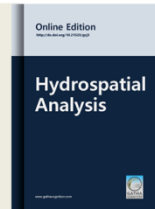




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Original Research Paper

Groundwater Yield Modeling in the Floodplain of Hadejia, Northwestern Nigeria



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Abstract

This paper proposed a model explaining variation of shallow groundwater yield and dynamic level with respect to river location in the floodplain of Hadejia, along Hadejia River Basin of Jigawa State, Northwestern Nigeria. To achieve the aim, six transects were established within one km² of floodplain and were oriented perpendicular to the river channel. Three tube wells were sampled and positioned along each transect at regular intervals making a total of 18 wells. Pumping test, which was repeated four times at 15 minutes interval in both morning and evening hours was used to measure groundwater yield. Multivariate statistical tools such as analysis of variance, Pearson product moment correlation, and cluster analysis were used, respectively, to test the research hypothesis and to classify sampling points into similar groups based on groundwater yield. Results show that the average yield of wells for evening hours recorded a higher yield of 3.3 L/s (55.93%) than the yield in the morning hours of 2.6 L/s (44.07%). Further, the 2-way ANOVA at 5% level of significance showed no significant difference in the groundwater yield related to relative location of wells in morning (p value, 0.30>0.05) and evening (p value, 0.21>0.05) hours. The results of ANOVA revealed no statistically significant difference between the points. It suggests that the adopted model can be applied in other similar sedimentary basins with a view to validating it. A decision support system is recommended among the strategies to improve groundwater resources management in the area.

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1 INTRODUCTION

Water is one of the environmental resources that make life possible as well as providing the quality of life (Patel et al., 2016). Water is used for a number of diversified human activities, principally the drinking and agricultural use (Olofin, 2011 and 2016). For this reason and other vital importance, water has been captured in the agenda, 1, 2, 3 of the Sustainable Development Goals (MDG, 2006). Reliance on groundwater for daily usage accounts for the one third of world population (Kura et al., 2016; Shin et al., 2020). Surface water scarcity resulting from poor

rainfall regime leads to high dependency on groundwater in many parts of Sahelian regions (Kumar et al., 2007). Dependency on groundwater is more evident in Sub-Saharan regions where a significant number of populations resort to groundwater use (Chidya et al., 2016). Despite the fact that only 28% of the total fresh water represents groundwater resources in Nigeria, however, the combined effect of rapid population growth, unpredicted climate variability and the subsequent surface water inadequacy made the teaming population (more than 85%) to have 100%

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reliance on groundwater since 2001 (Xu and Usher, 2006; Akujieze *et al.*, 2003). In Northern part of Kano region, surface water is too inadequate due to the geological formation and the semi-arid nature of climate. Subsequently, groundwater resource is the only reliable source of fresh water for both domestic and agricultural uses (Tukur *et al.*, 2018).

In Northwestern part of Nigeria, the semi-arid nature of the climate do not favor rainfall agriculture, therefore irrigated agriculture is the dominant socio-economic activity (Ajon *et al.*, 2014; Umar *et al.*, 2019a) utilizing groundwater resources mostly from shallow aquifers along the river basin (Mays, 2009; UNESCO, 2007; Tukur *et al.*, 2018). This has resulted in intensive cultivation and the subsequent over exploitation of groundwater because the water is occupied in shallow aquifer which is close to the surface (<10m). Findings of previous researches revealed an increase of more than 100% utilization of shallow groundwater in the floodplain (Iliya *et al.*, 2011). Therefore, irrigation water is primarily tapped from the only and the available shallow groundwater and has become the last alternative for the inhabitants of the area. Consequently, groundwater in the shallow aquifer is said to be vulnerable to degradation and pollution because of over exploitation and utilization.

Although there are many studies on groundwater condition along Hadejia river basin (Thompson and Polet, 2000; Sobowale *et al.*, 2010; Ifabiyi and Ojoye, 2013; Nabegu, 2013; Tukur *et al.*, 2018; Umar *et al.*, 2019a; Umar *et al.*, 2019b; Sule *et al.*, 2020), but they were limited to groundwater quality, vulnerability and rainfall run-off perspectives, with not much attention on establishing relationship between groundwater yield and dynamic level in relation to distance with the nearby river. The impact of river water on shallow groundwater yield has an important implication on the ecological functions of riparian areas and associated irrigated watersheds (floodplains). Therefore, understanding this scenario is important for water resources management in the floodplains, especially of the semi-arid regions where river serves as the principal source of water recharge to such floodplains (Gharbia *et al.*, 2020). On this background, this paper modeled the impact of river water on shallow groundwater yield and dynamic level. Specifically, this model was achieved by addressing this question: Is there a systematic change in groundwater yield and dynamic level related to wells positions relative to river?. The model was applied in morning and evening hours during the dry season in the study locations with a view to identifying if there could be diurnal variation in the model output. It is hope that the method and the outcome of the model used in this study will be used in another similar study area with a view to validating the result or otherwise.

2 STUDY AREA

2.1 Geography

Hadejia is positioned precisely from 12° 25' 10" to 12° 26' 15" N latitude and 10° 0' 0" to 10° 2' 35" E longitude (Graba *et al.*, 2016) which constituted part of Northwestern Nigeria. The study area falls within the sedimentary basin located along the Hadejia river basin. As described by Olofin (2014) (Figure 1), rainfall in the study location is characterized by spatiotemporal irregularities with a maximum of 600 mm/year. The rainiest months are June, July, August and September, other months being the dry season. The average temperature for each month of the year is about 27.1 °C. The warmest period of the year is from April to July, when the maximum temperature recorded is 36.7 °C. The lowest temperature is normally recorded during the coolest period between December and January (Tukur *et al.*, 2018). Sampling wells location within the study area is depicted in figure 1.

2.2 Geology and Hydrogeology

Chad sedimentary formation is the dominant geological formation of the area characterized by sand sediments which mostly unconsolidated and porous allowing high infiltration capacity. The nature of geological structure allows substantial storage of water in both deep and shallow aquifers. The deep aquifers which are the two top ones and the shallow aquifers found in floodplains along the river basin. Both deep and shallow aquifers serve as the primary sources of fresh water. For this reason, hundreds of tub wells were built in floodplain for over three decades thereby utilizing the shallow groundwater for both domestic and agricultural use, principally the irrigation agriculture. For this reason, agricultural activities have been intensified thereby cultivating crops in all year round.

