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Research Article

Studies on the Seasonal Variation and Behaviour of Hydraulic Head along River Benue Floodplain, Yola, North Eastern Nigeria

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Abstract: The aim of this research is to determine availability of water for irrigational practice during dry season farming along River Benue floodplain. Water table heights were estimated by automatic piezometer instrument and manual measurements. The results of the water level measurements help to quantify the variable response of hydraulic head and also help to indicate the direction of water movement. The results from the two monitored piezometers show a switch in the hydraulic gradient. In the dry season, the water level in the river is higher than the surrounding area and therefore, the river loses water to the surrounding area. Conversely, in the rainy season the water level in the surrounding area rises and therefore loses water to the river. The relationship between the water levels in the two piezometers suggests a linear relationship when P1>174.25 m, which shows time of flow to river. It was also observed that, in the northeast, southeast and southwest the direction of groundwater flows are from the river to the floodplain, whilst in the northwest the direction of groundwater flow is from the floodplain to the river. Hydrological data demonstrate that River Benue is the main source for recharge of the shallow alluvial aquifers of the floodplain during the dry season period.

Keywords: Alluvial aquifers, dry season, groundwater, irrigation activities, piezometer instrument, river Benue

INTRODUCTION

Globally in semi-arid environment, the shallow alluvial floodplain aquifers are main source of water supply for domestic purposes and irrigation (Taylor *et al*., 2013; Yusuf, 2014). However, the sustainability of these shallow alluvial floodplain aquifers to continued abstraction, particularly during the dry season, is affected by high water demand for irrigation as well as increasing population (Passadore *et al*., 2012). Globally groundwater storage constitutes approximately 97% of the world water resources (Holden, 2012). Most of arid and semi-arid environments depend on groundwater than the surface water during the dry season period, Scanlon *et al*. (2006), including the research area.

Groundwater sustainability is define as groundwater development in a manner that can be maintained for longer period without causing severe environmental impact, Cao *et al*. (2013) and groundwater withdrawal is sustained loss of groundwater. Fadama is refers to a small shallow depressions to the floodplain of major rivers but does not include permanently flooded or waterlogged marshes or swamps. Fadama are important not only for irrigation potential but also as a major source of water for domestic consumption and livestock grazing (Tarhule and Woo, 1997). Considering Fadama floodplain, groundwater sustainability can be defined as groundwater withdrawal, which will not cause severe lowering of the shallow floodplain aquifers for irrigation use and allow the growth of vegetables year long. Sustainability of the shallow alluvial aquifers along the floodplain depends on their ability for lasting longer without deteriorating (Alley *et al*., 1999).

Along River Benue floodplain, shallow alluvial aquifers are mostly available, where most of the farmers practice irrigation during the dry season. Sustainability of these shallow alluvial aquifers is useful especially for the irrigation farmers. It would not be economical to use machine drilling rigs for such formations because the farmers do not have the means to pay equipment, maintenance and security. Rather, simple and affordable hand-drilling techniques are used in order to boost agricultural production at a low-cost hand drilling. According to Sabo and Adeniji (2007), dry season vegetable production plays a key role in the

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economics of Adamawa State as a basic source of food, income and employment, especially for poor farmers.

Most of the floodplain shallow aquifers in Africa come from alluvial formation which represents approximately 25% of the land surface (MacDonald *et al*., 2011). These alluvial formations are permeable with high percolation during the rainy season that recharges the shallow floodplain groundwater (Nur and Kujir, 2006). Alluvial aquifers along the floodplain of River Benue are the main source of water supply for irrigation. Good knowledge on floodplain alluvial aquifers such as understanding their depth, spatial distribution and the geology could improve the sustainability of the groundwater (Park *et al*., 2007).

Measurements of depth to water, or its height above mean sea level, are necessary for understanding the groundwater condition of an area, e.g., for the recharge of an aquifer in the floodplain. The data from groundwater level measurement can be used to understand the flow direction of groundwater and to measure the impacts of abstraction. The measurement of water level fluctuations in piezometers and observation wells is an important parameter for many groundwater studies. The variation of groundwater levels across the floodplain can result from different hydrologic activities (Freeze and Cherry, 1979). Measurements of water levels in wells provide useful means for assessing the quantity and quality of groundwater and its relation with the shallow alluvial aquifers along the floodplain (Taylor and Alley, 2001).

