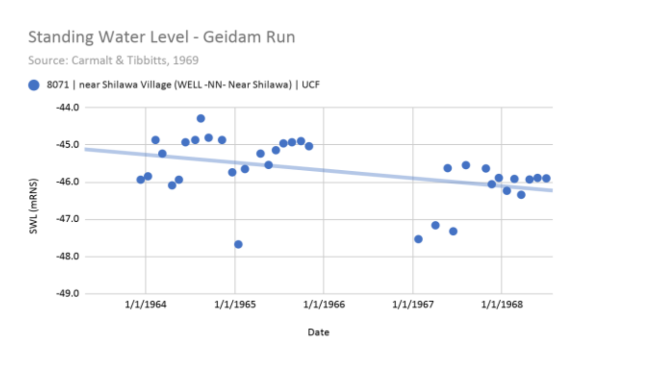

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
9249 | Yasku Village (GSN 2703) | MCF
-18.0
-18.3
-18.5
-18.8
-19.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

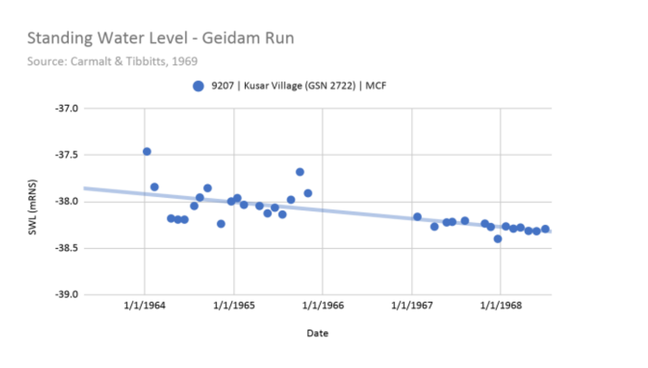

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8067 | Yasku Village (WELL -NN- Yasku) | UCF
-50.5
-51.0
-51.5
-52.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

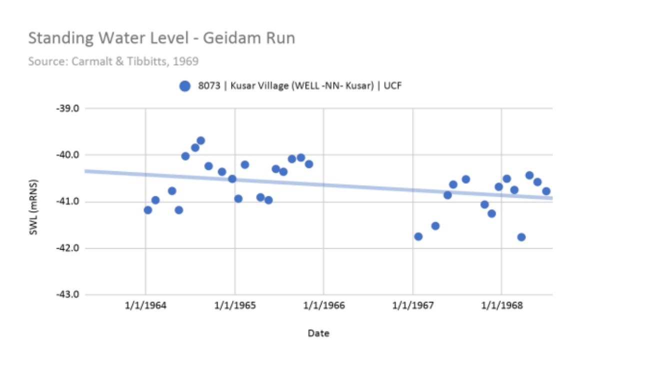

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
9205 | Dana Village (GSN 2705) | MCF
-19.0
-19.3
-19.5
-19.8
-20.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

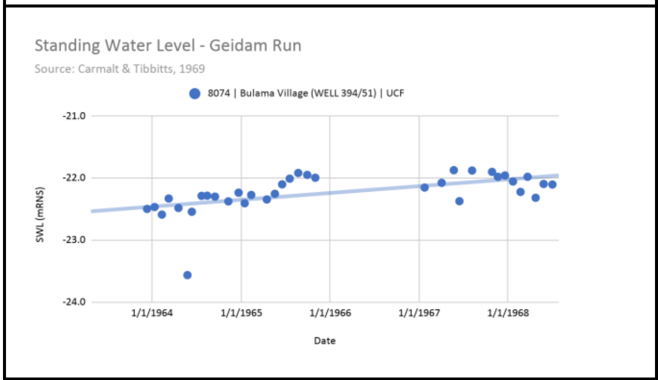

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8069 | Dana Village (WELL -NN- Dana) | MCF
-47.0
-48.0
-49.0
-50.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

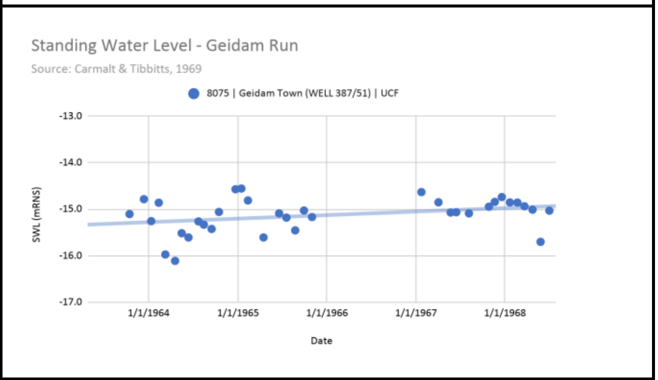

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8070 | Lumusu Village (WELL -NN- Lumusu) | UCF
-51.0
-52.0
-53.0
-54.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

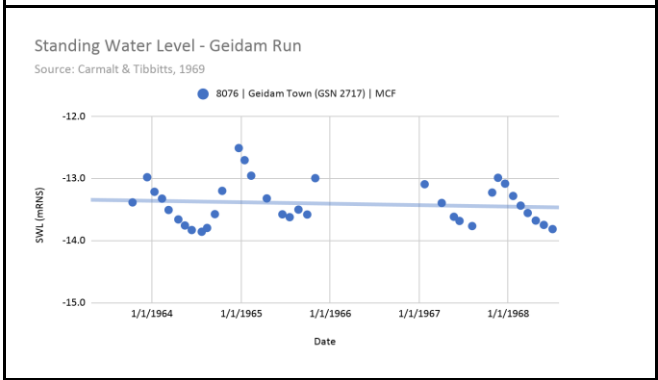

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8071 | near Shilawa Village (WELL -NN- Near Shilawa) | UCF
-44.0
-45.0
-46.0
-47.0
-48.0
-49.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

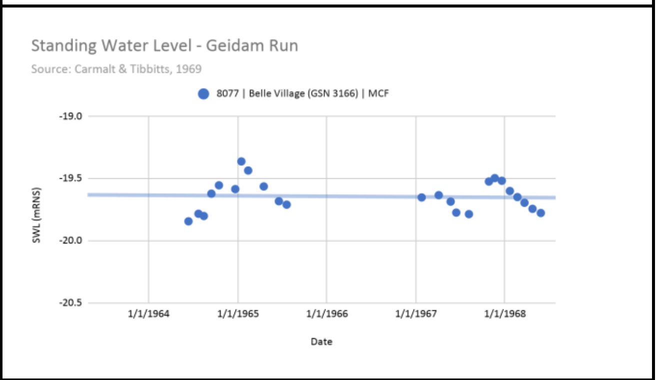

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
9207 | Kusar Village (GSN 2722) | MCF
-37.0
-37.5
-38.0
-38.5
-39.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

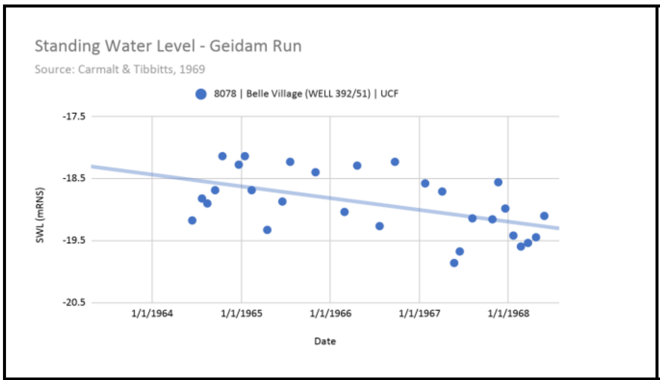

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8073 | Kusar Village (WELL -NN- Kusar) | UCF
-39.0
-40.0
-41.0
-42.0
-43.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

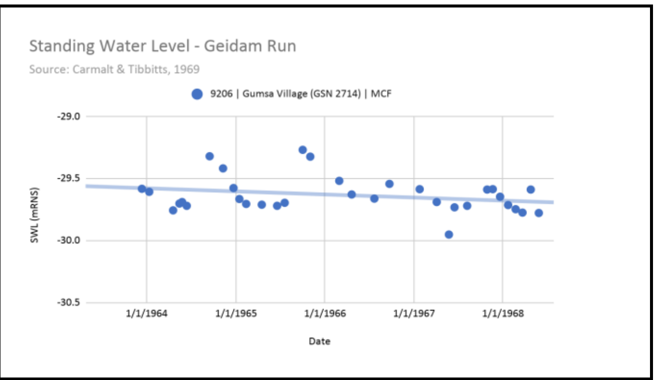

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8074 | Bulama Village (WELL 394/51) | UCF
-21.0
-22.0
-23.0
-24.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

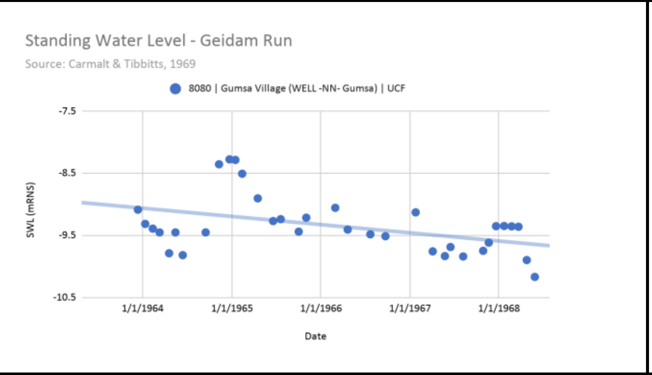

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8075 | Geidam Town (WELL 387/51) | UCF
-13.0
-14.0
-15.0
-16.0
-17.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

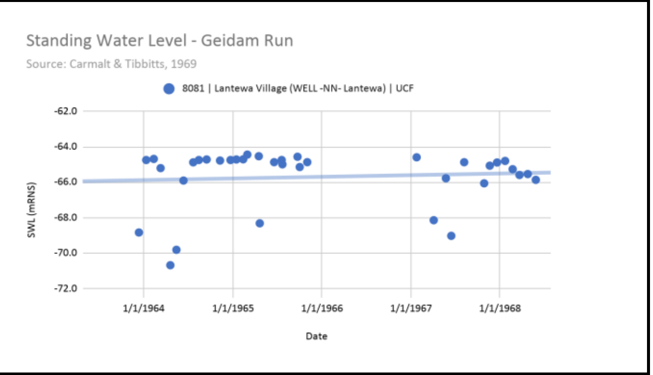

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8076 | Geidam Town (GSN 2717) | MCF
-12.0
-13.0
-14.0
-15.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

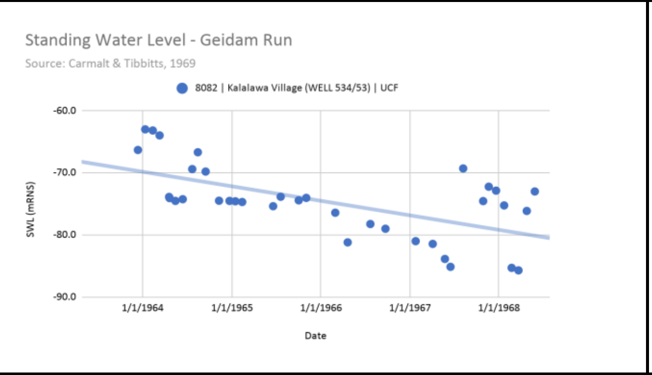

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8077 | Belle Village (GSN 3166) | MCF
-19.0
-19.5
-20.0
-20.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

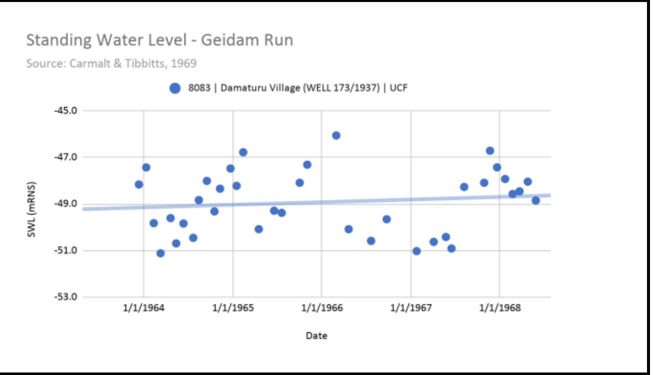

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8078 | Belle Village (WELL 392/51) | UCF
-17.5
-18.5
-19.5
-20.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

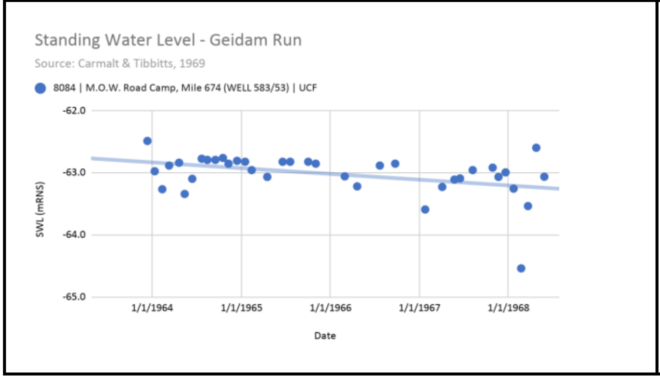

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
9206 | Gumsa Village (GSN 2714) | MCF
-29.0
-29.5
-30.0
-30.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

