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Hydrogeological Analysis of Cretaceous and Tertiary Aquifers in Semiarid Sokoto Basin, Northwestern Nigeria: Implications for Sustainable Groundwater Development

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ABSTRACT

Groundwater development in arid and semiarid regions is accelerated by expanded irrigation farming, industrialisation, and municipal water supply. This study provides a detailed hydrogeological analysis of sedimentary aquifers of the Sokoto basin, Northwestern Nigeria, for improved water resource development and management. Hydrogeological data, including static water level (Swl), pumping water level (Pwl), pumping test (Pt), and estimated yield (Ey), were analysed. A total of three hundred (300) observations on Swl, Pt, Pwl, Ey, and Hps were derived from boreholes and analysed using Factor analysis (FA) and Regression analysis (RA). Results showed that Gwandu Formation is the most prolific aquifer. Boreholes can yield more than 24000 litres per hour (L/h). This was followed by The Kalambaina limestone aquifer, which has the potential to yield about 15000 (L/h). However, the Taloka Formation is characterised by very poor aquifers in most of the basin, though along the Jega-Dogon Daji axis, boreholes can yield more than 24000 (L/h). Likewise, boreholes tapping the Wurno Formation can produce a maximum yield of 24000 (L/h). Estimated yields from boreholes were less than 1500 (L/h) from the Gundumi aquifer, and the maximum borehole yields were 17760 (L/h) in the Illo aquifer. Statistical modelling showed that all the analysed variables are significant concerning groundwater potentials and variability of borehole yields in the study area. Therefore, future groundwater resource development in the study area should be based on a proper analysis of the geological configurations of the Sokoto basin. This study provides an outlook on the groundwater potentials of the study area and aquifers that can provide a basis for sustainable groundwater development policy. Thus, the study has shown how multivariate and regression analysis can be used to study the hydrogeological conditions of a particular basin. Therefore, it is hoped that this study's findings will inspire other researchers to take a comparable approach.

1. Introduction

Global demands for groundwater resources have inflamed due to expanded irrigated agriculture, industrialisation, and urbanisation. At least 2.5 billion people drink groundwater [1-5]. Groundwater aquifers account for about 43% of agricultural water uses worldwide. Groundwater mining related to agriculture has caused considerable drops in the groundwater table [1]. Future forecasts suggested declines in groundwater quality and quantity. These would be worsened by growing human consumption (competing demands from agriculture, industry, and municipal supplies) and climate change [6-10]. Unchecked groundwater resource development under a changing climate, which is characterised by increased groundwater extraction, can lead to the depletion of groundwater aquifers. Thus, sustainable groundwater development, driven by increasing demands, requires prudent management decisions advised by the knowledge of hydrogeological processes. This is required since groundwater variability could be affected by both climatic and geological factors. The approach would be necessary to reduce groundwater depletion and boost global water and food security [11, 12].

Competing demands for groundwater by municipal supplies and agriculture have impacted the quality and quantity of water stored by aquifers worldwide. By 2050, the urban water demand will grow by 80% [13]. Over 27% of global cities would have more significant water demand, exceeding surface water capacity. Consequently, 19% of global cities that depend on surface water transfers may have more significant potential for conflict between agricultural and urban sectors. In 80% of the high-conflict breakpoints, improved agrarian water use could make available adequate water for urban supply [13]. However, groundwater is progressively developed in arid and semiarid regions to augment the surface water deficit [14, 15]. Groundwater abstraction in dry environments has impacted aquifers concerning the amount of water stored and storage quality. Different types of pollutants are added to surface and groundwater from agricultural, industrial, and municipal sources [16-19].