Despite a long history of exploitation of groundwater on the alluvial floodplain, very little research on the hydrological characteristics of these shallow aquifers exists, leading therefore to the present investigation. The aim of this research is to determine availability of water for irrigational practice during dry season farming along River Benue floodplain. The objectives of the research work are to observed changes in groundwater level and to examine variation in hydraulic head along the River Benue floodplain and to investigate the relationship of the water table to precipitation.

THE STUDY AREA

The study area (Fig. 1) is in Adamawa State which is located in the North Eastern part of Nigeria, between latitudes 7 and 9°N and longitudes 11 and 12°E. It shares a boundary with Cameroon Republic along its eastern border. The elevation of the study area varies from 149 to 228 m above mean sea level and falls within the Upper Benue Basin. The state covers a land area of about 38,741 km^2 with a population of 3, 168, 101 people and a population density of 82 persons per square kilometer (Census, 2006).

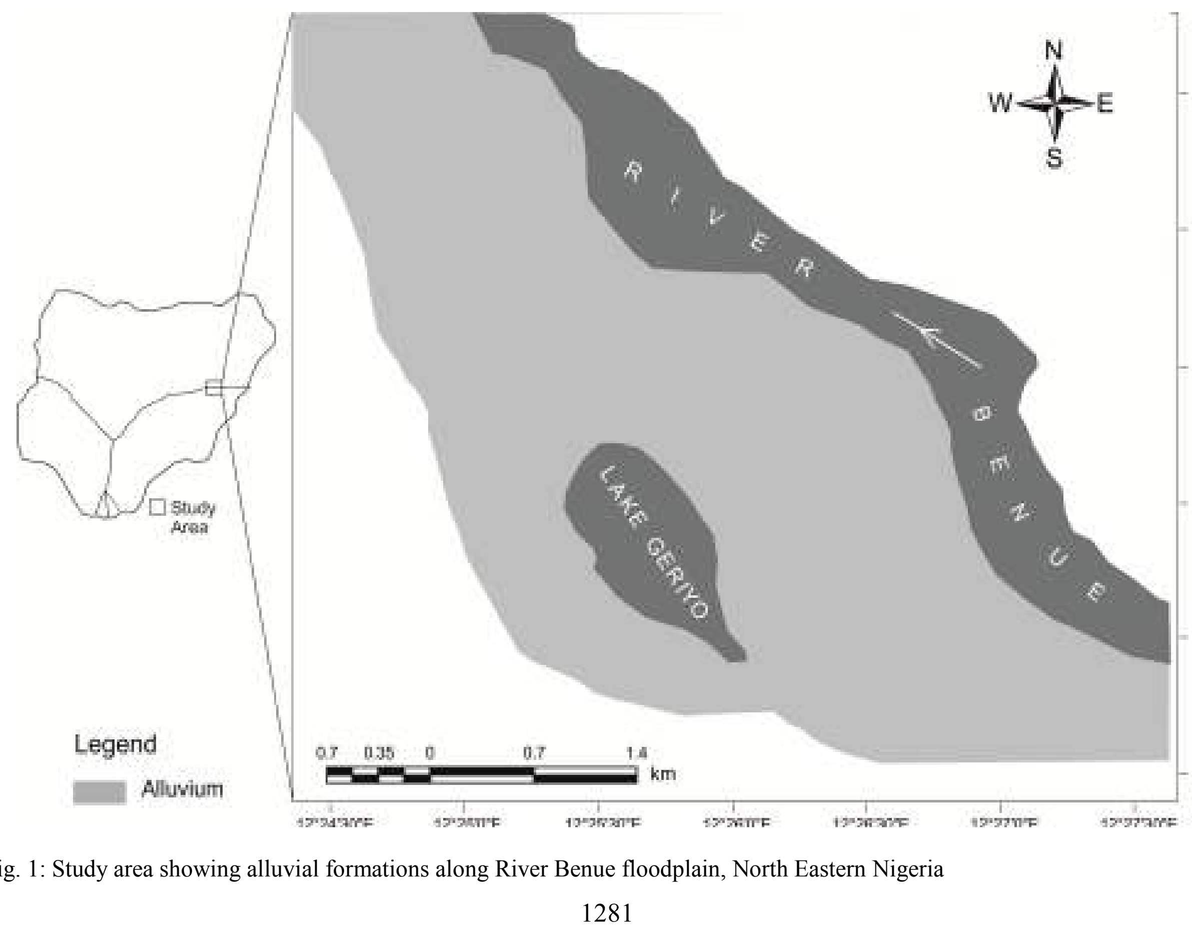


Fig. 1: Study area showing alluvial formations along River Benue floodplain, North Eastern Nigeria