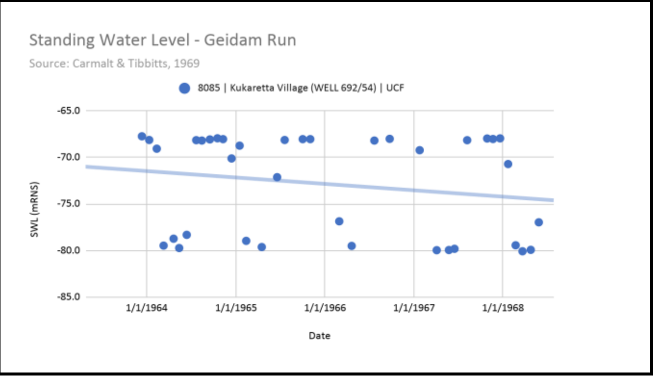

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8080 | Gumsa Village (WELL -NN- Gumsa) | UCF
-7.5
-8.5
-9.5
-10.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

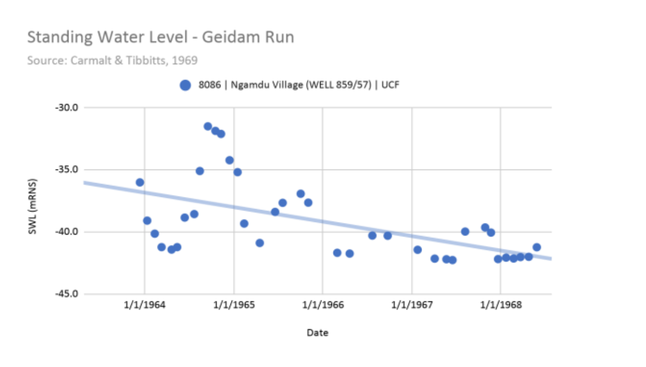

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8081 | Lantewa Village (WELL -NN- Lantewa) | UCF
-62.0
-64.0
-66.0
-68.0
-70.0
-72.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

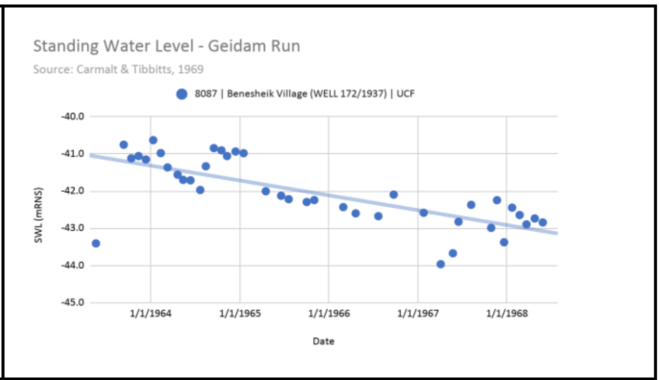

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8082 | Kalalawa Village (WELL 534/53) | UCF
-60.0
-70.0
-80.0
-90.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

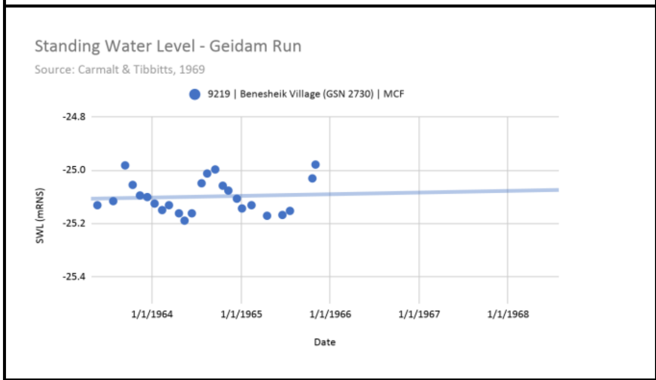

Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8083 | Damaturu Village (WELL 173/1937) | UCF
-45.0
-47.0
-49.0
-51.0
-53.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8084 | M.O.W. Road Camp, Mile 674 (WELL 583/53) | UCF
-62.0
-63.0
-64.0
-65.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8085 | Kukaretta Village (WELL 692/54) | UCF
-65.0
-70.0
-75.0
-80.0
-85.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8086 | Ngamdu Village (WELL 859/57) | UCF
-30.0
-35.0
-40.0
-45.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
8087 | Benesheik Village (WELL 172/1937) | UCF
-40.0
-41.0
-42.0
-43.0
-44.0
-45.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Geidam Run
Source: Carmalt & Tibbitts, 1969
9219 | Benesheik Village (GSN 2730) | MCF
-24.8
-25.0
-25.2
-25.4
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

Damboa Run Monitoring Points Location Map

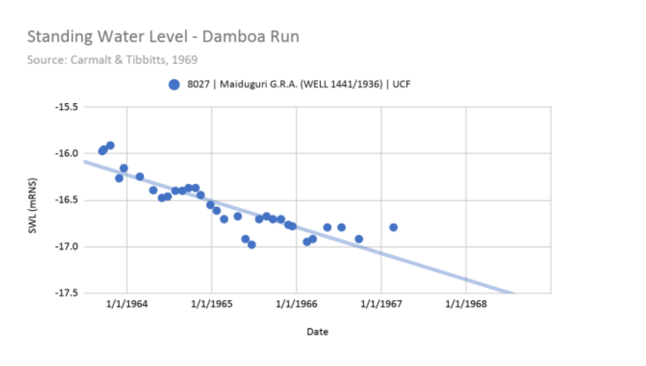
Location of Groundwater Level Monitoring Points included on the Damboa Run.

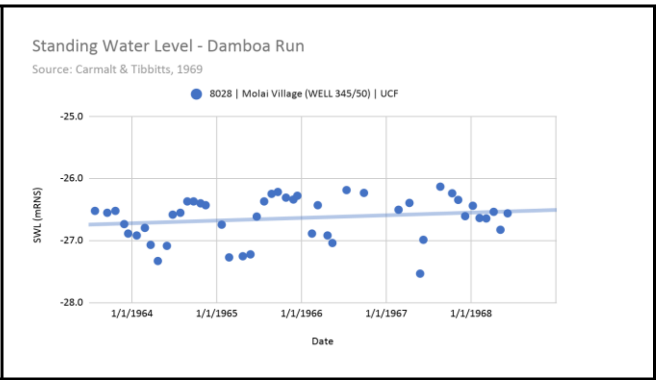
Damboa Run Monitoring Location Details

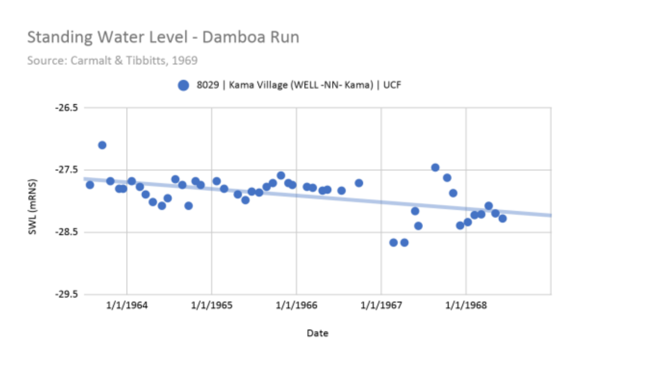
Geo9 ID	Well ID	Location Description
8027	Maiduguri G.R.A. (WELL 1441/1936)	ON G.R.A. ON A LOT DIAGONALLY OPPOSITE THE M.O.W. YARD
8028	Molai Village (WELL 345/50)	VILLAGE IS ON ROAD FROM MAIDUGURI G.R.A. TO MISSION HOSPITAL, About 4.6 MILES FROM MAIDUGURi
8029	Kama Village (WELL -NN- Kama)	TRACK LEADING TO KAMA VILLAGE TURNS OFF MAIDUGURI-DUMBOA ROAD AT 11.1 MILES FROM WHERE ROAD JOINS CLAPPERTON WAY IN MAIDUGURI. VILLAGE IS ABOUT 1/4 MILE WEST OF ROAD ALONG TRACK. WELL IS JUST OUTSIDE VILLAGE AT N Edge
8031	Delwa West Village (WELL 551/52)	VILLAGE IS ON MAIDUGURI-DUMBOA ROAD ABOUT 14.9 MILES!, WHERE Roan JOINS CLAPPERTON WAY IN mAIW1GURI. WELL IS IN VILLAGE ABOUT 1/4 MILE SE OF ROAD
10002	Delwa West Village (WELL 552/52)	DELWA WEST VILLAGE. VILLAGE IS ON MAIDUGURI-DUMBOA. ABOUT 14.9 MILES FROM WHERE ROAD JOINS CLAPPERTON WAY IN MAIDUGURI. WELL IS IN VILLAGE MARKET
8032	Tarteri Village (WELL 1575/62)	VILLAGE IS ON MAIDUGURI-DUmBOA ROAD ABOUT 17.2 MILES FROM IGI,HERE ROAD JOINS CLAPPERTON WAY IN MAIDUGURI. WELL IS ABOUT 150 FT. E OF ROAD.
8033	Masaba Village (WEL 561/53)	VILLAGE IS ON MAIDUGURI-DUMBOA ROAD ABOUT 19.1 WILES FROM WHERE IT JOINS CLAPPERTON WAY IN MAIDUGURI. WELL IS ABOUT 1/4 MILE E OF ROAD, IN VILLAGE
8034	Masta Fanameri Village (GSN 3045A)	ALONG MAIDUGURI-DUMBOA ROAD ABOUT 22.3 MILES FROM WHERE ROAD JOINS CLAPPERTON WAY IN MAIDUGURI. BOREHOLE IS ABOUT 200 FT. F OF ROAD
8035	Komala Village (WELL 564/53)	VILLAGE IS ON MAIDUGURI-DUMBOA ROAD ABOUT 27.8 MILES FROM WHERE IT JOINS CLAPPERTON WAY IN MAIDUGURI. WELL IS ABOUT 1/4 MILE W OF ROAD
8036	Musa Village (GSN 3046)	ON MAIDUGURI-DUMBOA ROAD ABOUT 33.6 MILES FROM WHERE ROAD JOINS CLAPPERTON WAY IN MAIDUGURI. BOREHOLE IS ABOUT 200 FT. W OF ROAD

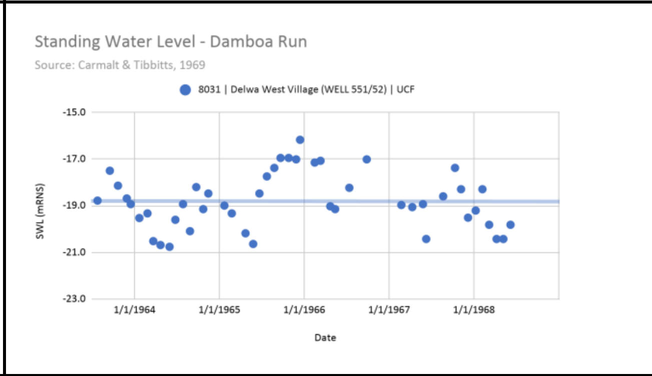
8037	Jirina Village (WELL 1571/62)	VILLAGE IS ABOUT 1.4 MILES FROM MAIDUGURI-DUMBOA ROAD ALONG MULGWE TRACK. WELL IS IN CENTER OF VILLAGE
8038	Kirikashima Village (WELL 1433/62)	VILLAGE IS ABOUT 3.5 MILES FROM MAIDUGURI-DUMBOA ROAD ALONG TRACK TO MULGWE. WELL IS IN CENTER OF VILLAGE
8039	Ngadniri Village (WELL -NN- Ngadiniri)	VILLAGE IS ABOUT 15.0 MILES FROM MAIIDUGURI-DUMBOA ROAD ALONG MULGWE TRACK. WELL IS IN CENTER OF VILLAGE
8040	Ajiri Village (WELL -NN- Ajiri)	VILLAGE IS ABOUT 19.4 MILES FROM MAIDUGURI-DUMBOA ROAD ALONG MULGWE TRACK. WELL IS TO NE OF ROAD, ABOUT 100 YARDS W OF VILLAGE
8041	Gamberi Village (WELL -NN- Gamberi)	VILLAGE IS ABOUT 0.8 MILES FROM MAIDUGURI-DUMBOA ROAD ALONG TRACK TO MULGWE. WELL IS IN CENTER OF VILLAGE
10003	Mulgwe Village (WELL -NN- Mulgwe)	VILLAGE IS ABOUT 26.7 MILES FROM MAIDUGURI-DUMBOA ROAD AT ENDS MULGWE TRACK. WELL IS IN CENTER OF VILLAGE
8043	Mulgwe Village (GSN 3167)	VILLAGE IS ABOUT 26.7 MILES SE OF MAIDUGURI-DUMBOA ROAD AT END OF MULGWE TRACK. BOREHOLE IS ABOUT 100 YARDS E OF VILLAGE
8044	Mulgwe Village (GSN 3180)	VILLAGE IS ABOUT 26.7 MILES SE OF MAIDUGURI-DUMBOA ROC AT END OF MULGWE TRACK. BOREHOLE IS ABOUT 200 FT. E OF VILLAGE. A CONCRETE SHELTER ENCLOSES THE BOREHOLE AND A STEVENS TYPE A-35 WATER LEVEL RECORDER.
8045	Mutube Village (GSN 3188)	VILLAGE IS ON E BANK OF YEDSERAM RIVER ABOUT 12 MILES E OF MULGWE ALONG FOOT PATHS. BOREHOLE IS ENCLOSED BY EASTERNMOST (OF TWO) CONCRETE SHELTER, AND IS AT THE TOP OF A NOTICEABLE MOUND
8046	Bulabulin Village (WELL 582/53)	VILLAGE IS ON MAIDUGURI-DUMBOA ROAD ABOUT 36.5 MILES FROM WHERE ROAD JOINS CLAPPERTON WAY IN MAIDUGURI. WELL IS ABOUT 100 FT. W OF ROAD, IN MIDDLE OF VILLAGE
8047	Faloni Village (GSN 3048)	ALONG MAIDUGURI-DUMBOA ROAD ABOUT 40.6 MILES FROM WHERE ROAD JOINS CLAPPERTON WAY IN MAIDUGURI. BOREHOLE IS APPROX. 100 FT. W OF ROAD
8048	Yaleri Village (WELL 578/53)	VILLAGE IS ON MAIDUGURI-DUMBOA ROAD ABOUT 44.5 MILES FROM WHERt ROAD JOINS CLAPPERTON WAY IN MAIDUGURI. WELL IS ABOUT 50 FT. W OF ROAD
8049	Sandia Village (WELL 639/54)	VILLAGE IS ON MAIDUGURI-DUMBOA ROAD ABOUT 50.2 MILES FROM WHERE ROAD JOINS CLAPPERTON WAY IN MAIDUGURI. WELL IS TO W OF ROAD, AT CORNER OF VILLAGE MARKET
8050	Jimleri Village (WELL -NN- Jimleri)	DUMBOA-GONIRI-NGAMDU TRACK ABOUT 13.2 MILES FROM DUMBOA. WELL IS ABOUT 300 YARDS E OF VILLAGE
8051	Kafa Village (WELL -NN- Kafa)	On DUMBOA-GONIRI-NGAMDU TRACK ABOUT 23.7 MILES FROM DUMBOA. WELL IS ABOUT 50 YARDS E OF ROAD
8052	Goniri Railroad Station (GSN 3162)	RR STATION IS ABOUT 1.2 MILES SW OF WHERE DUMBOA-GONIRI-NGAMDU TRACK CROSSES RAILROAD LINE. BOREHOLE IS ABOUT 400 YARDS NW OF STATION. A CONCRETE SHELTER ENCLOSES BOREHOLE AND A STEVENS TYPE A-35 WATER LEVEL RECORDER
10012	Goniri Railroad Station (WELL -NN- Goniri)	RR STATION IS ABOUT 1.2 MILES SW OF WHERE DUMBOA-GONIRI-NGAMDU TRACK CROSSES RAILROAD LINE. WELL IS ABOUT 50 FT. NE OF STATION