The climate has changed in the past and is currently shifting, and future change is expected. The large-scale observation of soaring temperatures may correlate to a natural warming phase, which began in the 19th century. Anthropogenic greenhouse gas releases further accelerate it from burning fossil fuels and emissions from wetlands [20-24]. The general fear raised by global heating is that climatic change can modify the hydrological cycle; indeed, numerous investigations have shown that the water cycle has been altered. The impact of climate change on the hydrological cycle is immense, resulting in costs on surface and groundwater due to changes in precipitation patterns and intensity [7, 25, 26].

Although groundwater tends to be resilient, the relationship between climate change and groundwater has been well investigated, and its impact cannot be overemphasised. Decreased precipitation in dry environments could produce exponentially significant drops in the groundwater table [27-29]. Many ambiguities bound the interpretation of climate and groundwater interactions due to significant differences in multi-scale local and regional disparities in hydrogeological settings [30, 31]. So, there is a need to analyse groundwater potentials in a semiarid basin.

Hydrological data, including hydraulic assessments for wells tapping the three aquifers, are discussed in detail by Anderson and Ogilbee [32, 33]. However, local but essentially floating groundwater is unearthed within the limestone aquifer of the Kalambaina Formation in the outcrop region. Likewise, an unconfined aquifer occurred in the Quaternary sandy deposits of the "*Fadama*" (floodplain) of the river Sokoto and its larger tributaries [32, 34, 35]. The sandy deposits rest on the Basement Complex of Pre-Cretaceous age. Major aquifers in the Sokoto basin are Gwandu, Illo, Kalambaina, Wurno, Taloka, and Gundumi Formations.

Consequently, the variation in the hydrogeological condition is expected to impact groundwater potentials and the productivity of boreholes. Analysis of groundwater potentials in the Sokoto basin showed differing hydraulic characteristics [34, 36, 37]. This study assesses the erraticism of the borehole yields in the Sokoto basin and its implications for sustainable groundwater development.

2. Geographical Setting

2.1. Location and Climate

The Nigerian sector of the Iullemmeden basin, otherwise known as the Sokoto basin, is the major basin in West Africa, covering a large portion of northwestern Nigeria [38-40]. The basin is located in the sub-Saharan Sudan Belt of West Africa, commonly categorised as semiarid. It lies between Latitudes 10º and 14º N and Longitudes 3º and 7º E (Fig. **1**). Sokoto basin covers an estimated area of ~65000 km^2 (Adelana *et al*., 2002) [41-46]. It is bordered in the north and west by the Republic of Niger and in the southwest by the Benin Republic. The climate is hot, semiarid, and tropical (AW) [47, 48]. It is the subject of two opposing airstreams: Tropical Continental and Tropical Maritime air masses [49]. The dry season prevailed from October to April, and the wet season occurred from May to September/October. Owing to the basin's position in extreme Northwestern Nigeria and over 1000 km away from the sea, the basin generally remains dry for most of the year [50-53]. Temperature is generally high and varies significantly with seasons. Annual rainfall ranged from 500 mm north to over 1200 mm in the south. The relative humidity is highest in August, ~90%, and is lowest in December, <10%. There is a general upsurge in relative humidity from north to south. The evaporation rate is generally high, and the study area can be classified as having an ustic soil moisture regime [47, 52, 53].

The Sokoto-Rima River network is the primary drainage system [48, 54]. The headwaters of the Rivers Rima and Sokoto and their offshoots rise in Pre-Cretaceous Crystalline Terrain in the eastern Sokoto basin and run west and south through a terrain underlain by sedimentary sways of Illo and Gundumi formations, the Rima and Sokoto groups, and the Gwandu Formation [32]. The Rivers Gagere, Bunsuru, Rima, Kware, Shella, Zamfara, Gulbin Ka, and Gayan Gulbe are the River Sokoto's major tributaries above its convergence with the River Niger [55].