2.3 Soil and Land Use

Two major soil types are found in the study area namely; zonal (ferruginous soil) and intra-zonal soil. The ferruginous soil type is the matured soil and covers the largest part of the area. The intra-zonal soil type on the other hand is hydromorphic soils popularly known as floodplain. Wetland is one of the unique land uses in the study area and also one of the unique environmental resources supporting the ecological and hydrological functions as well as the socio-economic activities. With the presence of wetland in the area, grazing areas has become more productive even during the dry period of the year. Similarly, wetland in the area supports diversification of agricultural activities thereby enhancing productivity and social life.

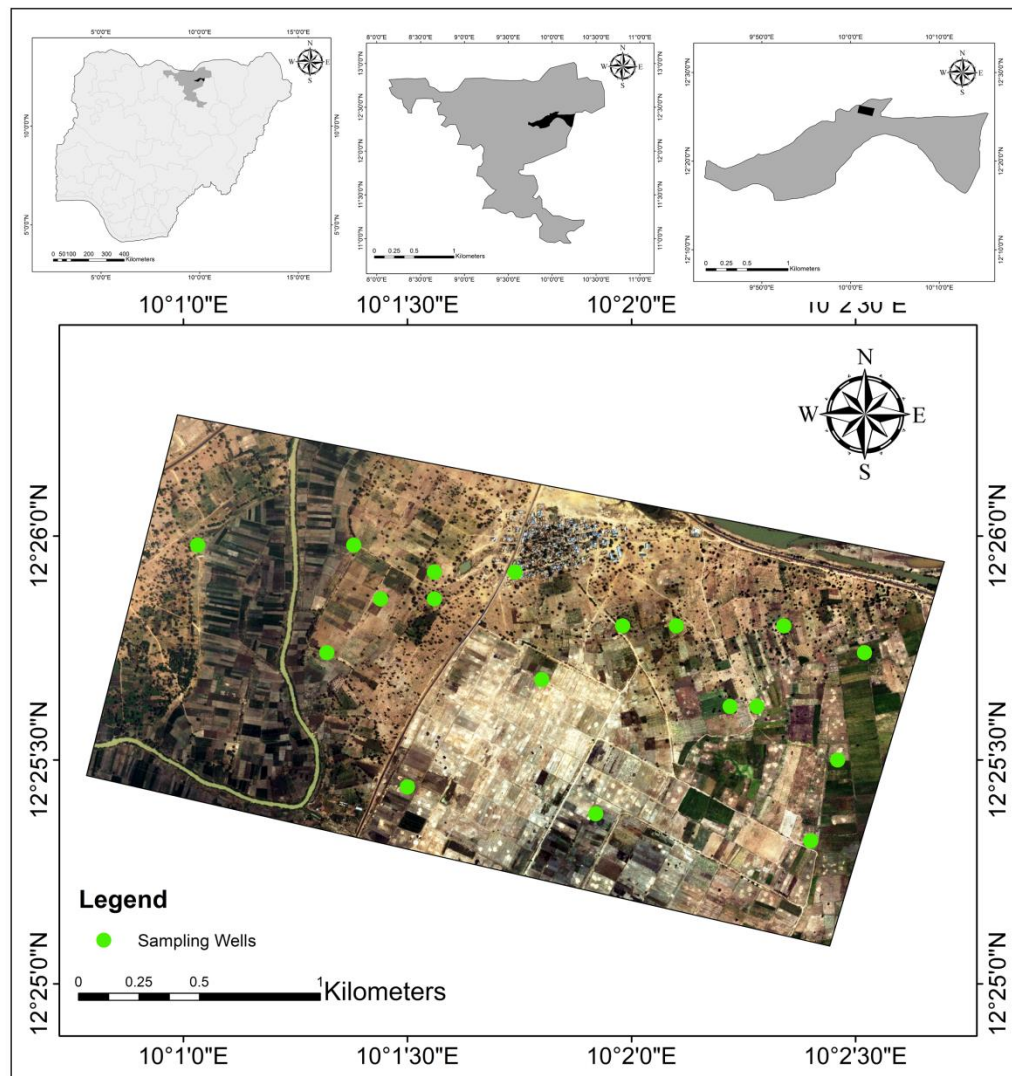


Figure 1. Study area with distribution of sampling wells

2.4 Population and Socioeconomic Activities

Hadejia constituted almost 30% of the state's teeming population. The dominant population consists largely of farmers. Agriculture, principally irrigated agriculture is the dominant socioeconomic activities in the area. Agricultural production especially the field crops and vegetable crops have substantially increased after the commencement of Hadejia Irrigation Scheme (Figure 1). This was achieved by harnessing the abundantly groundwater resource occupied in shallow aquifers through building of tube wells, open wells and digging of deep boreholes. This is because the water is close to the surface (<10 m) and the technique is simple and cheap for the farmers. Field crops (cotton, date palm, wheat, rice, maize, soybeans, onion, Irish potatoes, sweet potatoes, tomatoes, pepe, cherie, garen eggs, green beans, cucumber, okro groundnut, etc.), fruit crops such as sugarcane cowpea, corn, citrus, watermelon, etc. and vegetables (cavage, salat) are cultivated in the floodplain utilizing groundwater from shallow wells.

3 MATERIAL AND METHODS

3.1 Field Measurements

Field measurement was achieved by establishing transects running in perpendicular direction to the river direction starting from points near river, middle field and end field points away from the main river. On each transect, 3 wells were selected representing near river, middle field and end field sampling points. The study adopted and used pumping test technique because it is reliable and most commonly used (Streett, 2011). A water pumping generator was used at a constant rate to pump water from the tube well's aquifers at regular time interval within a day (early morning hours when the irrigation activities have commenced, peak irrigation hours at noon and evening hours). This was adopted to ensure a true estimation and maximum sustainable yield of the aquifer. In each tube well, a bucket of uniform capacity (15 L) and stop watch, respectively, were used to measure the volume of water pumped from the aquifer and the actual time at which the bucket is filled with water from the beginning of pumping. At each

monitoring hour (morning and evening), the measurement was repeated 4 times at 15 minutes interval when the level of groundwater from the aquifer is said to be at dynamic (pumping) level. In each sampling point, the water pumping generator was used at a constant rate with a view to have a true variation of the aquifer's sustainable yield. Each well was geo-referenced using a Germin Global Positioning System (GPS) model 72H by taking its coordinates. Furthermore, the name of the owner of each tube well was collected and an identity number was given to each tube well for easy identification during the main field activities.