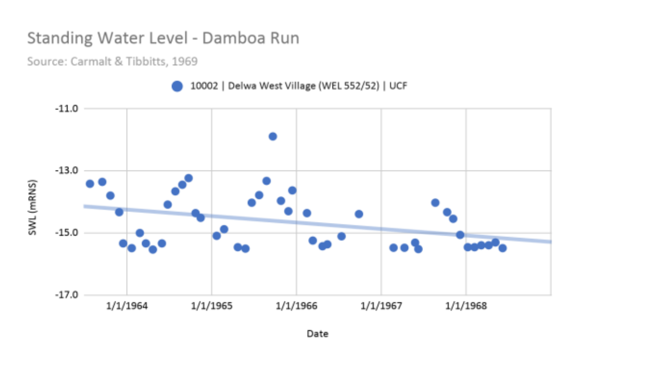
Damboa Run Monthly Manual Measurement Hydrographs

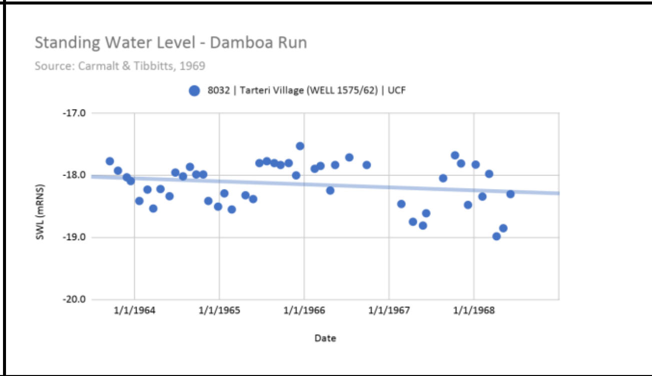


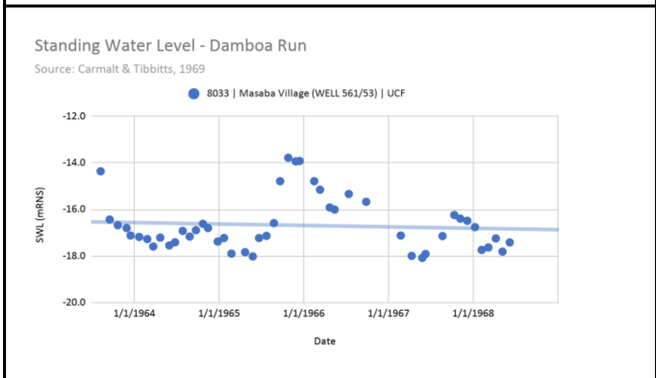


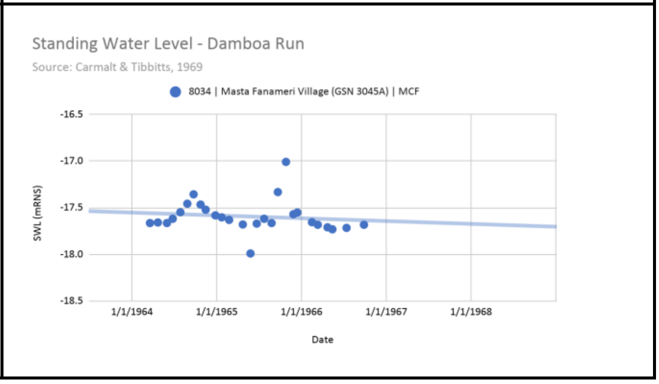


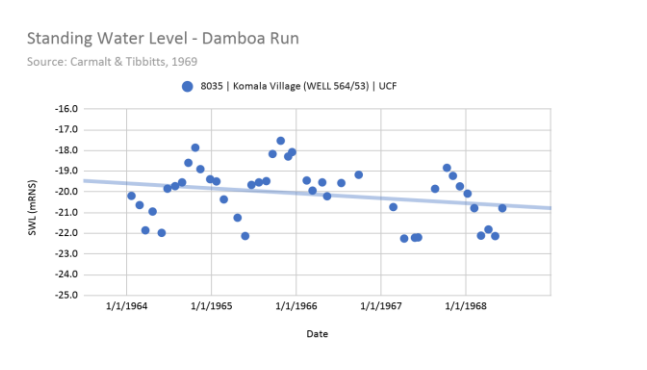


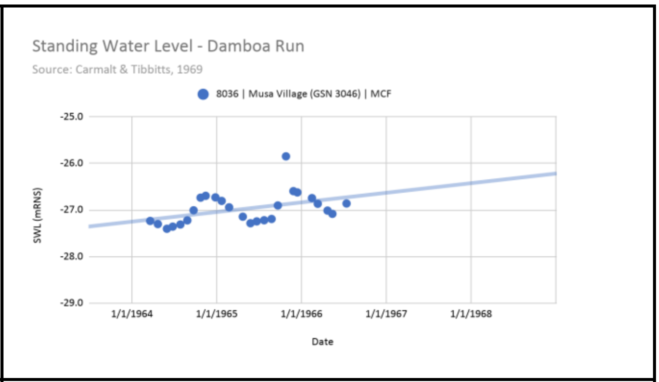


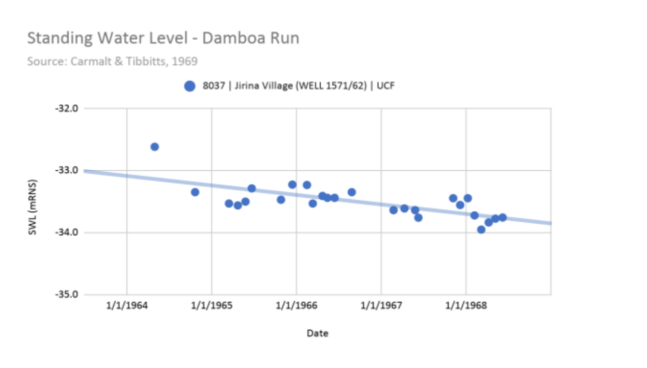


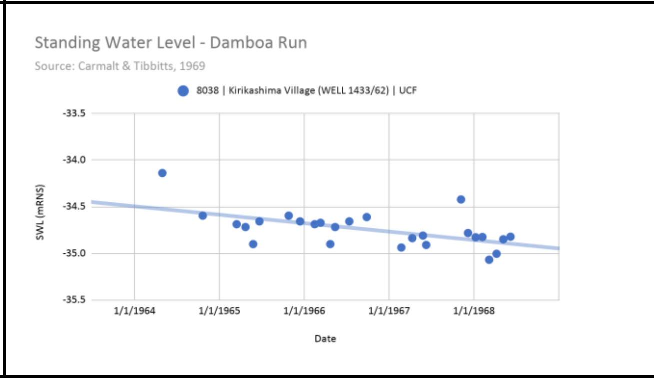


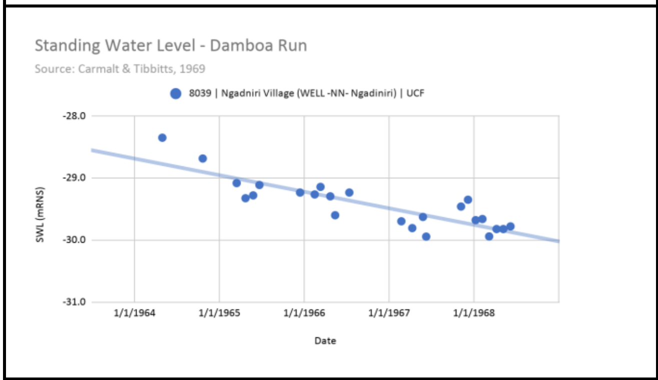


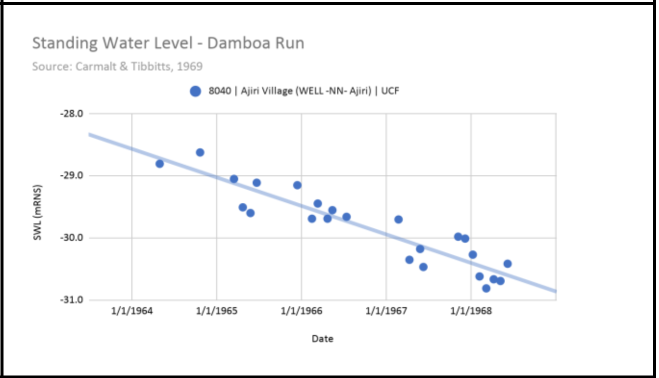

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8035 | Komala Village (WELL 564/53) | UCF
SWL (mRNS)
Date
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968

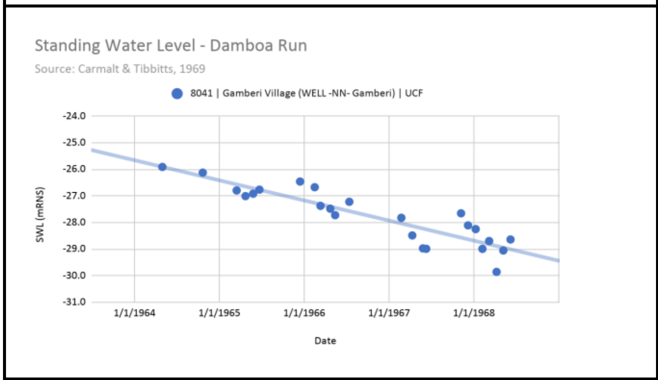

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8036 | Musa Village (GSN 3046) | MCF
SWL (mRNS)
Date

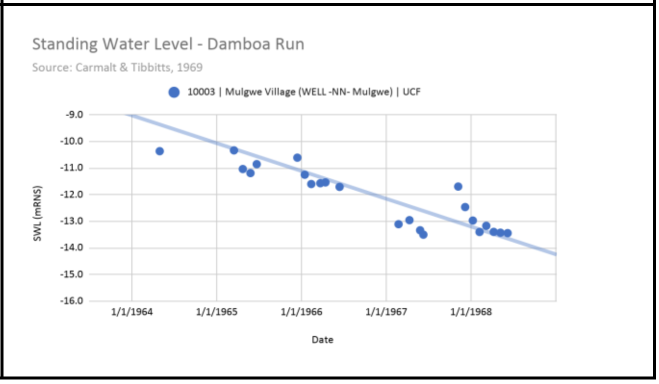

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8037 | Jirina Village (WELL 1571/62) | UCF
SWL (mRNS)
Date