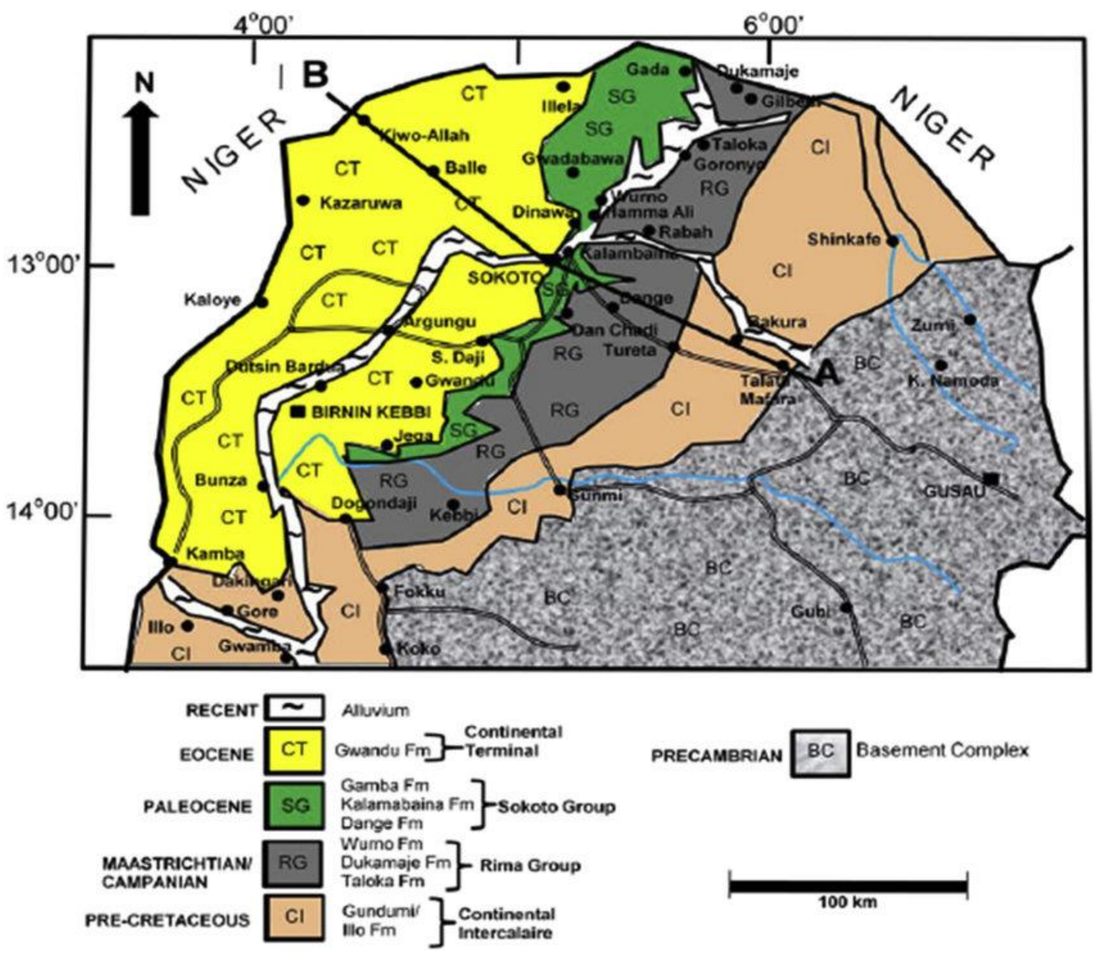

Figure 1: Map of Sokoto basin showing the study area [63].

2.2. Geological Setting

A succession of interbedded partly-fused sand, clay, limestone, and gravel characterises the semiarid Sokoto basin. The formations varied from Cretaceous to Quaternary in age and reached a depth of 1067 meters. Gundumi and Illo Group's Tertiary sediments are the older lodes of the Cretaceous period [56-59]. The Cretaceous and Tertiary sediments hit in a north-eastward course and dip roughly 7m/2km north-westward. The sediments also stiffened down dip; the Rima and Sokoto Groups pinched southward along the outcrop. Groundwater is confined as artesian water and unconfined beneath the ground surface [32, 33, 35, 60]. This condition occurred in most permeable Cretaceous and Tertiary sedimentary series members. Downward confined aquifers appeared in a semi-consolidated grit or sand, producing at least three critical aquifers in the Rima group, Gwandu Formation, and Gundumi Formation [34, 61, 62].