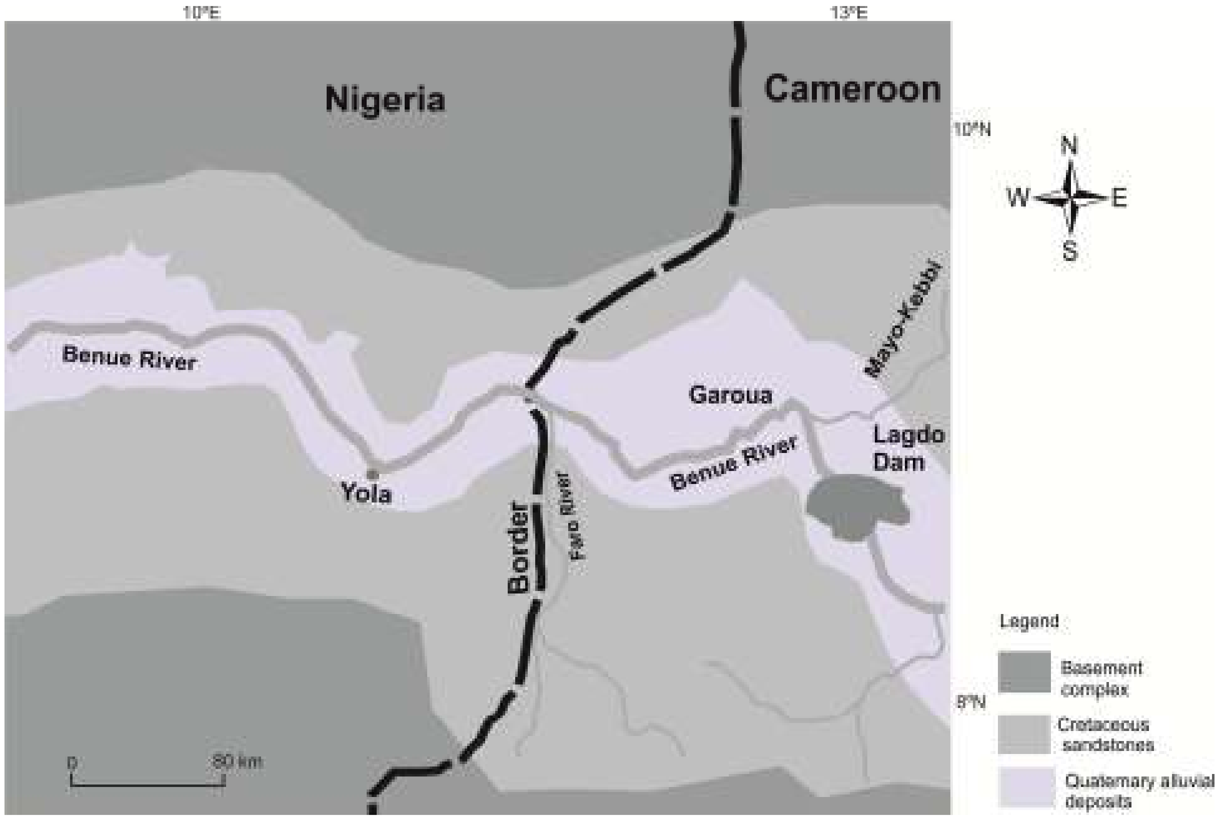


Fig. 2: Geological map of River Benue in Cameroon and Nigeria (Nigerian Geological Society, 2006; Tamfuh *et al*., 2011)

The region features broadly Sahelian characteristics such as a long dry season period, which start from November to May and it has only five months of wet season, from June to October. The annual mean rainfall for the region is high (914 mm), but this is as a result of large storm events usually occurring in the months of August and September each year (Adebayo, 1999). The maximum monthly mean temperatures range from 31 to 40°C and minimum temperatures range from 15 to 23°C. Highest temperatures were recorded in April; being the peak period of the dry season in the region (Ankidawa *et al*., 2015). The lowest mean monthly temperatures were recorded in the months of December and January; being the winter period in the region. The area is drained by the River Benue, which is the largest and only perennial river in the area (Ankidawa, 2015; Ankidawa and Tanko, 2015).