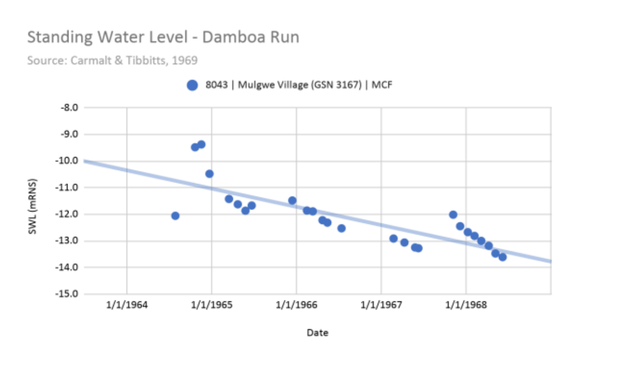

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8038 | Kirikashima Village (WELL 1433/62) | UCF
SWL (mRNS)
Date

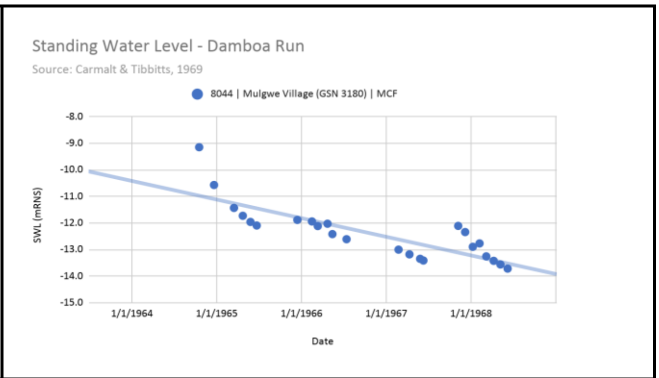

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8039 | Ngadniri Village (WELL -NN- Ngadiniri) | UCF
SWL (mRNS)
Date

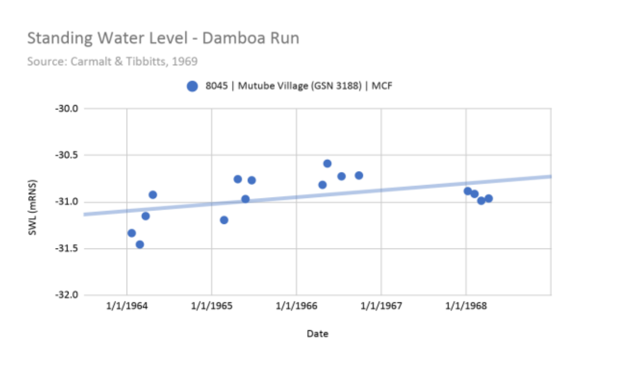

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8040 | Ajiri Village (WELL -NN- Ajiri) | UCF
SWL (mRNS)
Date

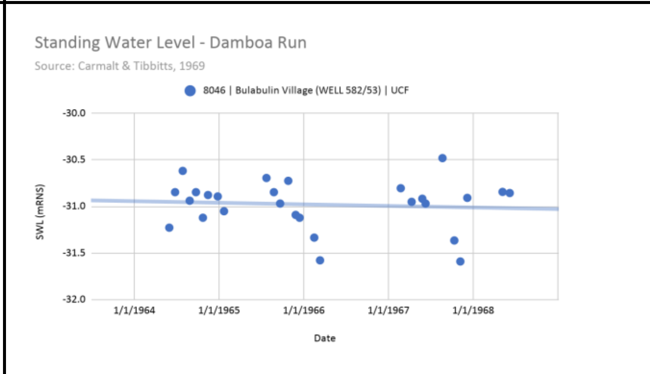

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8041 | Gamberi Village (WELL -NN- Gamberi) | UCF
SWL (mRNS)
Date

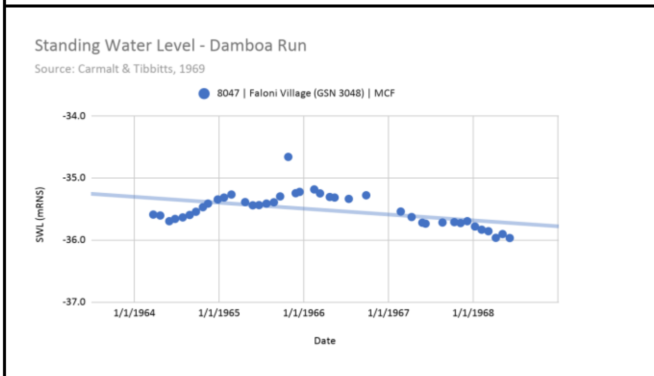

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
10003 | Mulgwe Village (WELL -NN- Mulgwe) | UCF
SWL (mRNS)
Date

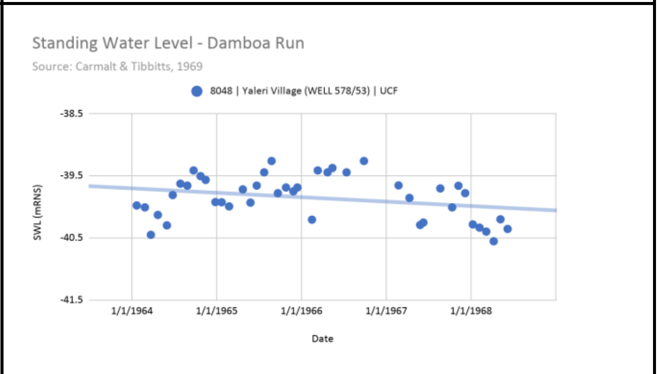

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8043 | Mulgwe Village (GSN 3167) | MCF
-8.0
-9.0
-10.0
-11.0
-12.0
-13.0
-14.0
-15.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

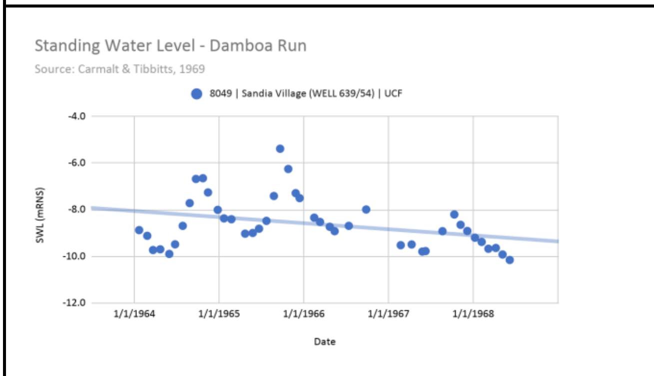

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8044 | Mulgwe Village (GSN 3180) | MCF
-8.0
-9.0
-10.0
-11.0
-12.0
-13.0
-14.0
-15.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

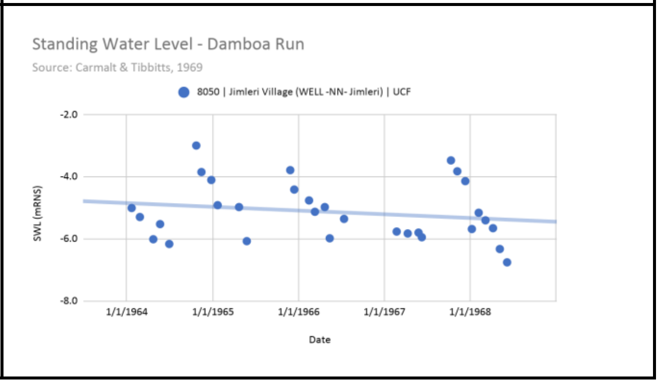

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8045 | Mutube Village (GSN 3188) | MCF
-30.0
-30.5
-31.0
-31.5
-32.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

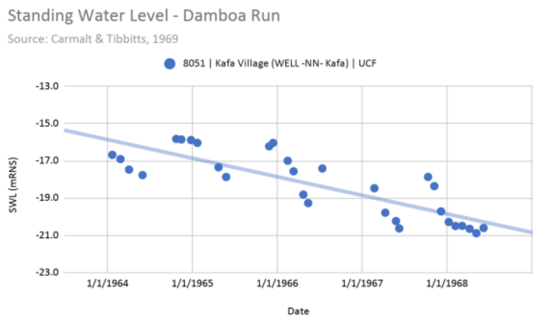

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8046 | Bulabulin Village (WELL 582/53) | UCF
-30.0
-30.5
-31.0
-31.5
-32.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

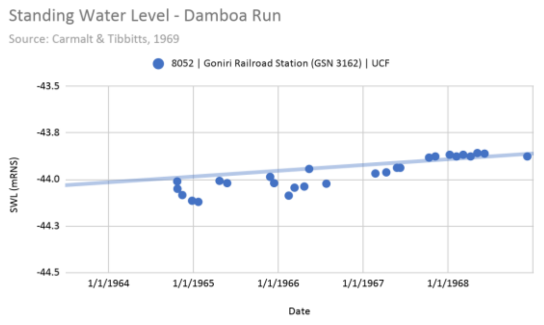

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8047 | Faloni Village (GSN 3048) | MCF
-34.0
-35.0
-36.0
-37.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

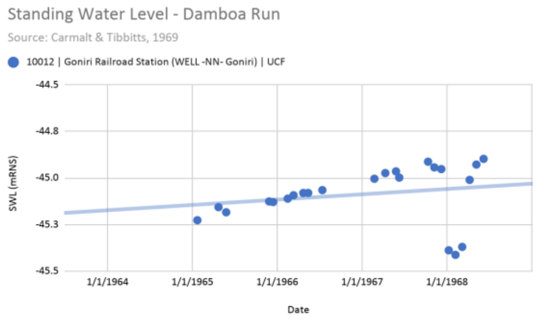

Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8048 | Yaleri Village (WELL 578/53) | UCF
-38.5
-39.5
-40.5
-41.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8049 | Sandia Village (WELL 639/54) | UCF
-4.0
-6.0
-8.0
-10.0
-12.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8050 | Jimleri Village (WELL -NN- Jimleri) | UCF
-2.0
-4.0
-6.0
-8.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8051 | Kafa Village (WELL -NN- Kafa) | UCF
-13.0
-15.0
-17.0
-19.0
-21.0
-23.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
8052 | Goniri Railroad Station (GSN 3162) | UCF
-43.5
-43.8
-44.0
-44.3
-44.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Damboa Run
Source: Carmalt & Tibbitts, 1969
10012 | Goniri Railroad Station (WELL -NN- Goniri) | UCF
-44.5
-44.8
-45.0
-45.3
-45.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

Ngala Run Monitoring Points Location Map

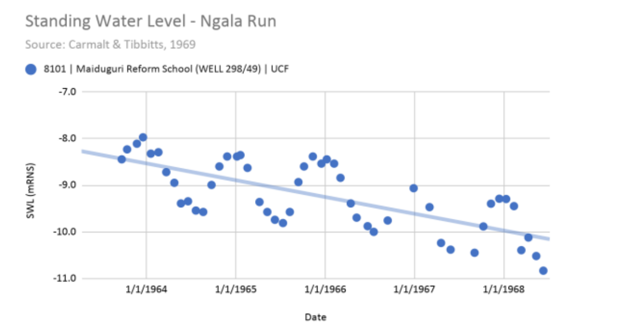
Location of Groundwater Level Monitoring Points included on the Ngala Run.