Concerning geology, the Sokoto basin is expansively explored. The basin is ultimately a cratonic basin created by tectonic pyrogenic movements or extending and rifting the tectonically calmed crust during the Palaeozoic. These movements became apparent from the commencement of the Palaeozoic. They persisted until the Upper Cretaceous when the opening of the Goa Trench prevailed. Sokoto basin is one of three significant sub-Sahara's inland basins comprising a broad syncline with gently dipping flanks [38]. The superimposing sedimentary sequences become gradually younger from the northeast to the southwest, indicative of successive Cretaceous marine transgressions' directions. Superimposing the Precambrian Basement unconformably are the Gundumi and Illo Formations. These are superimposed unconformably by the Maastrichtian Rima Group, divided by the fossiliferous shally Dukamaje Formation. Calcareous Kalambaina Formation separates the Paleocene Dange and Gamba Formations (chiefly shales). The superimposing Gwandu Formation (Continental Terminal) is of Tertiary age. These deposits dip slightly and stiffen progressively near the northwest, attaining a maximum depth of over 1000 meters near the frontier of the Nigeria-Niger border. The detailed geological and stratigraphical description of the Sokoto basin is well documented in the literature [4, 57, 59, 64, 65]. Fig. (**2**) summarises the stratigraphy of the Sokoto basin.

Age	Formation		
Eocene	Gwandu	Continental	Continental Termaire
Paleocene	Kalambaina Gamba	Marine Marine	Sokoto group
	Dange	Marine	
	Wurno	Continental	
Maastrichtian	Dukamaje	Marine	Rima Group
	Taloka	Continental	
	Illo	Continental	Continental Intercalaire
Pre Maastrichtian	Gundumi	Continental	
Pre Cambrian	Basement Complex Formation		

Figure 2: Stratigraphic succession of the Nigerian Sector of Illummeden (Sokoto) basin.

The Basement Complex's contact with the Gundumi Formation is conglomeratic [58, 59, 66]. Along the Sokoto-Gusau road, at Konar Rolga, an excellent outcrop of the basal conglomerates occurred at Talata Mafara about 11 km northward. These conglomerates' outcrops covered hundreds of square kilometres, with sizeable, well-rounded stones in a gigantic clayey ferruginous and feldspathic matrix. Similarly, around Tureta, the pebble conglomerates profusely occurred. The Illo Formation is a tangential equivalent of the Gundumi Formation [58, 59]. The former superimposes the basement rocks unconformably. The lodes are continental, fluviatile-fluvio-lacustrine in origin. Northwards, they dipped gently and struck westwards in a northeast-southwest direction. The Illo Formation contained cross-bedded sands principally with major intercalation of nodular and pisolitic clay [32, 37]. Lateritic ironstones and literates formed a resistant capping above the grits, and thin layers of multi-coloured ferruginous deposits occurred randomly within the pebbles. The lithologic-type section of the Illo Formation is exposed on a hill in eastern Gore village about 4 km north of Giro [58, 59].