3.2 Multivariate Statistical Analysis

Statistical computations provide a descriptive framework and explanations of spatial relationships, spatial differences, and spatial similarities between individual and group of variables through various statistical models (Suleiman et al., 2020). Various statistical models such as descriptive statistics, correlation and regression modeling, differences and variations models including multiple linear regressions, principal component and factor analysis, discriminate analysis, cluster analysis structural equation modeling artificial intelligence, artificial neural network (ANN) and fuzzy logic are used in addressing groundwater issues (Gaya et al., 2020). The combined use of these statistical techniques provides a holistic and comprehensive analysis of water samples by understanding the differences, relationships and variations scenarios both spatially and temporally (Al-Mukhtar and Al-Yaseen, 2019). The result outcome of the combined models is more reliable and perfect (Isikanye et al., 2018).

In this study, the hypothesis was tested using ANOVA and Pearson product moment correlation. Two-way Analysis of Variance (ANOVA) between locations and time was conducted to test the research hypothesis stating groundwater yield between morning and evening hours have no significant difference. There is no significance difference in the yield of wells between morning and evening hours. Normality test was performed on the data and found no suitable for parametric statistical test.

CA is one of the data reduction techniques that reduces and classifies data into homogenous groups popularly known as cluster. This is achieved by grouping similar and dissimilar variables in a homogenous group based on their similarities in behavior (Tukur et al., 2018). In this research, cluster analysis was applied to the groundwater yield and dynamic level with a view to grouping sampling points based on their similarities so as to reduce the number of sampling points in the future study. The reduction in the sampling points will be more economical without losing any significance of the outcome. Groundwater yield and dynamic level varies in spatial and time dimensions. 2-way ANOVA was applied to the spatial and diurnal

variation of groundwater yield and dynamic level at the sampling site. Two-way ANOVA is one of the parametric statistical models that test and explains the statistical differences in data that is normally distributed (Narany et al., 2014). Two-way ANOVA was used to understand and provide the justification variables that cause the spatial and diurnal differences in groundwater yield and dynamic level. For modeling the spatial variations, 18 wells were sampled. The diurnal variation was the morning and evening hours. Correlation test was also used to test the hypothesis of the relationship between groundwater yield and dynamic level in the study locations. Five percent (5%) level of significance was used to test all the formulated hypotheses. In other words, acceptance or rejection of the hypothesis was done at 95% confidence level.

3.3 Geospatial Analysis

Geographic Information System (GIS) is considered as the essential and valuable tool in groundwater studies globally (Abdullahi and Pradhana, 2018). The application of GIS in groundwater studies can be seen in so many aspects. GIS is used in identifying and mapping areas of contaminated plumes within an aquifer (Narany et al., 2018) and delineate and map out suitable zones for utilization (Adhikary et al., 2015). Moreover, GIS is useful in providing information on the groundwater quality condition which can be used for the water management and sustainable programs (Neshat et al., 2013; Narany et al., 2014; Narany et al., 2018). In addition to these, GIS can identify and provide useful information on the potential groundwater recharge areas. Having computed the groundwater yield and dynamic level, GIS-based software was used to generate map showing the spatial variation of both groundwater yield and dynamic level from the sampling wells. This was achieved by using geostatistical analysis through krigging approach by considering near observations with similar pattern and behavior (Narany et al., 2018).

4 RESULTS

4.1 Diurnal Variation of Groundwater Yield

Result obtained from pumping tests for diurnal variation of groundwater (Table 1) shows the minimum and maximum well yield as well as their average yield for both morning and evening hours. Well yield during morning hours ranges between 1.9 L/s (minimum) to 3.4 L/s (maximum). This could be attributed to the positions of tube wells with respect to river location, depth, etc. indicating that the depth and closeness of tube wells to the river do influence the yield capacity. Evening hours also recorded a similar variation of 3.3 L/s average yield. This shows that, the aquifer have a wide variation in their yield capacity both in morning and evening hours, respectively accounting for 44.07 and 55.93 % of the total yield in the day.

Generally, yield of wells in morning hours is lower (44.07%) than the yield of well in the evening period (55.93%) (Figure 2 and 3). Thus, there is a difference in

the yield of wells between morning and evening hours. In the morning period, farmers apply water to their crops at different hours in order to make the soil wet adequately to enable crops have enough moisture. In addition to this, herdsmen always make use of groundwater from shallow aquifers in floodplain during their grazing activities for watering their animals. Interview with the well owners, revealed that the yield of some tube wells in floodplain increases with the increase in pumping. In other words, the more time

taken for pumping water during the day time, the higher is the yield of the well. For this reasons, yield in morning hours is generally lower than the yield in evening hours.

Yield of wells showed no significant diurnal difference (p value, $0.00 < 0.05$) as revealed by two-way ANOVA test conducted. In conclusion, groundwater average yield in the floodplain is still under the acceptable standard for irrigation (2.5 L/s).