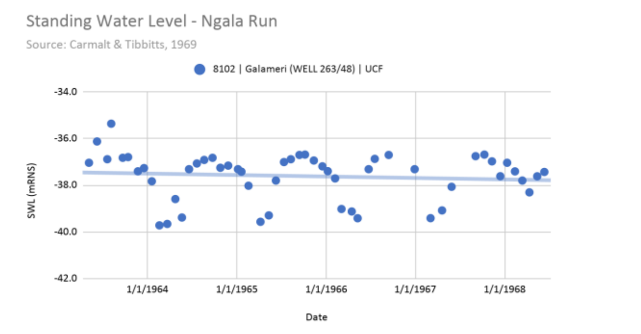
Ngala Run Monitoring Location Details

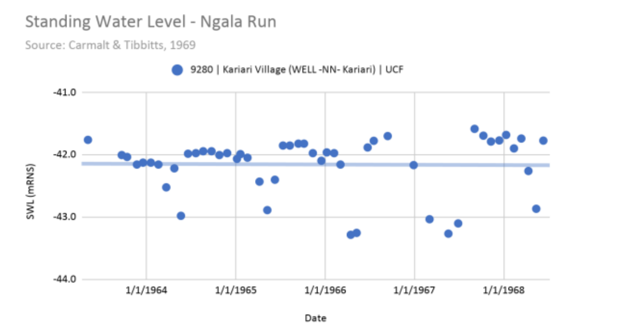
Geo9 ID	Well ID	Location Description
8101	Maiduguri Reform School (WELL 298/49)	ON MAIDUGURI-FT. LAMY ROAD JUST BEYOND CUSTOMS AREA. WELL IS NORTH OF IN CENTER OF REFORM SCHOOL COMPOUND
8102	Galameri (WELL 263/48)	On MAIDUGURI-FT. LAMY ROAD ABOUT 7.5 MILES FROM MAIDUGURI. WELL IS NORTH OF ROAD ABOUT 100 YARDS.
9280	Kariari Village (WELL -NN-Kariari)	MAIDUGURI-FT. LAMY ROAD ABOUT 9.9 MILES FROM MAIDUGURI. WELL IS ABOUT 75 YARDS SOUTH OF ROAD
8104	Bukarti Village (WELL 1053/59)	MAIDUGURI-FT. LAMY ROAD ABOUT 22.5 MILES FROM MAIDUGURI. WELL IS ABOUT 50 YARDS N OF ROAD
8105	Mafa Village (WELL -NN-Mafa)	ON MAIDUGURI-FT. LAMY ROAD ABOUT 30.5 MILES FROM MAIDUGURI. WELL IS IN NORTH WEST CORNER OF VILLAGE, IN A CLEARING SURROUNDED BY COMPOUNDS
8106	Ajiri Village (WELL -NN- Ajiri)	ON MAIDUGURI-ET. LAMY ROAD ABOUT 39.0 MILES FROM MAIDUGURI. WELL IS NORTH OF VILLAGE
9112	Mile 42.1 Maiduguri to Nagala (GSN 2266)	ON MAIDUGURI-FT. LAMY ROAD ABOUT 42.1 MILES FROM MAIDUGURI. BOREHOLE IS N OF ROAD, AT N SIDE OF DRY SEASON TRACK. A SMALL CONCRETE BLOCK HOUSE ENCLOSES THE BOREHOLE
8108	Koye Village (WELL -NN-Koye)	ON MAIDUGURI-FT. LAMP ROAD ABOUT 50.4 MILES FROM MAIDUGURI. WELL IS ABOUT 50. FT. NORTH OF ROAD.
8109	Mile 58.4 Maiduguri to Ngala (WELL 983/58)	ON MAIDUGURI-FT. LAMY ROAD ABOUT 58.4 MILES FROM MAIDUGURI. WELL IS ABOUT l00 YARDS NORTH OF ROAD.
8110	Gajibo Village (GSN 3027)	ON MAIDUGURI-FT. LAMY ROAD ABOUT 59.5 MILES FROM MAIDUGURI. BOREHOLE IS ABOUT 150 FT. S OF ROAD. A CONCRETE SHELTER ENCLOSES THE BOREHOLE AND a FOXBORO PRESSURE RECORDER
10011	Gajibo Village (WELL 1007/58)	ON MAIDUGURI-FT. LAMY ROAD ABOUT 61.8 MILES FROM MAIDUGURI. WELL IS ABOUT 200 FT. SOUTH OF ROAD, NEAR NA SCHOOL

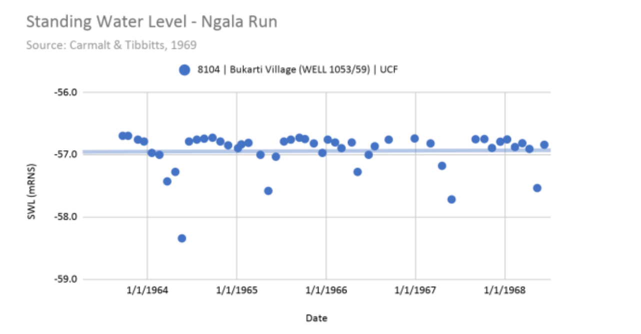
8112	Musone Village (WELL -NN-Musone)	ON MAIDUGURI-FT. LAMY ROAD ABOUT 74.2 MILES FROM MAIDUGURI. WELL IS ABOUT FT. NW OF NW CORNER OF VILLAGE AND IS THE ONE NOT OF STANDARD M.O.W. DESIGN
8113	Ngala Village (WELL 1026/58)	ON MAIDUGURI-FT. LAMY ROAD ABOUT 83.3 MILES FROM MAIDUGURI. WELL IS ABOUT 1,7, FT. SOUTH OF ROAD
8114	Near Ngala Village (GSN 3029)	ON MAIDUGURI-FT. LAMY ROAD ABOUT 83.9 MILES FROM MAIDUGURI. BOREHOLE IS ABOUT 150 FT. SOUTH OF ROAD. A CONCRETE SHELTER ENCLOSES THE BOREHOLE AND A FOXBORO PRESSURE RECORDER
10007	Gamberu Village (WELL 1006/58)	ON MAIDUGURI-FT. LAMY ROAD ABOUT 87.0 MILES FROM MAIDUGURI. WELL IS NORTH OF ROAD AND INSIDE M.O.W. ROAD CAMP COMPOUND, JUST WHERE ROAD BEGINS TO RISE TO BRIDGE WHICH IS INTERNATIONAL FRONTIER

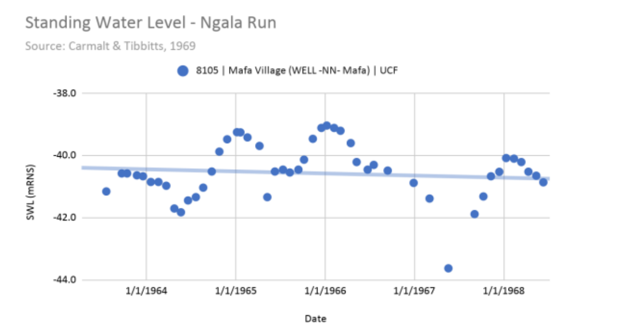
Ngala Run Monthly Manual Measurement Hydrographs

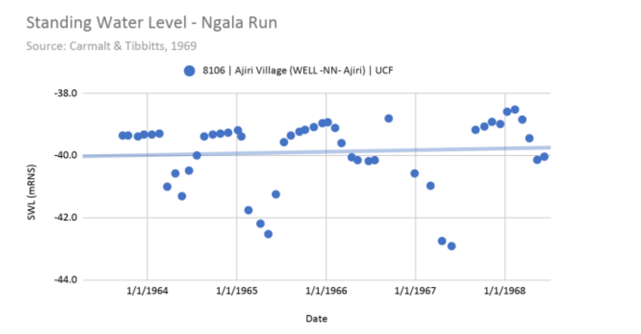


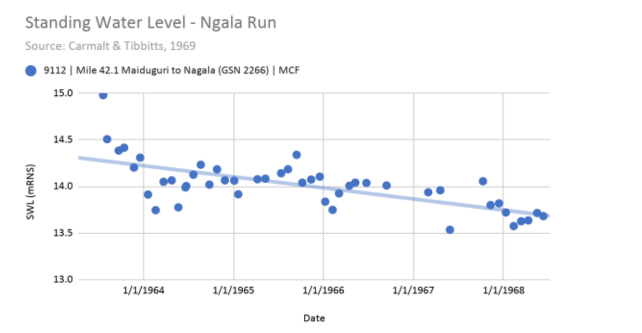


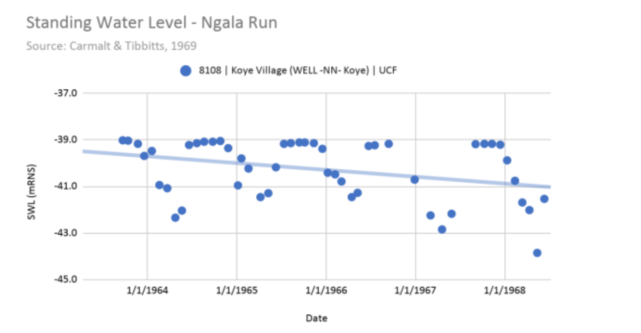


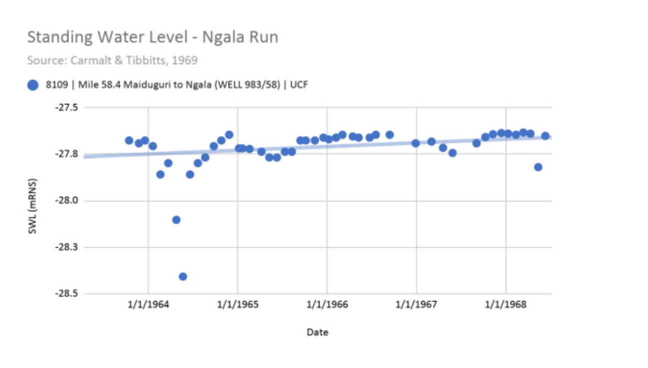


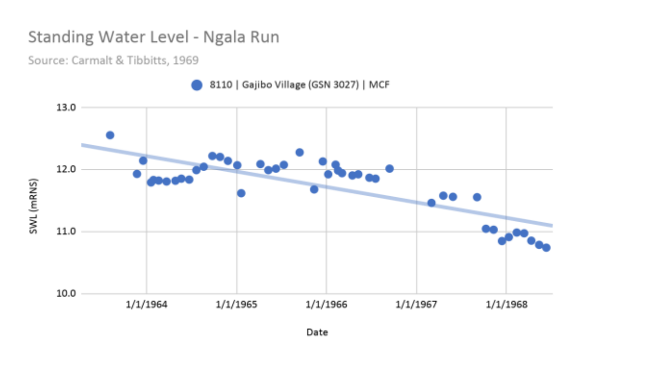


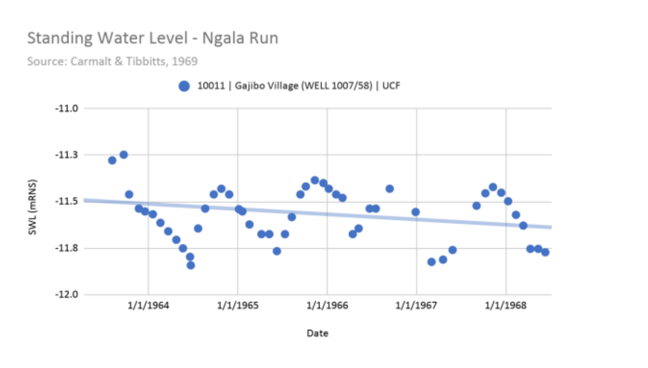


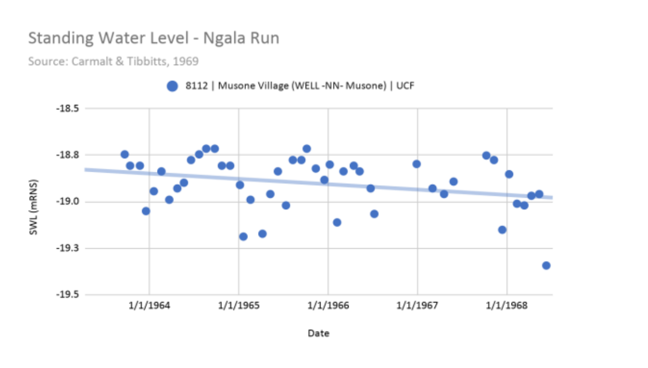


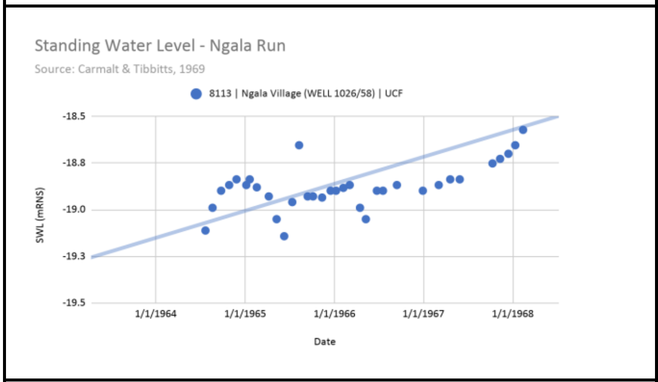


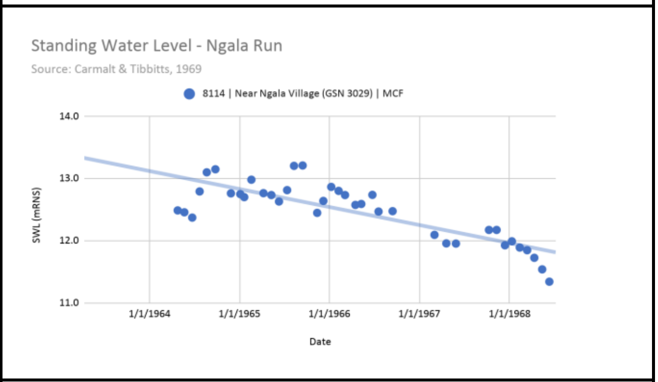

Standing Water Level - Ngala Run
Source: Carmalt & Tibbitts, 1969
8109 | Mile 58.4 Maiduguri to Ngala (WELL 983/58) | UCF
-27.5
-27.8
-28.0
-28.3
-28.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

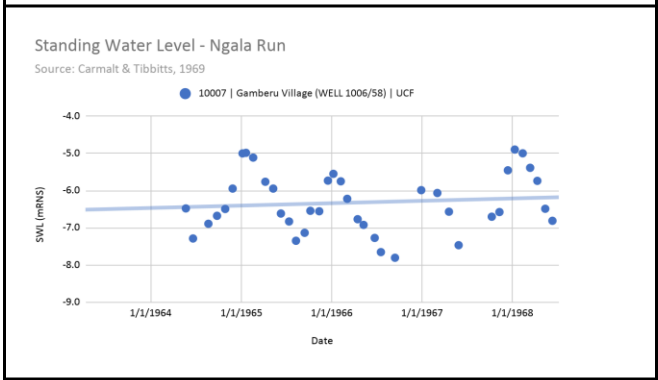

Standing Water Level - Ngala Run
Source: Carmalt & Tibbitts, 1969
8110 | Gajibo Village (GSN 3027) | MCF
13.0
12.0
11.0
10.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Ngala Run
Source: Carmalt & Tibbitts, 1969
10011 | Gajibo Village (WELL 1007/58) | UCF
-11.0
-11.3
-11.5
-11.8
-12.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Ngala Run
Source: Carmalt & Tibbitts, 1969
8112 | Musone Village (WELL -NN- Musone) | UCF
-18.5
-18.8
-19.0
-19.3
-19.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Ngala Run
Source: Carmalt & Tibbitts, 1969
8113 | Ngala Village (WELL 1026/58) | UCF
-18.5
-18.8
-19.0
-19.3
-19.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Ngala Run
Source: Carmalt & Tibbitts, 1969
8114 | Near Ngala Village (GSN 3029) | MCF
14.0
13.0
12.0
11.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Ngala Run
Source: Carmalt & Tibbitts, 1969
10007 | Gamberu Village (WELL 1006/58) | UCF
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

Bama Run Monitoring Points Location Map

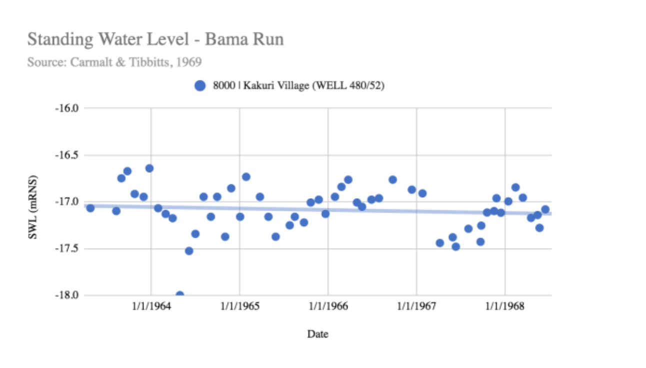
Location of Groundwater Level Monitoring Points included on the Bama Run.