The Rima Group was accrued unconformably during the Maastrichtian Era over Pre-Maastrichtian Continental Strata [58, 59, 67, 68]. It represents the second phase in the depositional history of the sedimentary lodes of the Sokoto basin. The deposits are comprised of the Dukamaje, Taloka, and Wurno Formations. At Wurno, the unconformity is noticeable. The Taloka Formation contained lower mudstones and sandstones of the Rima Group and reached a maximum thickness of about 100 meters. Outcrop of the Taloka Formation is observable at Goyonyo, Shinaka, and Taloka [57-59, 69]. The outcrops of the upper section of the basal beds further east are visible near Gidan Mata and Takarau. It contains fine-grained, white, friable sandstones and siltstones with tinny incorporated mudstones, shales, or carbonaceous mudstones. In the northern section of the Rima Valley in the Gilbedi District, the formation occupied the bottom of a high scarp feature representing the north terminal of the Dange Scarp [58, 70, 71]. It formed a prominent topographic feature running towards Dange in a southwards direction. The younger formations occupied the upper limits of the escarpment. The hills are lower in the southern section of the Rima valley, near Goronyo. The more significant portion of the mountain is covered by the Taloka Formation's sediments, overlain by the poorly developed Dukamaje Formation. Laterite represents the Wurno Formation at the summit [58].

The Wurno Formation is similar to the Taloka Formation. The dregs comprised fine-grained sandstones, pale friable siltstones, and interleaved mudstones. The borehole sections showed that the sediments are dark-coloured due to the existence of carbonaceous material and finely dispersed iron sulfides. Excellent exposures of this formation can be seen at Gada near the frontier with the Republic of Niger. The Palaeocene deposits represent the third phase of the depositional history of the Sokoto basin's sediments [58, 59, 72]. During the Palaeocene, the Sokoto Group, comprising the Dange, Gamba, and Kalambaina Formations, amassed unconformably over the Rima Group. The Dange Formation occupied the bottom of the Sokoto Group. The marginally hardened bluish-grey shale was interbedded with thin layers of yellowish-brown limestone. A maximum thickness of 22 meters was attained near Sokoto, though in boreholes, up to 45 meters were recorded [58, 59].

The Kalambaina Formation consists of white marine shales and clayey limestone [58, 59, 63, 73]. The type section is exposed at the cement factory's quarry near Kalambaina village, about 6 km southwest of Sokoto. The formation's thickness is exceptionally variable due to the subsurface dissolution of limestone. A maximum thickness of 20 meters was attained in boreholes penetrating the formation. However, only about 12 meters of the section is typically outcropped at the quarry site. Around Dange village, the formation is condensed to about 5 meters. However, at Birnin kebbi, southward, the formation is about 18 meters thick.

The Gamba Formation contains laminated grey shale, superimposing the Kalambaina Formation. The shales are folded due to the removal by the solution of the underlying limestone and the sagging of superimposing beds. The formation is covered by a mantle of weak laterite and sand, whereas Gwandu Formation does not protect it. The laterite is typically 1.5 to 3 meters thick and regularly passes down into Oolitic ironstone, varying from 3 to 5 meters wide. The Gamba Formation type is visible near Sokoto at Gamba village [58, 59, 69]. At the quarry of the Cement Company of Northern Nigeria, in the borehole (GSN 2458), the thickness of the shale ranged from 4 to 10 meters in the outcrop section of the quarry.

The tertiary marine deposits of the Sokoto Group comprise a profuse sequence of sediments comprising mainly red and spotted clays, with sandstone interbedding disconformably superimposing the entire sedimentary basin of Northwestern (N.W.) Nigeria [58]. These sediments belong to the Gwandu Formation. ***Its typical section and type area covered most of the Gwandu Emirate.*** The formation outcropped in a vast area of about 22000 Km^2 in N.W. Nigeria [58]. It contained several prominent ridges and groups of smooth-topped, steep-sided hills covered by ironstone. Rock outcrops are rare, but many can be found on the hillsides, where they are generally small and masked by rainwash and ironstone scree. Extensive outcrops occurred in Northern Benin and the Republic of Niger. They correlate to the Miocene-Pliocene age of Mauritania and the Central African Republic [58].