Table 1. Diurnal variation in groundwater yield

Time	Diurnal variation (L/s)			
	Minimum	Maximum	Average	%
Morning	1.9	3.4	2.6	44.07
Evening	2.3	4.0	3.3	55.93

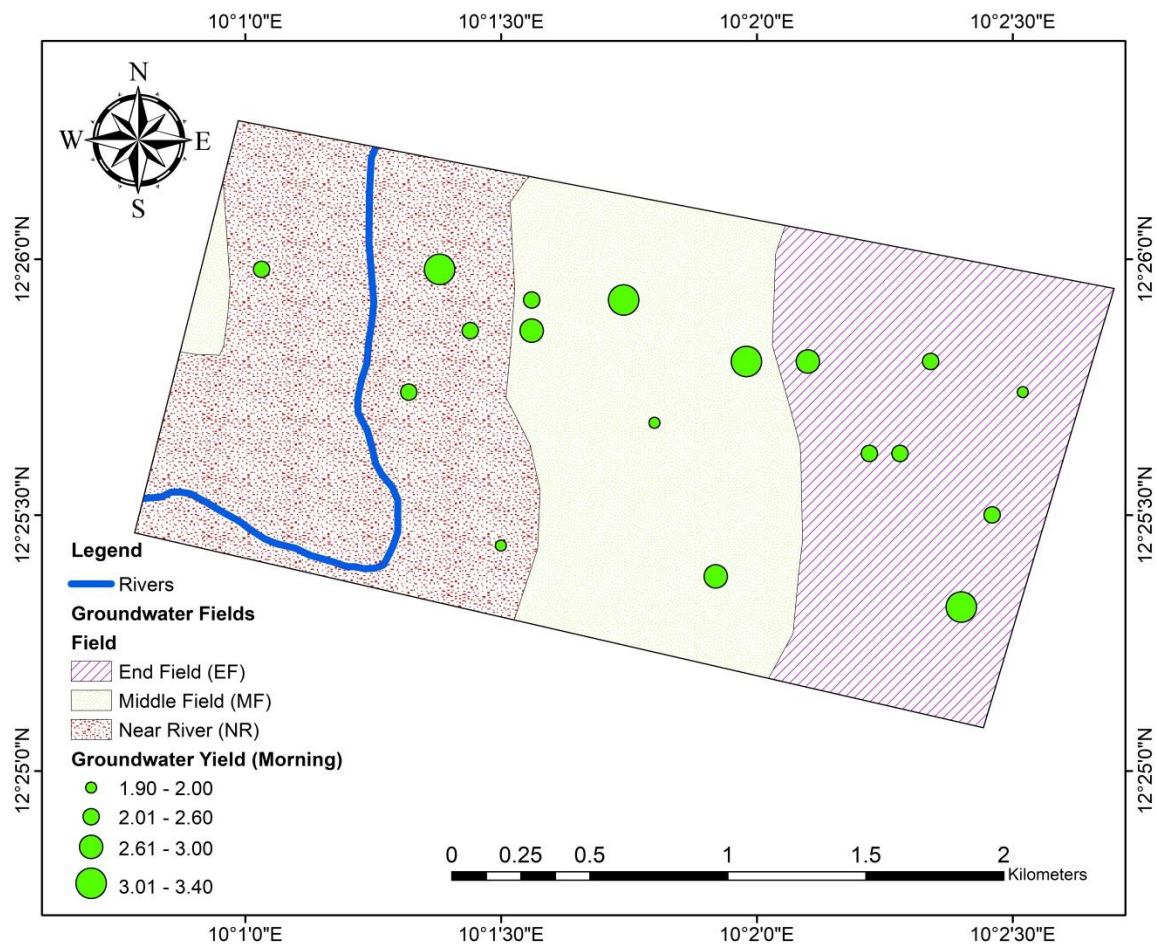


Figure 2. Spatial distribution of groundwater yield: Morning hours

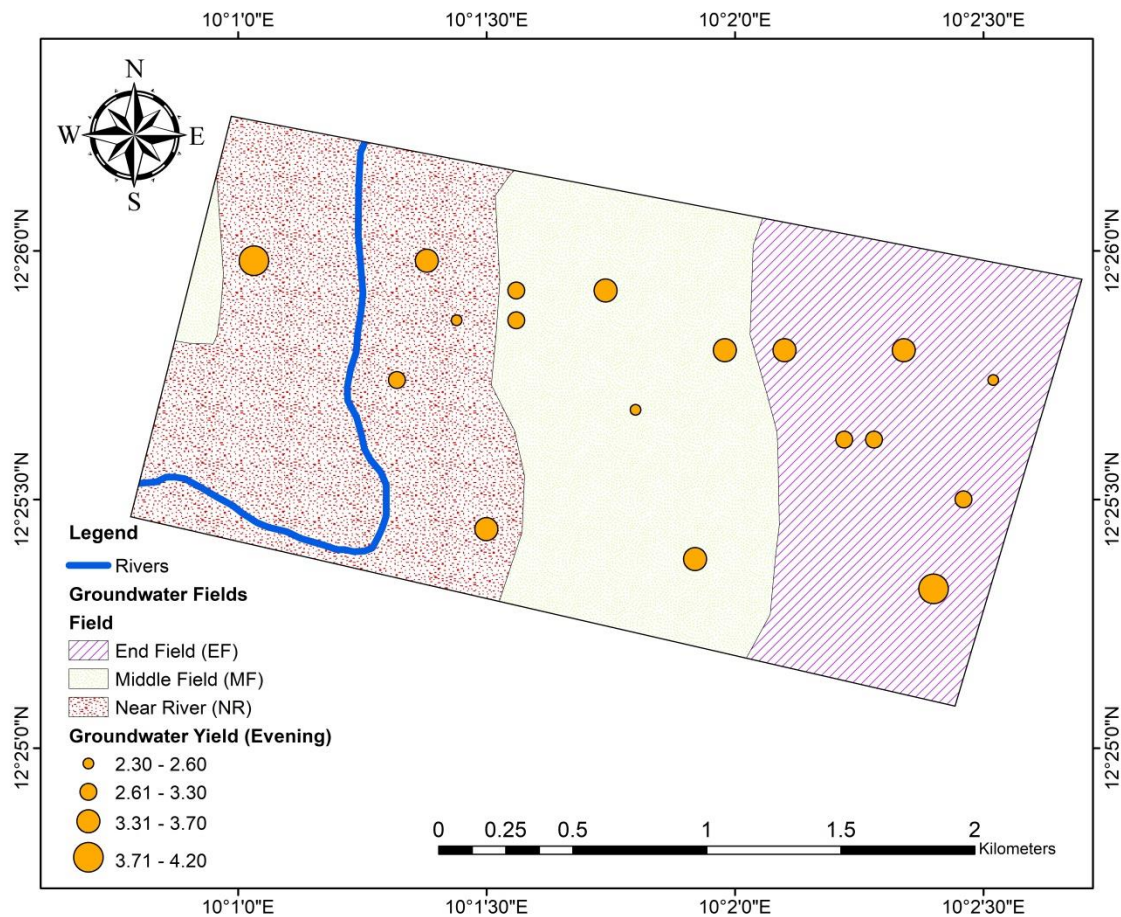


Figure 3. Spatial distribution of groundwater yield: Evening hours

4.2 Variation of Groundwater Yield

Impact of surface water (like the one in river) on groundwater yield is a critical issue in irrigated watershed of semi-arid regions (Helmus *et al.*, 2009). In view of this, spatial variation of groundwater yield was modeled with a view to know whether the river has an influence on the yield of tube wells. This was achieved by sampling tube wells position with respect to distance away from river. Thus, tube wells positions within 30 to 40 meters, 500 and 1000 m away from river was named Near River (NR), Middle Field (MF) and End Field, respectively. Yield of tube wells in each field was measured both in morning and evening hours throughout the field work activities.

Table 2 shows the spatial variation of groundwater yield for both morning and evening hours. Yield of tube wells near river and middle field recorded a similar minimum (2.5 L/s) and maximum yield (3.4 L/s), respectively, with a mean value of 2.83 and 2.90 L/s, each accounting for 36% of the total yield. The yield of tube wells in the end field positions recorded the

minimum average yield of 2.23L/s, accounting for 28% of the total yield. The same model was repeated in the evening hours of irrigation activities with a view to finding out if there could be a difference from the model result of morning hours. This is because of results in table 3 shows that the yields of wells recorded in the evening hours were found to be higher than the yields recorded in the morning hours. Table 3 shows the output of the model for the yields in the evening hours. Output of the model revealed somewhat similar well yield variation as obtained in the morning hours across near field, middle field and end field positions. In other words, wells positioned in the near and middle field were found to have the highest average yield capacity (36%), followed by end field wells (28%). The result, subjected to 2-way analysis of variation, showed no significant difference in the groundwater yield related to wells positions relative to river location (p -value, $0.30 > 0.05$) in morning hours.. Thus, wells positions relative to river location have no significant impact on the yield of these wells.

Table 2. Variation in groundwater yield

Well No.	Well positions	Diurnal yield (L/s)	
		Morning hours	Evening hours
1	Near river	2.5	4.0
4		3.0	3.3
7		2.6	2.9
10		2.9	3.5
13		3.4	4.2
16		2.6	3.6
2	Middle field	3.4	3.7
5		3.3	3.5
8		2.0	3.6
11		2.5	3.0
14		2.7	3.6
17		3.3	3.7
3	End field	2.4	3.3
6		2.3	2.5
9		1.9	2.3
12		2.4	3.2
15		2.4	2.9
18		2.0	2.6
	Min.	1.9	2.3
	Max.	3.4	4.0
	$\bar{X}$	2.6	3.3

Generally, tube wells positioned in the near and middle field were found to have highest yield capacity (36%) followed by the tube wells in the end field recording the lowest yield capacity (28%). The 2-Way ANOVA at 5% level of significance showed no significant difference in the groundwater yield related to wells positions relative to river location showed no statistical significance difference as revealed by 2-way ANOVA test (p-value, $0.21 > 0.05$) in evening hours. This means that, the study is 95% confident in accepting the null hypothesis. The fact that the result of ANOVA revealed no statistically significant difference between points suggests that the adopted model can be applied in other similar sedimentary basins with a view to validating it.

4.3 Cluster Analysis of Groundwater Yield

The result rendered a dendrogram as shown in [figure 4](#), grouping all the 18 sampled wells into four statistically significant clusters: Cluster 1 (well 4, 5, 7, 10 and 14), cluster 2 (well 2, 13 and 16), cluster 3 (well 3, 12 and 15) and cluster 4 (well 1, 6, 8, 9, 11, and 17). The dendrogram grouped all wells positioned in near river and end field in cluster 1. Similarly, wells in cluster 3 are all positioned in end field of the river. This suggests that wells grouped in one single cluster have similar yield capacity. Therefore, instead of monitoring groundwater yield from all the 18 wells, only four sites

would be selected in future spatial sampling without affecting the result adversely. In other words, instead of selecting all the wells belonging to one cluster, only one well from each cluster would be selected.

4.4 Variation in Groundwater Dynamic Level

Dynamic level of groundwater was determined in the field for the following reasons: to ensure a true estimation and maximum sustainable yield of the aquifer; to find out where the groundwater level varies with respect to distance away from river; and to know whether groundwater level has a relationship with the yield. [Table 3](#) shows the spatial variation of the groundwater dynamic level in the study area. Model output shows that, groundwater dynamic level varies from 4.5 to 6 meters, with an average level of 5.0, 5.5 and 6.0 meters in the wells positioned near river, middle field and end field, respectively. Thus, the dynamic level of groundwater in the wells varies with the positions of the wells relative to the river such that those in the end field recording the maximum ([Figure 5](#)). This indicates that the level of groundwater lowers with distance away from the river in the area. The dynamic water levels in wells positioned in the end field have higher depths of about 36.4% more than those in the middle field (33.3%) and near river (30.3%), unlike in the case of yield capacity of wells located in the near field recorded the highest yield capacity.