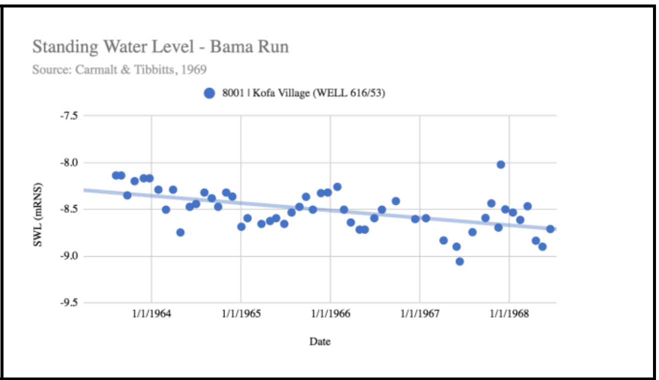
Bama Run Monitoring Location Details

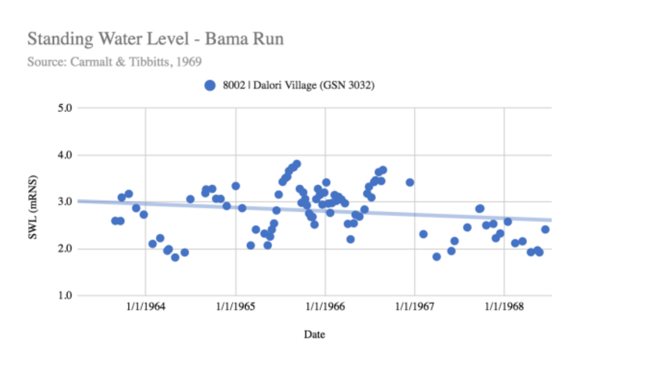
Geo9 ID	Well ID	Location Description
8000	Kakuri Village (WELL 480/52)	MILE 8.2 ON SW SIDE MAIDUGURI-BAMA RD, ABOUT 25 FT. FROM PAVEMENT.
8001	Kofa Village (WELL 616/53)	MILE 11.7 ON NE SIDE MAIDUGURI-BAMA RD, ABOUT 350 FT. FROM PAVEMENT.
8002	Dalori Village (GSN 3032)	IN DALORI VILLAGE ABOUT 200 FT. SE OF GSN 3019 AND 15 FT. SECT SHELTER OVER GSN 3C33. A CONCRETE SHELTER ENCLOSES THE BOREHOLE AND A FOXBORO PRESSURE RECORDER.
8003	Dalori Village (GSN 3033)	IN DALORI VILLAGE ABOUT 185 FT. SE OF GSN 3019 AND 15 FT. NW OF SHELTER OVER GSN 3032
8004	Dalori Village (GSN 3019)	IN DALORI VILLAGE ABOUT 195 FT. NW OF SHELTER OVER GSN 3033
8005	Kadiri Village (WELL 700/54)	MILE 15 ON NE SIDE MAIDUGURI-BAMA RD, ABOUT 100 YARDS FROM PAVEMENT
8006	Kasalari Village (WELL 933/57)	MILE 17.3 ON NE SIDE MAIDUGURI-BAMA RD, ABOUT 80C FT. FROM PAVEMENT
8007	Jaytaytay Village (WELL 932/57)	MILE 18.1 ON NE SIDE MAIDUGURI-BAMA RD, ABOUT 150 FT. FROM PAVEMENT
8008	Kondua Village (WELL 722/54)	MILE 25.5 ON NE SIDE MAIDUGURI-BAMA RD, ABOUT 35C FT. FROM PAVEMENT
8009	Mairambi Village (WELL -NN-Mairambi)	MILE 30.6 ON NE SIDE MAIDUGURI-BAMA RD, ABOUT 500 YARDS FROM PAVEMENT
8010	Gauramari Village (WELL 601/53)	MILE 35.6 ON NE SIDE MAIDUGURI-BAMA RD, ABOUT 375 FT. FROM'PAVEMENT
8011	Bama Roundabout (WELL 736/54)	MILE 38.9 ON NE SIDE MAIDUGURI-BAMA ROAD, CLOSE TO PAVEMENT
8012	Bulabulin Village (WELL 1061/59)	NW CORNER OF FIRST ROUNDABOUT ENTERING BAMA ON MAIDUGURI-BAMA ROAD

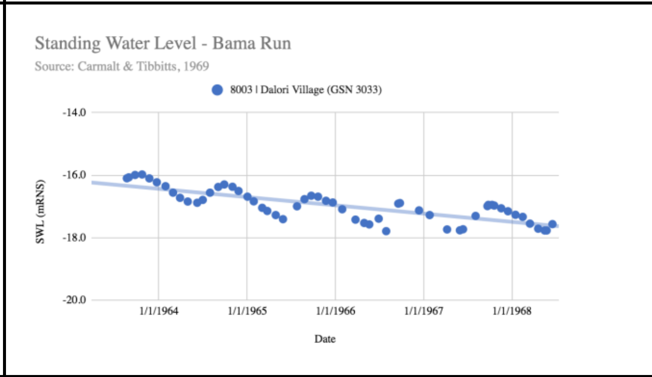
9286	Bulabulin Village (GSN 2526)	FROM WELL 1061/59 (BAMA) N ON DIKWA TRACK L TH' MILES, THEN NW ON WORN FOOTPATH 1.6 MILES TO VILLAGE. BH IS APPROX. 100 YARDS E OF VILLAGE.
8014	Bama Village (WELL 604/53)	FROM WELL 1061/59 (BAMA) N ON DIKWA TRACK L TH' MILES, THEN NW ON WORN FOOTPATH 1.6 MILES TO VILLAGE. BH IS APPROX. 100 YARDS E OF VILLAGE.
9283	Bama Village (GSN 2507)	IN BAMA TOWN ON G.R.A. NEAR BUSH REST HOUSE. A CONCRETE SHELTER ENCLOSES THE BOREHOLE AND A STEVENS TYPE FM WATER LEVEL RECORDER
8016	Bama Village (WELL 294/49)	IN DANA VILLAGE ON G.R.A. NEAR BUSH REST HOUSE AND ABOUT 50 YARDS NW OF GSN 2507
8017	Bama Village (WELL 328/50)	ON EAST SIDE OF ROUNDABOUT WHERE ROAD FROM GWOZA ENTERS BAMA
8018	near Bama Village (GSN 3031)	ON BAMA-GWOZA ROAD 2.2 MILES FROM BARRIER AT EDGE OF BAMA TOWN. BOREHOLE IS AT EAST SIDE OF ROAD
8019	Soye Village (WELL 1085/59)	ON BAMA - DAR-AL-JIMEIL ROAD ABOUT 5 MILES FROM BARRIER AT EDGE OF BAMA VILLAGE. SOYE VILLAGE IS REACHED JUST AFTER TURNING OFF BAMA-GWOZA ROAD. WELL IS IN YARD OF NA SCHOOL, AT EAST EDGE OF TOWN
8020	Bulongo Village (WELL 1046/59)	BAMA - DAR-AL-JIMEIL ROAD 8.6 MILES FROM BARRIER WHERE ROAD ENTERS BAMA. WELL IS IN CENTER OF VILLAGE, TO NORTH EAST OF ROAD
9287	Dala Gonebori Village (GSN 2527)	ON BAMA - DAR-AL-JIMEIL ROAD ABOUT 15.9 MILES FROM BARRIER AT BAMA. BOREHOLE IS IN FIELD AT SW CORNER OF VILLAGE.
9596	Dala Gonebori Village (WELL 499/53)	ON BAMA - DAR-AL-JIMEIL ROAD ABOUT 15.9 MILES FROM THE BARRIER AT BAMA VILLAGE. WELL IS ABOUT 85 FT. N OF ROAD
8023	Dipchari Village (WELL 292/49)	ON BAMA - DAR-AL-JIMEIL ROAD ABOUT 18.1 MILES FROM BARRIER AT BAMA VILLAGE. WELL IS IN CENTER OF VILLAGE
9288	Jere Village (GSN 2528)	JERE IS ABOUT 2.7 MILES E OF DIPCHARI ON FOOTPATH. BORE-HOLE IS IN A FIELD ABOUT 1/4 MILE E OF VILLAGE CENTER
8025	Jere Village (WELL 485/52)	JERE IS ABOUT 2.7 MILES E OF DIPCHARI ON FOOTPATH. WELL IS IN VILLAGE MARKET
8026	Dar-Al-Jimell Village (Well -NN-Dar-Al-Jimeil)	AT END OF BAMA - DAR-AL-JIMEIL ROAD, ABOUT 24.5 MILES FROM BARRIER IN BAMA. WELL IS NEAR NA SCHOOL

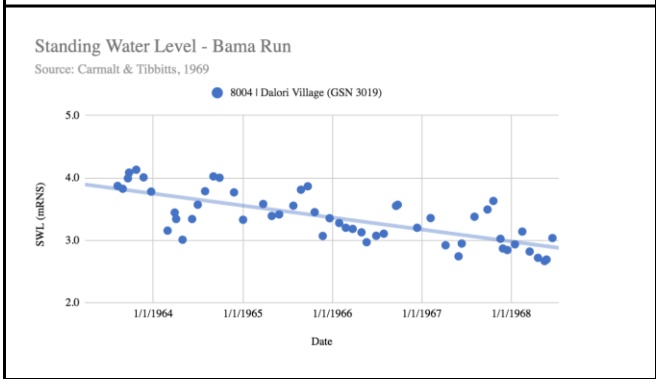
Bama Run Monthly Manual Measurement Hydrographs