To be more precise, the Gwandu Formation can be connected to the continental environment or lacustrine environment. Good exposure to the Gwandu Formation is visible between Argungu and Birnin Kebbi. The deposits contain enormous, white-coloured clays intercalated with medium and coarse-grained red mudstones and sandstones with irregular peat bands. Laying below the clays is the lateritic capping of hard ferruginous sandstone coating, easily erodible within a network of gullies. These are underlain by reddish sand, clays, and white mudstones, permanently stained white-brown or pink. The mudstones with intercalated sandstones expand throughout the section. Comparable sections of the formation occur on the hills of Gwandu outliers in the Kalambaina Formation on the Sokoto town's peripheries in the vicinity of the Sokoto Cement Factory [58, 59, 69]. Red-coloured sands at the surface showed regular colour bands and low stratification. The mudstones show a typical modular structure with nodes indicative of regional turbulence in the depositional environment. Compared with palynomorphs of Tertiary Sediments, the tentative age of the Gwandu Formation was put at Eocene-Miocene [58].

3. Materials and Methods

3.1. Data Sources

This study analysed hydrogeological data consisting of static water level (Swl), pumping water level (Pwl), pumping test (Pt), and estimated yield (Ey) obtained from 300 boreholes covering most parts of the sedimentary section of the Sokoto basin. Hydrogeological data were acquired from the Department for Rural Water Supply and Sanitation records, Birnin kebbi (RUWASSA), and summarised in the SUPPLEMENTARY TABLE below to this paper (Table **S1**).

3.1.1. Statistical Analysis and Factor Analysis

Basic statistics (Min, Max, Mean, and Standard Error) were used to summarise and standardise data. Three hundred observations on Swl, Pt, Pwl, Ey, and Hps were derived from 300 boreholes and used in Factor analysis (FA) and Regression analysis (RA). Factor analysis (FA) is widely applied in hydrogeochemical and hydrogeological investigations. FA is used to study the interrelationships between hydrogeological variables by categorising the multidimensional data into a more interpretable form [74-76]. FA typically involved the calculation of $n \times n$ comparation matrix, where *n* corresponds to the number of variables and *n* is normally extensive; a practical limitation of 200 variables was initially faced even on large computers [77].

Consequently, Calgary and Brown Factor Analysis (CABFAC) was invented to lodge up to 1500 variables. It was possible by employing specific properties of the matrices applied in the analysis instead of factoring an $n \times n$ data matrix of comparable coefficients. An $n \times n$ data matrix of cross products is factored when the $n = nunber\ of\ variable$ used. Typical to a Q-mode FA contains tile following steps as defined by Klovan and Imbrie [77]:

$$W = QF_p\text{; the principal Factor equation} \quad (Eq.\ 1)$$

$$WW = S\text{, the cosine-theta matrix} \quad (Eq.\ 2)$$

$Q - mode$, the Factor connected to S, is calculated such that:

$$QQ' = S\text{, condition on} \quad (Eq.\ 3)$$

$$Q' = \Lambda\text{, and} \quad (Eq.\ 4)$$

$$e.\ \ F_p'F_p' = I \quad (Eq.\ 5)$$

It is also real that:

$U'SU = \Lambda$, and it trails that:

$$Q = U\Lambda^{\lambda}. \quad (Eq.\ 6)$$

The Factor score matrix is perhaps derived from $W = QF_p' and\ W = AF_p{}'$.

$$F_p = W'Q\Lambda^{-1}. \quad (Eq.\ 7)$$

The technique developed in the CABFAC model takes advantage of certain features of these matrices to get similar results but with less rigorous storage prerequisites. The steps in this technique are:

$$W'W = P, \text{the } n \times n \text{ cross-products matrix} \quad (Eq.\ 8)$$

Klovan and Imbrie (77) also defined:

$\dot{U}'P\dot{U} = \dot{\lambda}$, where $\dot{U}$ and $\dot{\Lambda}$ are the eigenvectors and eigenvalues related to

$$P, \text{ i.e., } P = \dot{U}\dot{\Lambda}\dot{U}' \quad (Eq.\ 9)$$

It is noteworthy that the order of P = number of columns of X, although the order of S = number of rows of X. It has been established from the 'Matrix Theory' that nonzero values of Λ, which formed the eigenvectors of $W'W$ = the nonzero values of Λ, the eigenvalues of $W'W$.