Geology and hydrogeology of research area: The geology of the research area was classified according to the age of formations (Fig. 2). These formations are the recent Quaternary river coarser alluvial at the top and the older Cretaceous Bima sandstone formation underneath (Ishaku and Ezeigbo, 2000). The upper alluvial aquifers constitute recent Quaternary sediments; while the lower semi-confined aquifer system constitutes the Cretaceous sediments (Obiefuna and Orazulike, 2010; Ishaku, 2011). The alluvial deposits are composed of recent sediments that reach more than 80 m in thickness. Diagonally along the southeast-northwest part of the research area, the alluvial aquifer decreases in thickness as it moves away from the River Benue interfingering with some saturated sand lenses (Obiefuna and Orazulike, 2010). The hydrogeology, as described by Obiefuna and Orazulike (2010), indicates the occurrence of two aquifer systems; an upper unconfined alluvial aquifer and the lower semi-confined to confined aquifer, capable of yielding quantities of water. The upper unconfined alluvial aquifer is recharged through surface precipitation and River Benue during the dry season period, while the lower semi-confined to confined aquifer is recharged through precipitation and lateral groundwater volumes flowing through the sandstone formations bounding the aquifer.

METHODOLOGY

Monitoring hydrological processes at the River Benue floodplain was carried out for one year period to investigate the variability in water storage and water flow through the alluvial floodplain. This helps to understanding hydrological processes in alluvial floodplain and it is important to identify the main controls on rates and directions of water movement (Bradley, 1997).

Twelve different borehole points were monitored manually on daily basis to observe the groundwater levels of the floodplain for the period of twelve months. The manual measurements were taken by using deep stick in the wells. Deep stick was inserted into the well down to the bottom of the wells.

Additional two automatic piezometer MAlog itmsoil instrument were installed 500 m and 1, 000 m away from the river to continue monitoring the water levels in the wells for the period of twelve months in order to estimate the changes in the groundwater levels. The piezometers were used to examine the variation in hydraulic head with distance from the River Benue to determine the hydrological significance of the river and to investigate the relationship of water table of the floodplain to precipitation. Weekly groundwater level measurements were taken with MAlog automatic piezometer to the vertical accuracy of ±0.0002 cm. The elevations of the piezometers were determined with respect to a standard datum with an approximate accuracy of ±0.0002 to 0.0003 cm. The automatic piezometer, MAlog (mili-Amp logger), is designed as a low power, easily installed, web-enabled data acquisition system which can read 4-20 mA sensors (Itmsoil, 2012).

RESULTS AND DISCUSSION

Hydrological data were obtained through the monitoring of groundwater level at twelve borehole points across the floodplain by two automatic piezometers and manual measurements for the period of one year.

Figure 3 shows the spatial distribution of the static water levels for the twelve monitoring wells along the floodplain.

The static water levels were subtracted from the mean height above sea level to obtain the hydraulic head which was used for the construction of Fig. 4. It can be seen that Borehole 1 (further upstream) shows the highest hydraulic heads whilst Borehole 11, further observation, recorded the lowest water level. Boreholes 1 and 11 (downstream) are both close to the river, but they show high variation of hydraulic head. Similar observation is shown between Boreholes 2 and 8, with much variation of hydraulic heads between these two wells. Consistent hydraulic heads were observed in Boreholes 3, 4, 5, 6, 7, 9, 10 and 12.

These differences observed at four Borehole locations could be due to the differences in elevations along the floodplain and rate of recharge due to