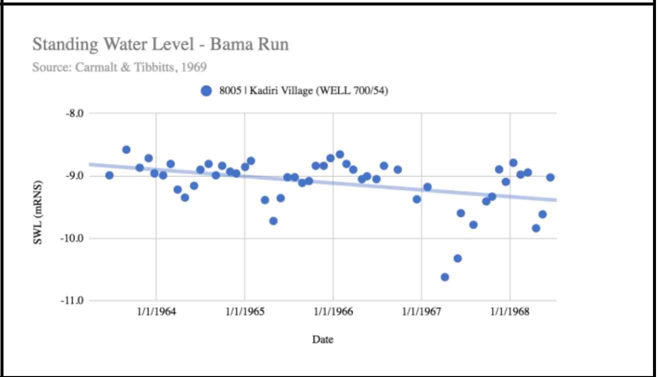


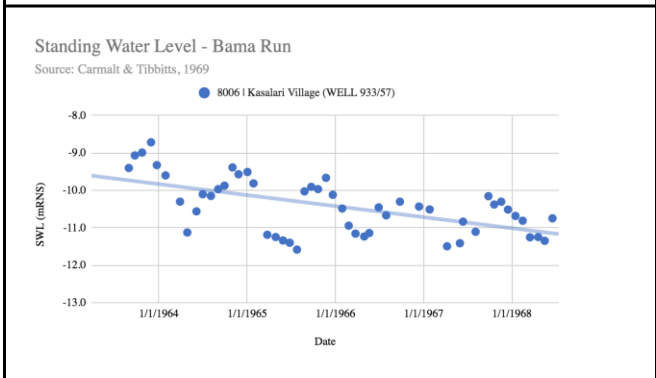


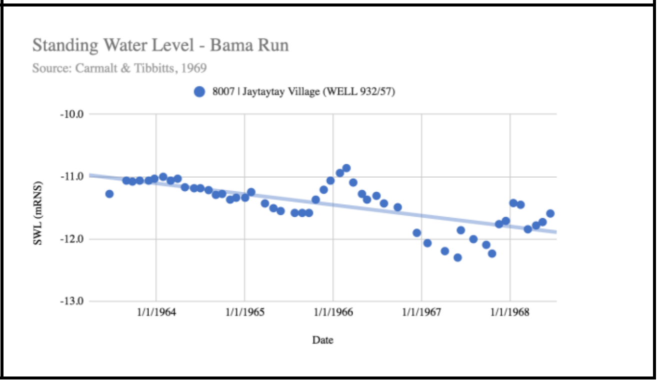


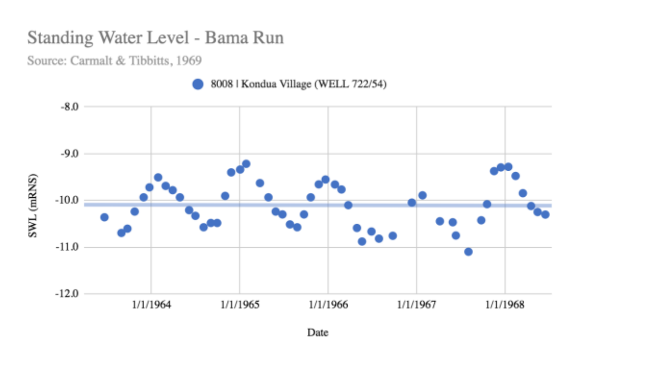


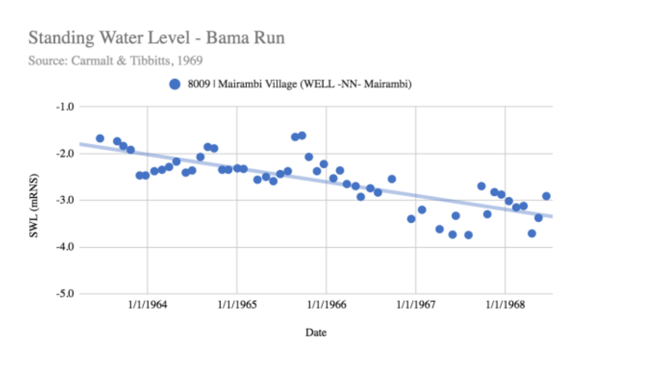


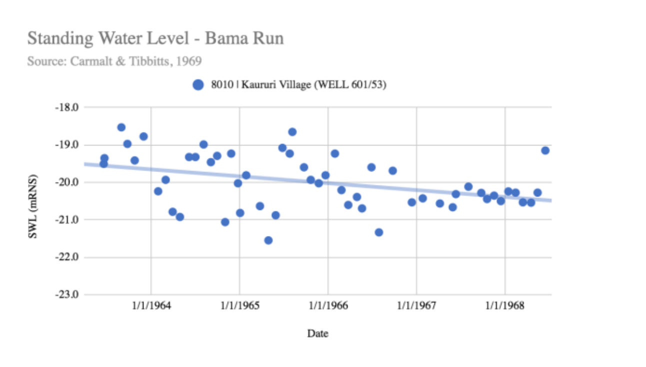


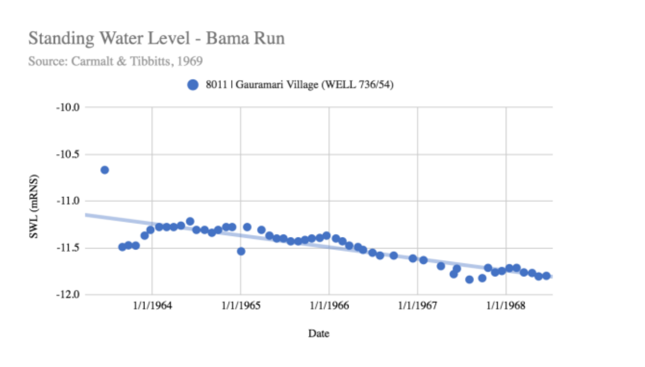


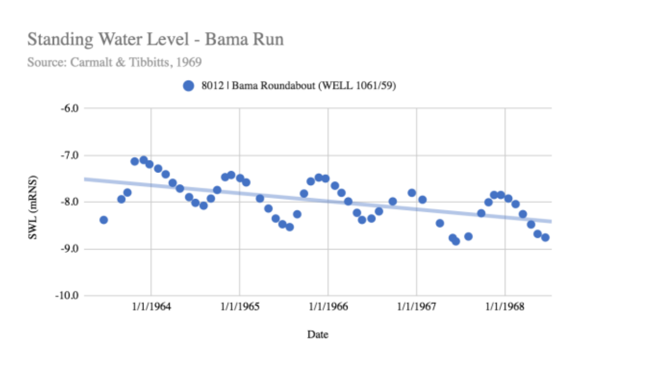



Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8008 | Kondua Village (WELL 722/54)
SWL (mRNS)
-8.0
-9.0
-10.0
-11.0
-12.0
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8009 | Mairambi Village (WELL -NN- Mairambi)
SWL (mRNS)
-1.0
-2.0
-3.0
-4.0
-5.0
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8010 | Kaururi Village (WELL 601/53)
SWL (mRNS)
-18.0
-19.0
-20.0
-21.0
-22.0
-23.0
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8011 | Gauramari Village (WELL 736/54)
SWL (mRNS)
-10.0
-10.5
-11.0
-11.5
-12.0
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8012 | Bama Roundabout (WELL 1061/59)
SWL (mRNS)
-6.0
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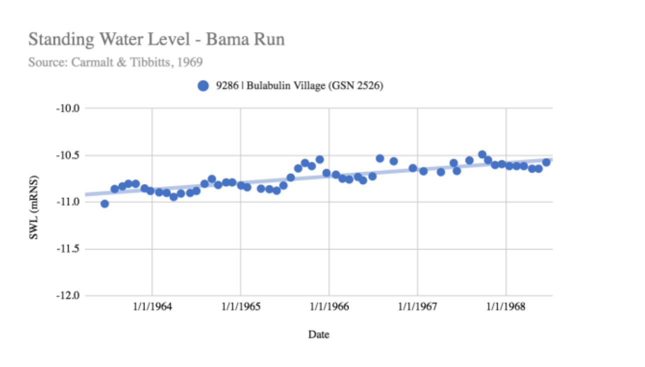
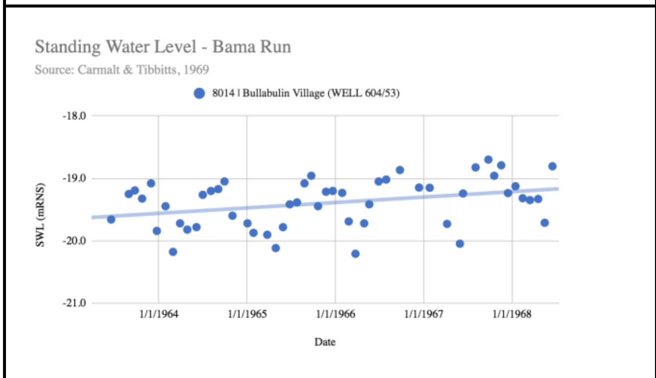
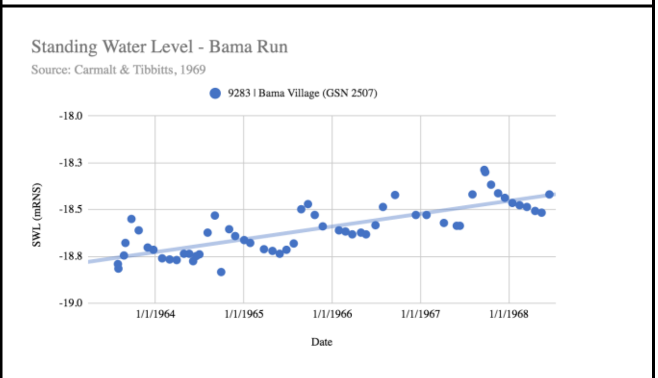
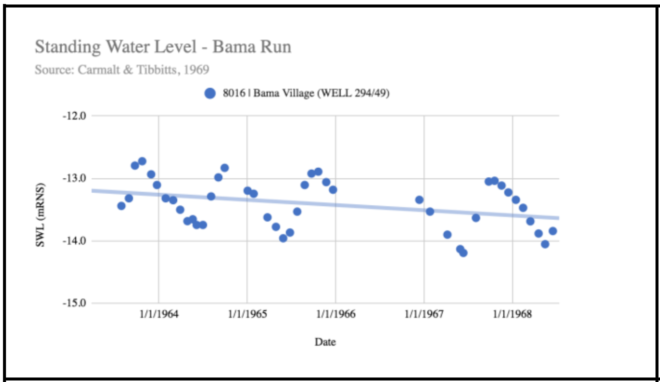
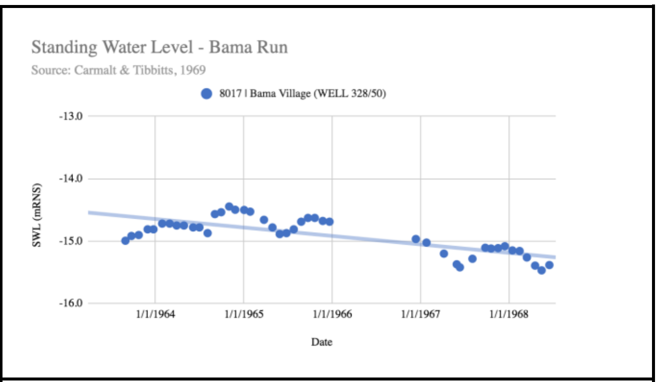
-8.0
-9.0
-10.0
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

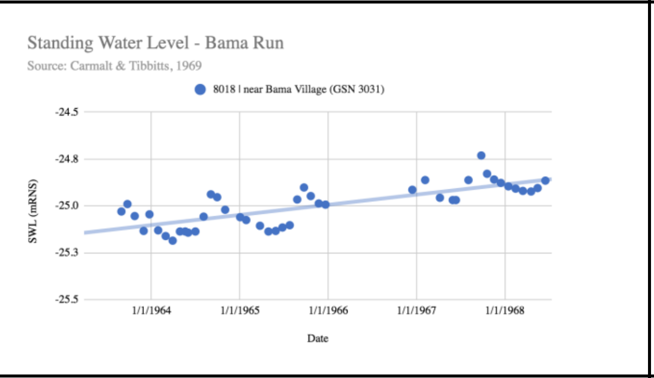

Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
9286 | Bulabulin Village (GSN 2526)
SWL (mRNS)
-10.0
-10.5
-11.0
-11.5
-12.0
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

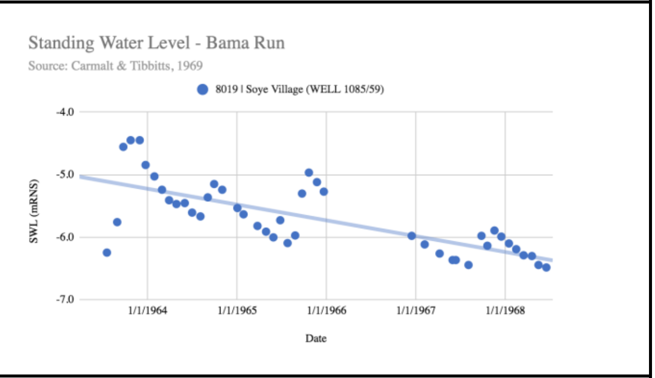

Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8014 | Bullabulin Village (WELL 604/53)
SWL (mRNS)
-18.0
-19.0
-20.0
-21.0
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

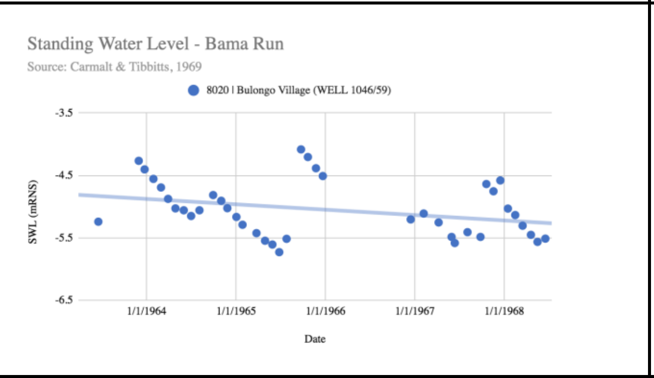

Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
9283 | Bama Village (GSN 2507)
SWL (mRNS)
-18.0
-18.3
-18.5
-18.8
-19.0
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

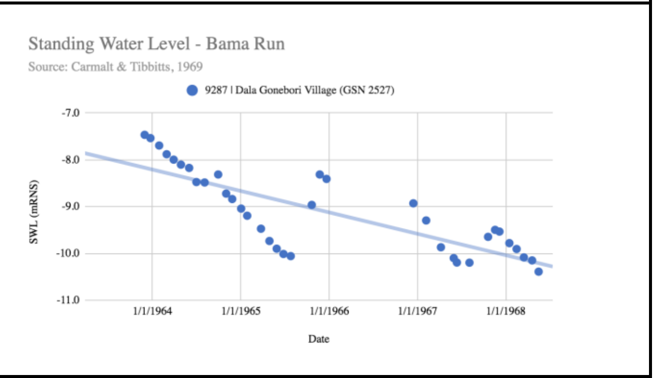

Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8016 | Bama Village (WELL 294/49)
-12.0
-13.0
-14.0
-15.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