$\Lambda = \dot{\Lambda}$. Since $\dot{U}$ is orthonormal, it can be written in step (2) as

$$S = WW' = W\dot{U}\dot{U}'W' \text{ or } S = W\dot{U}(W\dot{U})' \quad (Eq.\ 10)$$

As a result of (xi), it can be written that

$$A = \dot{U}P\dot{U}\ or\ A = \dot{U}'W'W\dot{U} \text{ or } \lambda = (W\dot{U})'W\dot{U} \quad (Eq.\ 11)$$

Equating (iii) with (xii) and (iv) with (xiii) results to:

$$QQ' = s = W\dot{U}\big(W\dot{U}\big)' \quad (Eq.\ 12)$$

$$Q'Q = \lambda = \big(W\dot{U}\big)'W\dot{U} \quad (Eq.\ 13)$$

Thus, it can be written as:

$$Q = W\dot{U}. \quad (Eq.\ 14)$$

The principal factor-score matrix converts to

$$F_p = W'^{QA^{-1}} = W'W\dot{U}A^{-1} = P\dot{U}A^{-1} = U\Lambda\dot{U'}\dot{U}^{-1} = \dot{U} \quad (Eq.\ 15)$$

where $W = D^{-1/2}X$ presents the row standardised data matrix, i.e., individual variables in W have unit vector dimension, $S = WW'$ represents the $N \times N$ cosine-theta matrix, i.e., the degree of relative similarity among individual variables, $P = W'W$ represents the $n \times n$ matrix of cross-products between the n observations, Λ = diagonal matrix of nonzero eigenvalues of S, U= column-wise, an orthonormal matrix of eigenvectors linked with Λ, Q = factor loadings matrix, F_p = column-wise orthonormal factor score matrix, F_{ps} = scaled factor score matrix, V = varimax factor loading matrix, F_r = varimax factor score matrix, and F_{rs} = scaled varimax factor score matrix [77].

Therefore, instead of diagonalising and storing the $n \times n$ matrix S, when similar results can be achieved by diagonalising the $n \times n$ matrix P, and gaining simple matrix multiplication to reach the anticipated matrix Q. As illustrated in (Eq. 15), the delineated technique determines the factor scores, which approximate the factors' configuration. Since the size of the numbers obtained in F_p is, in part, an image of the number of variables involved in the analysis. It represents the program and the factor scores above, scales, or adjusts the Factor scores by multiplying them by the square root of the number of observations. The F_{ps} resultant matrix makes the comparison of factor scores between studies in which different numbers of observations (or variables) have been involved possible. Each scaled score equals unity if all the analysis variables are likewise crucial in a factor. A factor score's minimum absolute value is 0, signifying that an observation contributes less to a particular factor. The maximum possible absolute value, stirring when other observations have 0 scores, is $\sqrt{n}$ [77].

The loadings, often labelled as factor scores, are chosen based on a linear model (Eq. 1). Therefore, Factor 1 outlines the highest variance in the hydrogeological data matrix, followed by Factor 2, which describes the second-highest variance delimited in the data matrix, but that is erected orthogonally to Factor 1, and consequently, is independent of Factor 1. It is calculated as follows:

$$FA_{jk} = a_{j1}x_{k2} + \cdots + a_{jn}x_{kn} \qquad (Eq. 16)$$

where FA_{jk} is the FA score *j* for object *k* (the score for object *j* on loading *k*), aj_1 is the loading of variable 1 on factor *j*, xk_1 is the degree of the loading for variable 1 on item *k,* and *n* is the total number of variables analysed. The FA was carried out on a subset of five hydrogeological variables that outlined the Sokoto basin's hydrogeological condition. The analysis was carried out using the PAST3 (version 3.14) statistical software package.