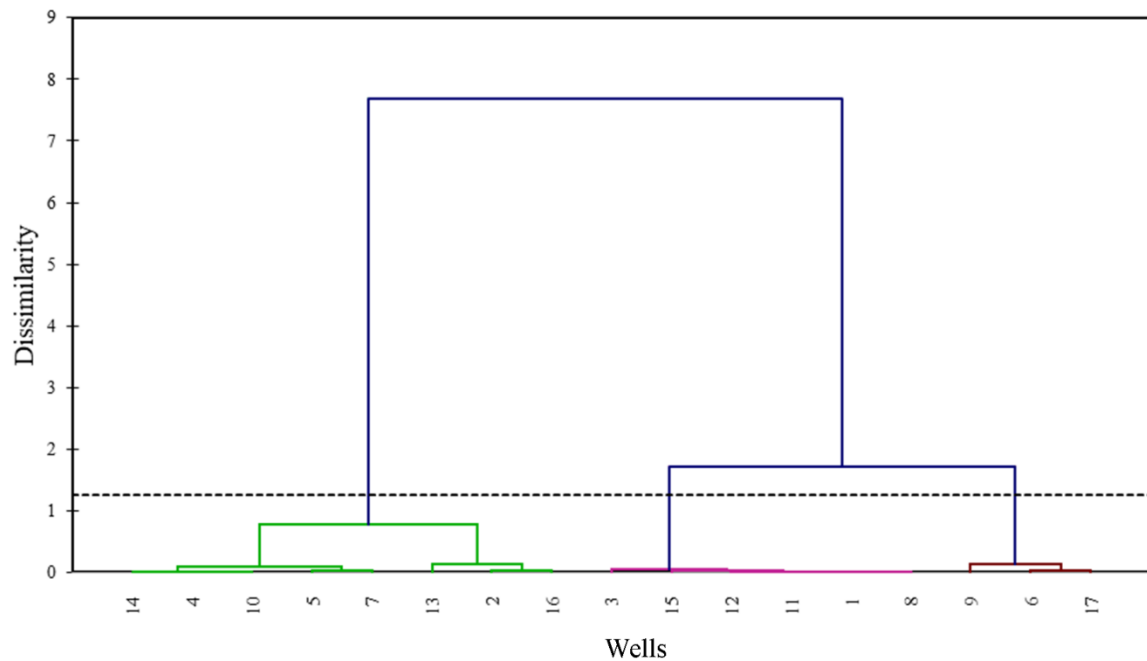


Figure 4. Dendrogram clustering similar and dissimilar sampling wells for groundwater yield

Table 3. Variation in groundwater levels

Well No.	Well Positions	Dynamic Water Level (m)
1	Near River	6
4		4.5
7		4.5
10		4.5
13		6
16		4.5
2	Middle Field	6
5		6
8		6
11		4.5
14		4.5
17		6
3	End Field	6
6		6
9		6
12		6
15		6
18		6
	Min.	4.5
	Max.	7.5
	$\bar{X}$	5.5

Groundwater dynamic level with respect to river location shows no significant spatial difference (p -value $0.842 > 0.05$) as revealed by 2-Way ANOVA test. Pearson product moment correlation test at 5 % level of significant was used to test the relationship between groundwater yield and dynamic level. The result

revealed that there is significant relationship between groundwater dynamic level and yield (p -value, $0.045 < 0.05$). In other words, groundwater dynamic level has good relationship with the yield in the floodplain of Hadejia.