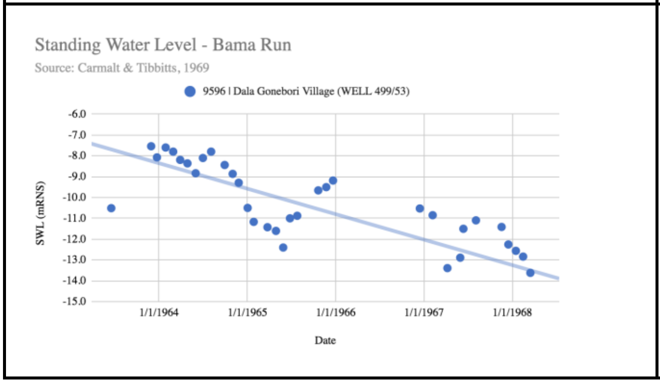

Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8017 | Bama Village (WELL 328/50)
-13.0
-14.0
-15.0
-16.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

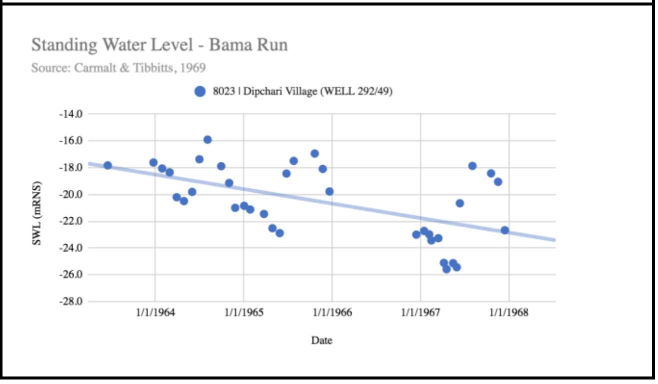

Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8018 | near Bama Village (GSN 3031)
-24.5
-24.8
-25.0
-25.3
-25.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

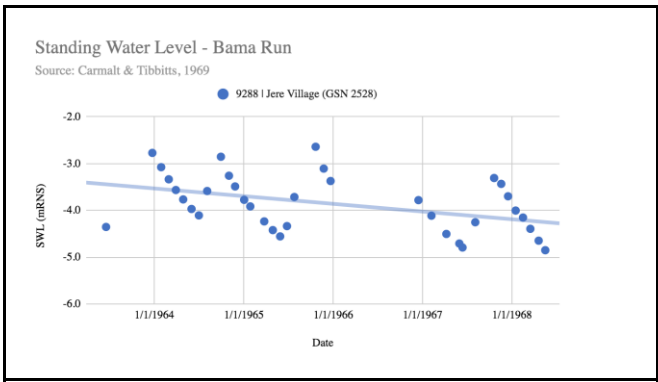

Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8019 | Soye Village (WELL 1085/59)
-4.0
-5.0
-6.0
-7.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

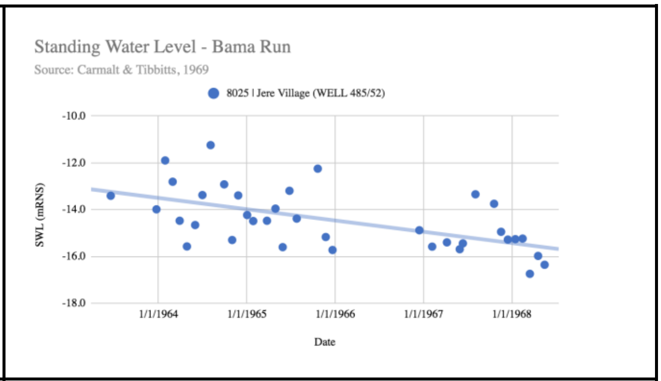

Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8020 | Bulongo Village (WELL 1046/59)
-3.5
-4.5
-5.5
-6.5
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

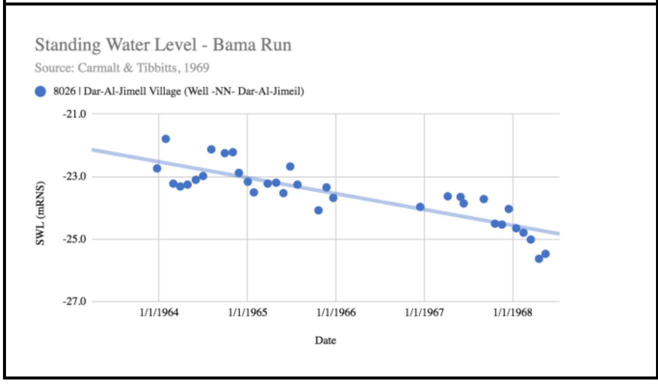

Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
9287 | Dala Gonebori Village (GSN 2527)
-7.0
-8.0
-9.0
-10.0
-11.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
9596 | Dala Gonebori Village (WELL 499/53)
-6.0
-7.0
-8.0
-9.0
-10.0
-11.0
-12.0
-13.0
-14.0
-15.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

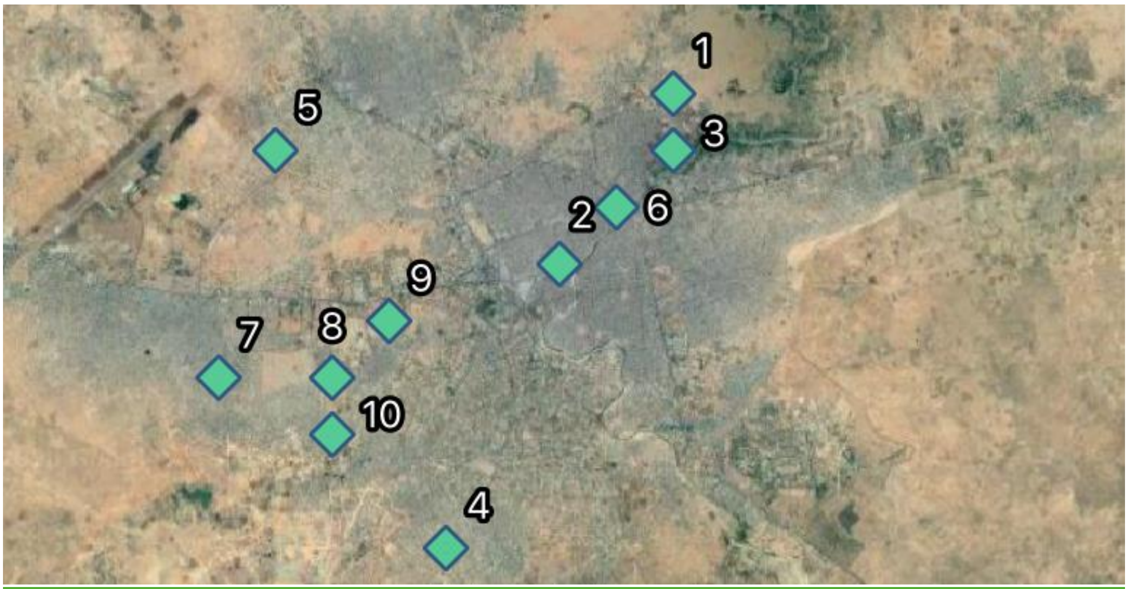

Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8023 | Dipchari Village (WELL 292/49)
-14.0
-16.0
-18.0
-20.0
-22.0
-24.0
-26.0
-28.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
9288 | Jere Village (GSN 2528)
-2.0
-3.0
-4.0
-5.0
-6.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date


Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8025 | Jere Village (WELL 485/52)
-10.0
-12.0
-14.0
-16.0
-18.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

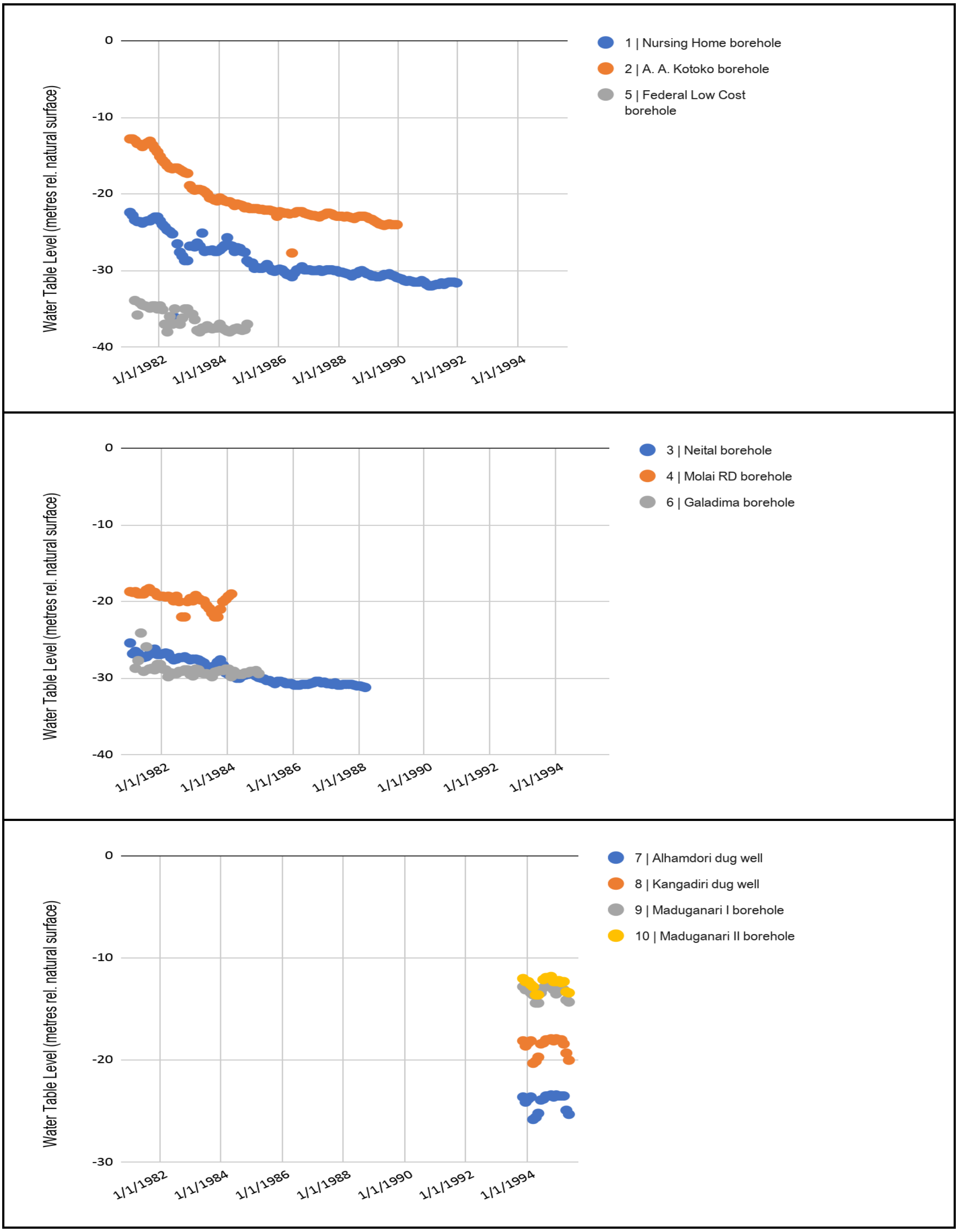

Standing Water Level - Bama Run
Source: Carmalt & Tibbitts, 1969
8026 | Dar-Al-Jimell Village (Well -NN- Dar-Al-Jimeil)
-21.0
-23.0
-25.0
-27.0
SWL (mRNS)
1/1/1964
1/1/1965
1/1/1966
1/1/1967
1/1/1968
Date

Annex 3 Maiduguri City Upper Chad Formation Hydrographs



Location of UNIMAID Groundwater Level Monitoring Points - 1980's automatic monitoring program

Geo9 ID	Well ID	Monitoring Run	Location Description
1	Nursing Home borehole	Maiduguri Run	
2	A. A. Kotoko borehole	Maiduguri Run	
3	Neital borehole	Maiduguri Run	
4	Molai RD borehole	Maiduguri Run	
5	Federal Low Cost borehole	Maiduguri Run	
6	Galadima borehole	Maiduguri Run	
7	Alhamdori dug well	Maiduguri Run	
8	Kangadiri dug well	Maiduguri Run	
9	Maduganari I borehole	Maiduguri Run	
10	Maduganari II borehole	Maiduguri Run	


Water Table Level (metres rel. natural surface)
0
-10
-20
-30
-40
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1 | Nursing Home borehole
2 | A. A. Kotoko borehole
5 | Federal Low Cost borehole
Water Table Level (metres rel. natural surface)
0
-10
-20
-30
-40
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
3 | Neital borehole
4 | Molai RD borehole
6 | Galadima borehole
Water Table Level (metres rel. natural surface)
0
-10
-20
-30
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
7 | Alhamdori dug well
8 | Kangadiri dug well
9 | Maduganari I borehole
10 | Maduganari II borehole