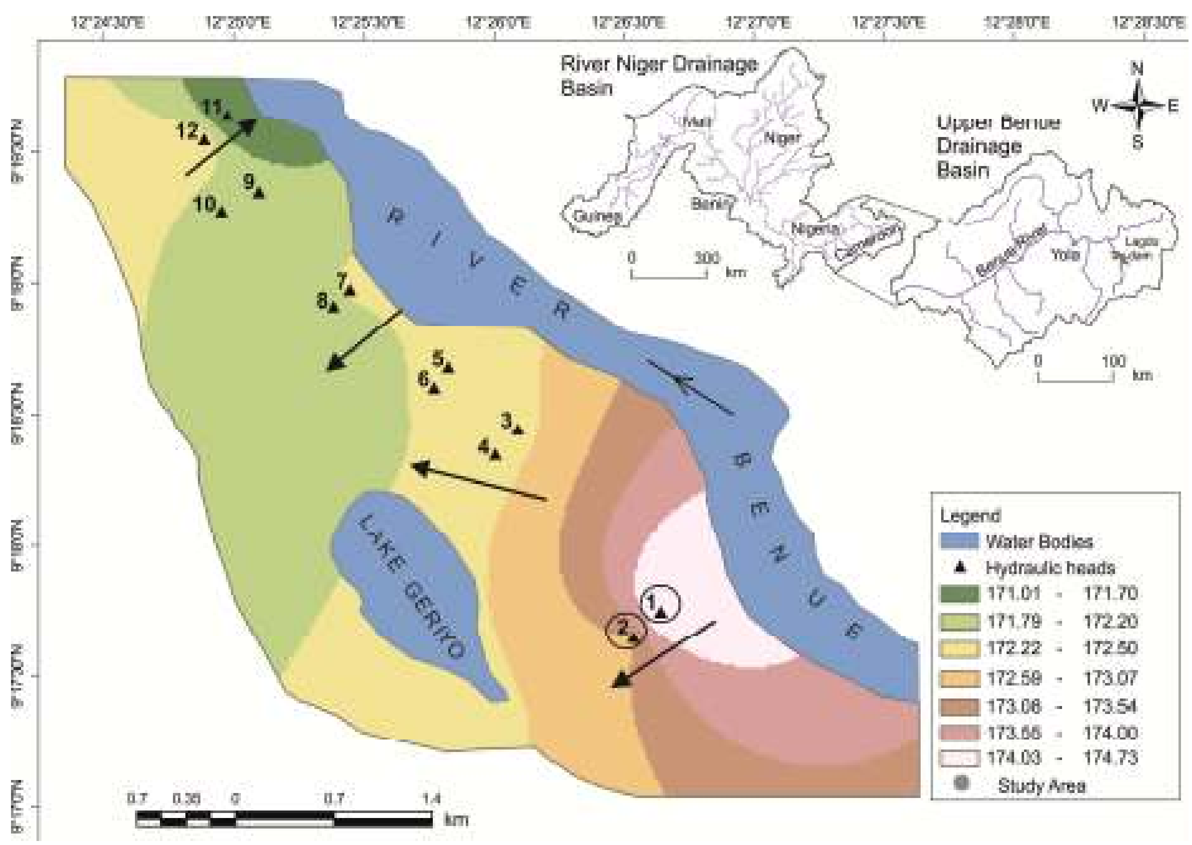


Fig. 3: Spatial distribution for the water level of the twelve monitoring wells and their locations in the floodplain. The green colour shows the lowest hydraulic heads and white shows the highest hydraulic heads in wells across the floodplain. The black circles indicate the two automatic monitoring wells

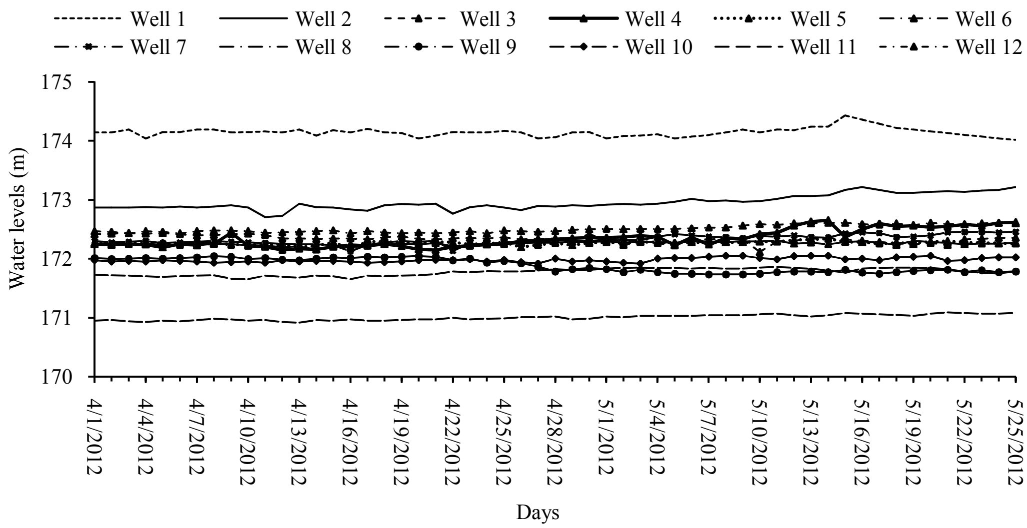


Fig. 4: Daily water levels at twelve boreholes on the floodplain for the period April to May 2012