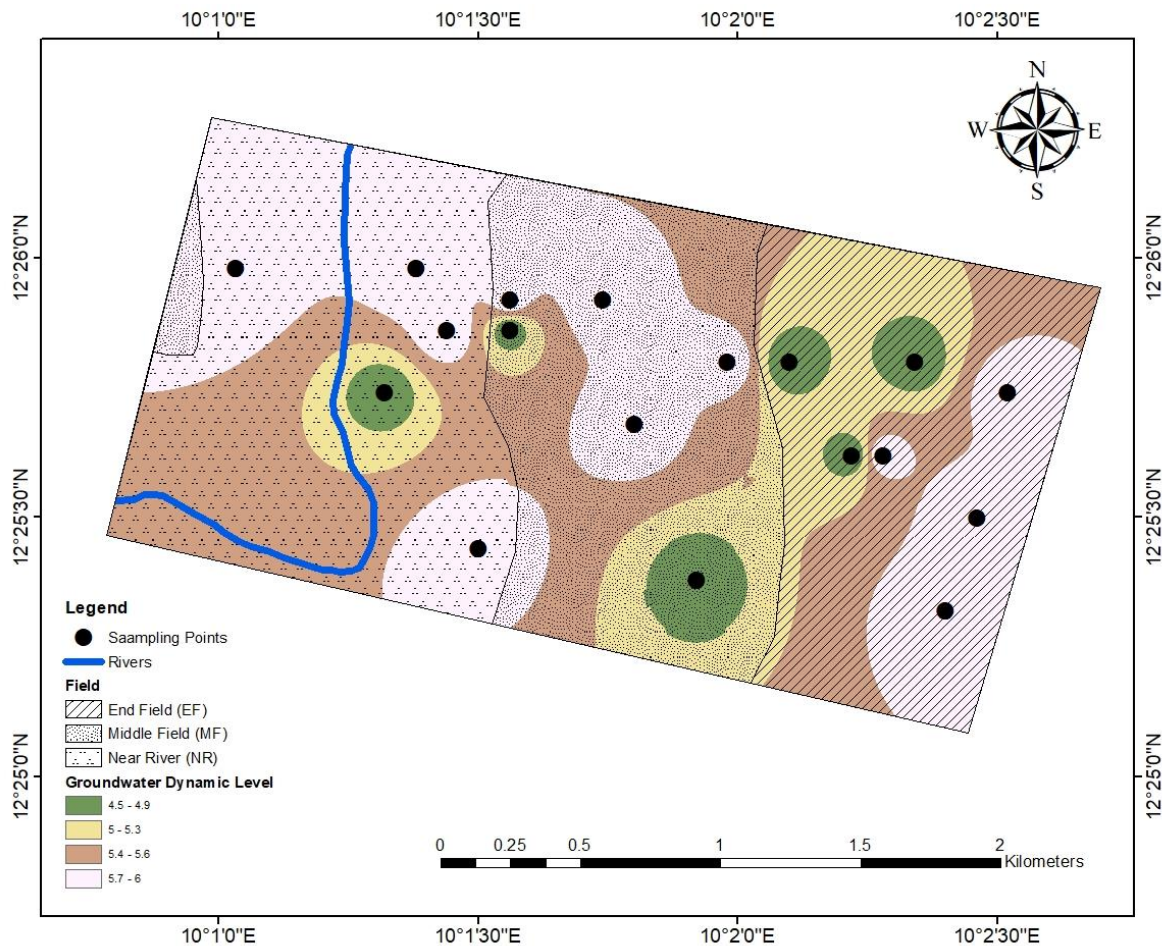


Figure 5. Spatial variation of groundwater levels

5 CONCLUSION

A combination of painstaking measurements and multivariate statistical modelling was used to develop a model explaining the relationship between groundwater yield and the dynamic level of water in a nearby river. Although average yield of groundwater in the morning hours is lower (44.07%) than in the evening period (55.93%), but they falls under the acceptable standard for irrigation based on FAO (1998). Model outputs of 2-Way ANOVA shows no significance spatial difference (p -value, $0.21 > 0.05$) in the yield of wells with respect to river location. However, the diurnal difference in the yield of wells shows statistical significant difference (p value $0.00 < 0.05$, suggesting the impact of time differences on groundwater yield. Relationship between groundwater yield and dynamic level was to be significant (p -value, $0.045 < 0.05$). Furthermore, since this study is a sort of a pioneering research of its kind, it is recommended that the study should be replicated in other parts of the study area as well as other sedimentary structures in similar environments to validate the findings of this study.

CONFLICT OF INTEREST

The authors do not have any conflicts of interest.

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ABBREVIATIONS

ANOVA: Analysis of Variance; **CA:** Cluster Analysis; **GIS:** Geographic Information System; **MDG:**

Millennium Development Goals; **UNESCO**: United Nations Educational; Scientific and Cultural Organization.

REFERENCES

- Abdullahi, S., Pradhan, B., 2018. Land use change modeling and the effect of compact city paradigms: integration of GIS-based cellular automata and weights-of-evidence techniques. *Environmental Earth Sciences*, 77, 251. DOI: <https://doi.org/10.1007/s12665-018-7429-z>
- Adhikary, P. P., Chandrasekharan, H., Trivedi, S. M. and Dash, C. J., 2015. GIS applicability to assess spatio-temporal variation of groundwater quality and sustainable use for irrigation. *Arab. J. Geosci*, 8, 2699-2711. DOI: <https://doi.org/10.1007/s12517-014-1415-x>
- Ahmad, M. T., Haie, N., Yen, H., Tuqan, N. A. S., 2017. Sufficiency of a water use system: The case of Kano river irrigation project, Nigeria. *International Journal of Civil Engineering*. DOI: <https://doi.org/10.1007/s40999-017-0235-2>
- Ajon, A. T., Utsev, J. T., and Nai, C. C., 2014. Physicochemical quality of irrigation water in river Katsina-Ala catchment areas of northern Nigeria. *Current World Environment*, 9(2), 301-311. DOI: <http://dx.doi.org/10.12944/CWE.9.2.10>
- Akujieze, C. N., Coker, S. J. L. and Oteze, G. E., 2003. Groundwater in Nigeria: A millennium experience - distribution, practice, problems and solutions. *Hydrogeology Journal*, 11, 259-274. DOI: <https://doi.org/10.1007/s10040-002-0227-3>
- Al-Mukhtar, M. and Al-Yaseen, F., 2019. Modeling water quality parameters using data-driven models, a case study Abu-Ziriq Marsh in South of Iraq. *Hydrology*. DOI: <https://doi.org/10.3390/hydrology6010024>
- Driezum, I. H. V., Chik, A. H. S., Jakwerth, S., Lindner, G., Farnleitner, A. H., Sommer, R., Blaschke, A. P., Kirschner, A. K. T., 2018. Spatiotemporal analysis of bacterial biomass and activity to understand surface and groundwater interactions in a highly dynamic riverbank filtration system, *Science of the Total Environment*, 627 450-461. DOI: <https://doi.org/10.1016/j.scitotenv.2018.01.226>
- Gaya, M. S., Abba, S. I., Abdu, A. M., Tukur, A. I., Saleh, M.A., Esmaili, P., Abdul Wahab, N., 2020. Estimation of water quality index using artificial intelligence approaches and multi-linear regression. *IAES Journal of Artificial Intelligence*, 9(1), 126-134. DOI: <https://doi.org/10.11591/ijai.v9.i1.pp126-134>
- Garba, A., Ekanem, E. O., Garba, I. H., and Mustapha, A., 2016. Multivariate statistical analysis of groundwater chemistry data from Hadejia local government area of Jigawa state, Nigeria, *Global Journal of Advanced Research*, 3(8), 713-722.
- Gharbia, S. S., Gill, L., Johnston, P. and Pilla, F., 2020. GEO-CWB: GIS-based algorithms for parametrising the responses of catchment dynamic water balance regarding climate and land use changes. *Hydrology*. DOI: <https://doi.org/10.3390/hydrology7030039>
- Helmus, A. M., Fernald, A. G., Vanleeuwen, D. M., Abbott, L. B., Ulery, A. L. and Baker, T. T., 2009. Surface water seepage effects on shallow ground-water quality along the Rio Grande in northern New Mexico. *Journal of the American Water Resources Association*, 45(2), 407-418. DOI: <https://doi.org/10.1111/j.1752-1688.2008.00293.x>
- Ifabiyi, I. P. Ojoye, S. 2013. Rainfall trends in the Sudano-Sahelian ecological zone of Nigeria. *Earth Science Research*, 2(2). DOI: <https://doi.org/10.5539/esr.v2n2p194>
- Iliya, M. A., Muhammad-Baba T. M., and Oppon-Kumi, A., 2011. Climate change, land degradation, forced migration and farmers- pastoralists conflicts in the Sokoto-rima basin in north-western Nigeria: observation and extrapolations. *First National Conference on Climate Change*, 24th May, 2011, Bayero University Kano, Nigeria
- Isikanye, O. M., 2018. Distribution and multivariate pollution risks assessment of heavy metals and natural radionuclides around abandoned iron-ore mine in North Central Nigeria. *Earth Syst. Environ*, 2, 331-343. DOI: <https://doi.org/10.1007/s41748-018-0035-0>
- Kumar, M., Kumari, K., Ramanathan, AL. and Saxena, R., 2007. A comparative evaluation of groundwater suitability for irrigation and drinking purposes in two intensively cultivated districts of Punjab, India. *Environ Geol*, 53, 553-574. DOI: <https://doi.org/10.1007/s00254-007-0672-3>
- Kura, N. U., Ramli, M. F., Sulaiman, W. N. A., Ibrahim, S., and Aris, A. Z., 2016. An overview of groundwater chemistry studies in Malaysia, *Environ Sci. Pollut Res*, 25, 7231-7249. DOI: <https://doi.org/10.1007/s11356-015-5957-6>
- Mays, L. W., 2009. Integrated urban water management: Arid and semi-arid regions, Tylor and Francis Group plc: Leiden, The Netherlands, UNESCO Publishing, Paris, France, 1-73.
- MDG [Millennium Development Goals]. 2006. The millennium development goals report. United Nations New York.
- Nabegu, A. B. 2013. Effect of sand mining on groundwater in Kano river catchment, *Journal of Environment and Earth Science*, 3(2).
- Chidya, R. C. G., Matamula, S., Nakoma, O., and Chawinga, C. B. J., 2016. Evaluation of borehole water quality in rural-areas of northern Malawi: Case of Zombwe in Mzimba, *Physics and Chemistry of the Earth*, 93, 55-62. DOI: <https://doi.org/10.1016/j.pce.2016.03.013>
- Narany, T. S., Ramli, F. R., Aris, A. Z., Sulaiman, W. N. A., and Fakharian, K., 2014. Spatiotemporal variation of groundwater quality using integrated multivariate statistical and geostatistical approaches in Amol-Babol Plain, Iran. *Environ Monit. Assess*, 186, 5797-5815. DOI: <https://doi.org/10.1007/s10661-014-3820-8>
- Narany, T. S., Sefie, A., Aris, A. Z., 2018. The long-term impacts of anthropogenic and natural processes on groundwater deterioration in a multilayered aquifer. *Science of the Total Environment*, 630, 931-942. DOI: <https://doi.org/10.1016/j.scitotenv.2018.02.190>
- Neshat, A., Pradhan, B., Pirasteh, S. and Shafri, H. Z. M., 2013. Estimating groundwater vulnerability to pollution using modified DRASTIC model in the Kerman agricultural area. Iran. *Environ Earth Sci*, 71, 3119-3131. DOI: <https://doi.org/10.1007/s12665-013-2690-7>
- Olofin, E. A., 2011. Geographical hydrology lecture note series, Department of geography, Bayero University, Kano, 3-4.
- Olofin, E. A., 2014. Location, relief and landform. In (Ed.) Tanko and Momale, Kano: Environment, society and development, Adonis and Abbey, London and Abuja, 1-11
- Olofin, E. A., 2016. Water resources planning and management: lecture notes on WMA501: Water resources planning and management, Department of Water resources management and agro-meteorology,