Table 1: Statistical correlation values and significance range between twelve monitored wells (Significance p-value range 0, 0.001, 0.01, 0.05. Not significant p-value range 0.06 to 1

Parameter		Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8	Well 9	Well 10	Well 11	Well 12
Well 1	Correlation	1											
	p-value	0											
Well 2	Correlation	0.232	1										
	p-value	0.088	0										
Well 3	Correlation	0.007	-0.452**	1									
	p-value	0.96	0.001	0									
Well 4	Correlation	0.174	0.848**	-0.386**	1								
	p-value	0.203	0	0.004	0								
Well 5	Correlation	0.205	0.384**	-0.231	0.442**	1							
	p-value	0.133	0.004	0.089	0.001	0							
Well 6	Correlation	0.019	0.487**	-0.438**	0.460**	0.356**	1						
	p-value	0.891	0	0.001	0	0.008	0						
Well 7	Correlation	0.095	0.874**	-0.448**	0.768**	0.457**	0.573**	1					
	p-value	0.489	0	0.001	0	0	0	0					
Well 8	Correlation	0.027	0.534**	-0.692**	0.577**	0.461**	0.722**	0.602**	1				
	p-value	0.842	0	0	0	0	0	0	0				
Well 9	Correlation	-0.046	-0.709**	0.632**	-0.723**	-0.379**	-0.693**	-0.773**	-0.870**	1			
	p-value	0.736	0	0	0	0.004	0	0	0	0			
Well 10	Correlation	0.142	0.577**	-0.329*	0.545**	0.490**	0.360**	0.565**	0.536**	-0.650**	1		
	p-value	0.302	0	0.014	0	0	0.007	0	0	0	0		
Well 11	Correlation	0.128	0.842**	-0.618**	0.793**	0.423**	0.619**	0.820**	0.756**	-0.860**	0.588**	1	
	p-value	0.351	0	0	0	0.001	0	0	0	0	0	0	
Well 12	Correlation	0.280*	0.882**	-0.518**	0.889**	0.508**	0.471**	0.840**	0.631**	-0.799**	0.692**	0.876**	1
	p-value	0.038	0	0	0	0	0	0	0	0	0	0	0

heterogeneity of the geologic materials. Table 1 shows the statistical analysis for the twelve boreholes on the floodplain. Moderate to strong positive correlation was observed between boreholes 2, 5, 6, 7, 8, 11 and 12, with their correlation values ranging between 0.5 to 0.88 (p-value of 0). This suggests insignificant variation of the hydraulic heads in the wells.

In the northeast, southeast and southwest parts of the study area, the direction of groundwater flow is from the river to the floodplain, whilst in the northwest the direction of groundwater flow is from the floodplain to the river (Fig. 4). This suggests that River Benue is recharging significant part of the floodplain shallow aquifers during the dry season period.

Figure 5 shows weekly water levels at wells 1 and 2 situated 500 m and 1000 m from the River Benue. It can be observed that the water level quickly rises as the rainy season approaches and lowers more slowly in the dry season. Water levels were monitored during periods of extensive irrigation, which was not possible to prevent during the study and this must have slightly affected the measurements such as brief low in 16/06/2012. Two month manual water level measurements at wells 1 and 2 were made. No variations between the automatic and manual water level (Fig. 5) were observed.

The period between 7th April 2012 to 25th August 2012 in Fig. 5 shows the time the automatic piezometers worked and stopped. The horizontal lines between 25th August 2012 and 13th October 2012 show the missing data and the time the piezometers stopped working as a result of the severe flood that occurred that year, which submerged the floodplain. However, weekly monitoring of the groundwater levels continued manually afterwards. Figure 6 shows a switch in the hydraulic gradient when the rains started: piezometer 1