- Federal University of Oye-Ekiti, Ikole Campus, Nigeria, 4-12.
- Patel, P., Raju, N. J., Reddy, B. C. S. R., Suresh, U., Gossel, W. and Wysick, P., 2016. Geochemical processes and multivariate statistical analysis for the assessment of groundwater quality in the Swarnamukhi river basin, Andhra Pradesh, India. *Environ Earth Sci.*, 75, 611. DOI: <https://doi.org/10.1007/s12665-015-5108-x>
- Shin, M., Moon, S.H., Kang, K. G., Moon, D. C. and Koh, H. J., 2020. Analysis of groundwater level variations caused by the changes in groundwater withdrawals using long short-term memory network, *Hydrology*, 7(3). DOI: <https://doi.org/10.3390/hydrology7030064>
- Sobowale, A., Adewumi, J. K., Otun, J. A. and Adie, D. B., 2010. Water resources potentials of Hadejia river sub - catchment of Komadugu Yobe river basin in Nigeria. *Agric Eng Int: CIGR Journal*, 12(2), 1-6.
- Streett, B., 2001. Guide to conducting well pumping tests, Water Stewardship Information Series, British Columbia, 1-8.
- Sule, I. A., Saleh, M., Lawan, M., Bunawa, A. A. and Jibril, F. M., 2020. Assessment of groundwater quality condition at Tarauni dumpsite area, Kano northwestern Nigeria, *International Journal of Physical Science*, 15(1), 1-9. DOI: <https://doi.org/10.5897/IJPS2018.4784>
- Suleiman, A. A., Ibrahim, A., Abdullahi, U. A., 2020. Statistical explanatory assessment of groundwater quality in Gwale LGA, Kano state, northwest Nigeria. *Hydrospatial Analysis*, 4(1), 1-13. DOI: <https://doi.org/10.21523/gcj3.2020040101>
- Thompson, J. R. and Polet, G., 2000. Hydrology and land use in a Sahelian floodplain wetland. *Wetlands*, 20 (4), 639-659. DOI: [https://doi.org/10.1672/0277-5212\(2000\)020\[0639:HALUIA\]2.0.CO;2](https://doi.org/10.1672/0277-5212(2000)020[0639:HALUIA]2.0.CO;2)
- Tukur, A. I., Nabegu, A. B., Umar, D. A., Olofin, E. A. and Sulaiman, W. A. S., 2018, Groundwater condition and management in Kano region, northwestern Nigeria. *Hydrology*, 5(16), DOI: <https://doi.org/10.3390/hydrology5010016>
- Umar, D. A., Ramli, M. F., Aris, A. Z. and Zaudi, M. A., 2019a. Hydrological response of semi-arid river catchment to rainfall and temperature fluctuations. *Pertanika Journal of Science and Technology*, 27(4), 2333- 2349.
- Umar, D. A., Ramli, M. F., Aris, A. Z., Jamil, N. and Tukur, A. I., 2019b. Surface water resources management along Hadejia river basin, Northwestern Nigeria, *H₂Open Journal*, 2(1). DOI: <https://doi.org/10.2166/h2oj.2019.010>
- UNESCO [United Nations Educational, Scientific and Cultural Organization], 2007. UNESCO Water portal newsletter No. 161: water-related diseases.
- Xu, Y. and Usher, B., 2006. Groundwater pollution in Africa. *Taylor and Francis Group*, 23-25.