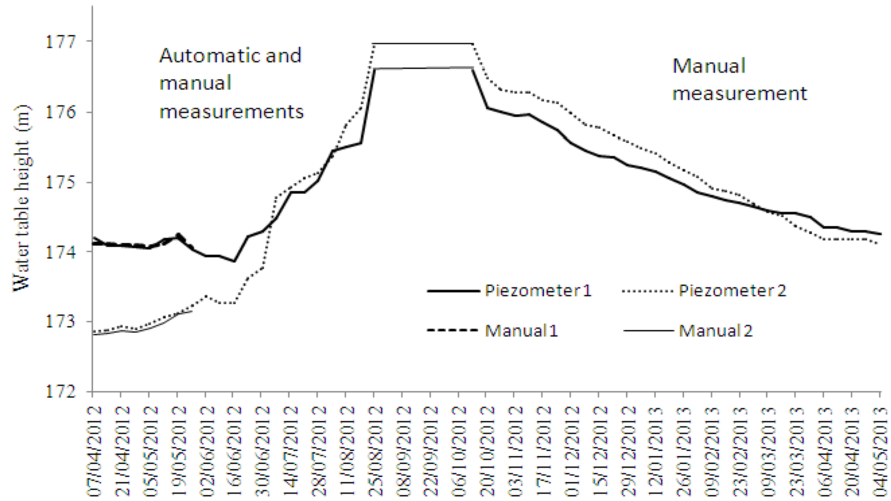


Fig. 5: Weekly water levels at wells 1 and 2 situated 500 and 1000 m respectively from River Benue for the period April 2012 to April 2013. The horizontal lines show the missing data and the time the piezometers stopped working as result of severe flood that occurred that year

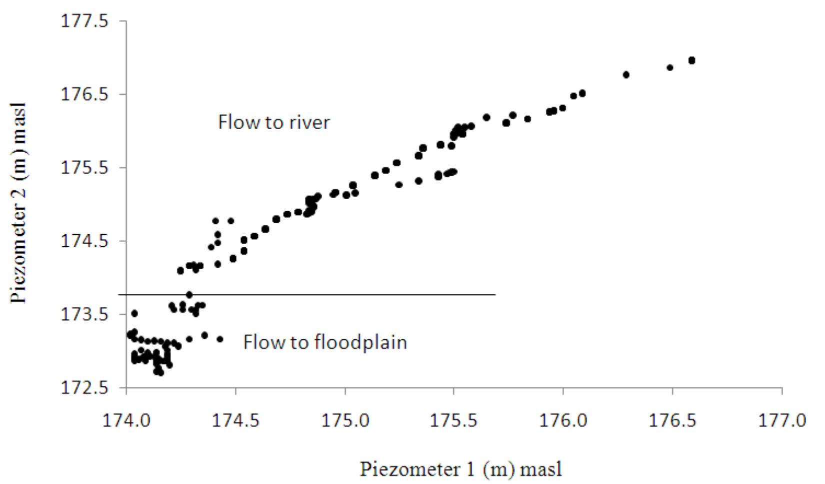
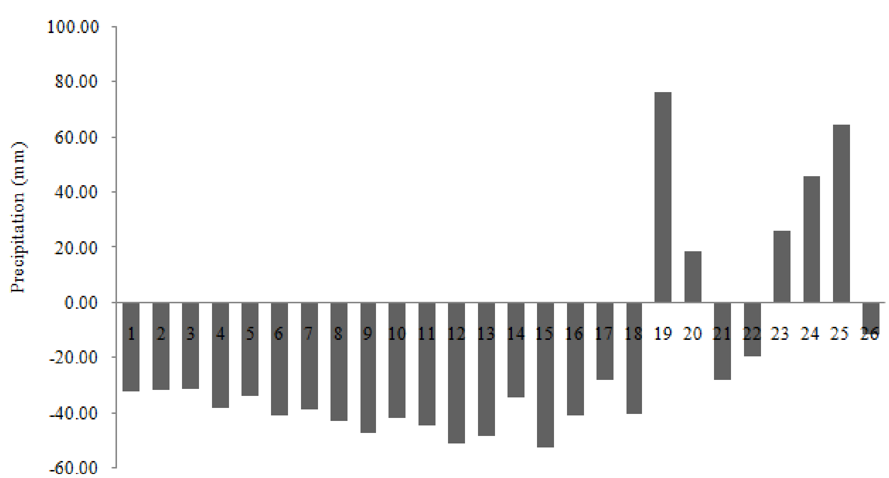
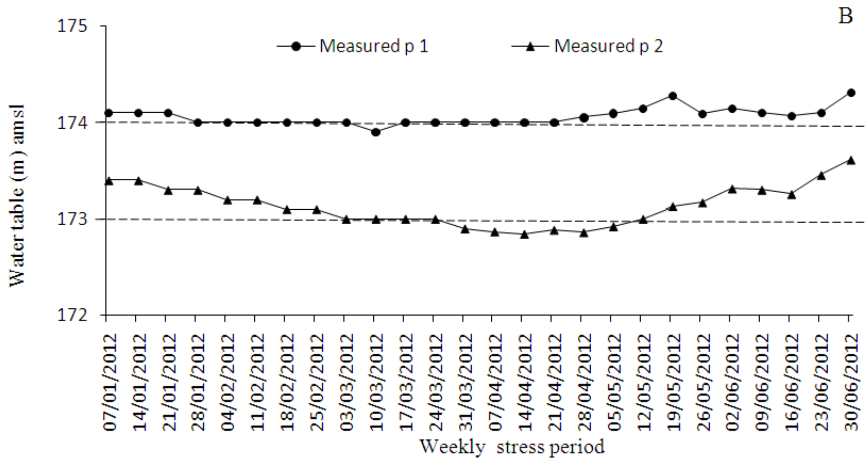


Fig. 6: Relationship between Piezometers 1 and 2 groundwater levels



(A)



(B)

Fig. 7: Comparison between precipitation and groundwater level for the period January to June 2012. A: Shows weekly precipitation (precipitation-potential evaporation) for the period January to June 2012; B: shows weekly time series of water table variation for piezometers 1 and 2 for the period January to June 2012 situated 500 and 1,000 m away from River Benue

Table 2: Statistical correlation values and significance range between piezometers 1 and 2 (Significance p-value range 0, 0.001, 0.01, 0.05. Not significant p-value range 0.06 to 1)

Parameter		Piezometer 1	Piezometer 2
Piezometer 1	Correlation	1	
	p-values	0	
Piezometer 2	Correlation	0.966**	1
	p-values	0	0

is higher than piezometer 2 and then a switch occurred on 7/7/2012. This suggests that during the dry season, the water level in the river is higher than the surrounding area. Therefore, the river loses water to the surrounding area. Conversely, in the rainy season the water level in the surrounding area rises and therefore loses water to the river. This is because the groundwater levels are lower in the peak of the dry period, as rainfall approaches the groundwater levels tend to rise. The relationship between the hydraulic heads in the two piezometers (Fig. 6) suggests a linear relationship when P1>174.25 m, which shows the time of flow to the river.

Strong positive correlation was observed between Piezometer 1 and Piezometer 2 water levels having correlation value of 0.966 (p-value of 0) (Table 2), indicating no much variation between groundwater levels at piezometer 1 and piezometer 2.

Weekly usable precipitation was obtained by subtracting the evaporation from total precipitation occurring over 7-day periods from January to June 2012 (Fig. 7A). The groundwaters of the floodplain are low between stress periods (weekly measurement) 1 and 18 and begin to rise between stress periods 19 and 26 (Fig. 7A). Figure 7B shows detailed time-series plots of water-table positions for the two Piezometers, numbers 1 and 2 during the dry season period.

The groundwater levels of the floodplain are responsive to rainfall events, which accounts for the high peaks in the water-table level, hence high rate of recharge. The Piezometers show an immediate variation of the water table in response to the rainfall events. For example on 19th May 2012 (stress period 19) (Fig. 7B), groundwater level rises as the rainy season started. The water table is at the lowest position between April to June (Fig. 7B) and begins to rise as rainfall increases up to the peak in August and September (Fig. 5). Although we have no monitoring data for August and September data (Fig. 7B), it is well established from literature that these two months are when the water table of the floodplain reaches its highest peak due to high rainfall storm during this period. In November, the water table starts to decline as the rainfall ceases.

The water levels also fluctuate due to groundwater withdrawal rates. For example it is likely that what happened on 10th March 2012 in piezometer 1 (Fig. 7B). The floodplain was flooded on 10th March 2012 due to high storm rainfall and sudden release of water from Lagdo Dam in Cameroon upstream.

CONCLUSION

This research work can be concluded as follows:

- The result of the water level measurements help to quantify the variable response of hydraulic head across the floodplain.
- The result also indicates the direction of water movement across the floodplain.

- The monitored piezometers show that, in the dry season, the river is recharging the aquifer, but in the rainy season, the gradient is towards the river.
- The result indicates that River Benue is the main recharge source of the floodplain shallow aquifers during the dry season period.

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