3.1.2. Regression Analysis

A generalised regression model was applied to study the relationship between hydrogeological variables. It aids the identification of the relationship between hydrogeological variables by fitting a linear equation to the hydrogeological data. Values of the discrete variables x are related to a value of y (i.e., dependent variable). The regression model of hydrogeological data for p experimental variables $x_1, x_2, x_3, \ldots\ldots x_p$ is:

$$\mu_\gamma = \beta_o + \beta_1 + x_1 + \beta_2 x_2 + \cdots + \beta_p x_p \qquad (Eq. 17)$$

How the mean response μ_γ differs from experimental variables described by the model. The perceived *y* values tend to vary with their means. μ_γ. Moreover, these are supposed to have an analogous standard deviation σ. The fitted values $b_0 b_1, \ldots. b_p$, estimate the variables $\beta_0, \beta_1, \ldots, \beta_p$ of the regression model. The perceived y values vary with their mean; the model delimited an expression for this variance. It is defined as Data = fit + residual. The term "fit" is expressed as follows:

$$\mu_\gamma = \beta_o + \beta_1 + x_1 + \beta_2 x_2 + \cdots + \beta_p x_p \qquad (Eq. 18)$$

"RESIDUAL" is the deviation of the perceived *y* value(s) from the means. μ_γ. It is characteristically circulated with mean 0 and variance σ. The symbol of the model is ε. The model is correctly given n observation and expressed as:

$$y_i = \beta_o + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots \beta_p x_{ip} + \varepsilon_i \; for \; i = 1,2, \ldots n \qquad (Eq. 19)$$

The best-fit line and least-squares models for the hydrogeological data are calculated by reducing the squares of the vertical deviations from the discrete data spot to the line. If a spot lies precisely on the fitted line, its vertical deviations = 0. Since the variations are squared and then estimated, there are no cancellations between negative and positive values. The least-squares values $b_0 b_1, \ldots. b_p$ are usually measured using the statistical software package(s). The fitted values using the equation $b_0 b_1 x_{i1} + \cdots + b_p x_{ip}$ expressed as $\hat{y}_i$, and the residuals e_i are equal to $y_i - \hat{y}_i$, the variance between the fitted and observed values. The outline of the residuals = 0. The variance $\sigma_2$is calculated as:

$$S^2 = \frac{\sum e_i^2}{n - p - 1} \qquad (Eq. 20)$$

It is identified as M.S.E., i.e., mean squared error. The calculated standard error is given as $s = \sqrt{MSE}$. The analysis used a MINITAB (mbt 16) statistical software package.

4. Results and Discussion

Table **1** and Fig. (**3**) present a summary of hydrogeological parameters: static water level (Swl), pumping water level (Pwl), pumping test (Pt), estimated yields (Ey), and hand pump setting (Hps). The Swl varied from 0.00 m to 71.19 with a mean Swl of 20.84±0.94 m. The pumping water level varied between 1.00 to 78.40 m with a mean Pwl of 25.69±1.05 m. Pumping tests ranged from 6.00 to 150.00 (Lpm) with a mean Pt 52.52±1.91 (Lpm). Estimated yields ranged from 10.00 to 400.00 lpm. Mean Ey was 244.69±8.88 (Lpm). The Hps varied from 6.00 m to 78.00 m with a mean Hps of 29.32±1.00 meters.

Table 1: Summary of hydrogeological parameters from boreholes.

Parameter	Swl(m)	Pt (Lpm)	Pwl (m)	Ey (Lpm)	Hps (m)
Min	0.00	6.00	1.00	10.00	6.00
Max	71.19	150.00	78.40	400.00	78.00
Mean	20.84	52.52	25.69	244.69	29.92
SE	0.94	1.91	1.05	8.88	1.00

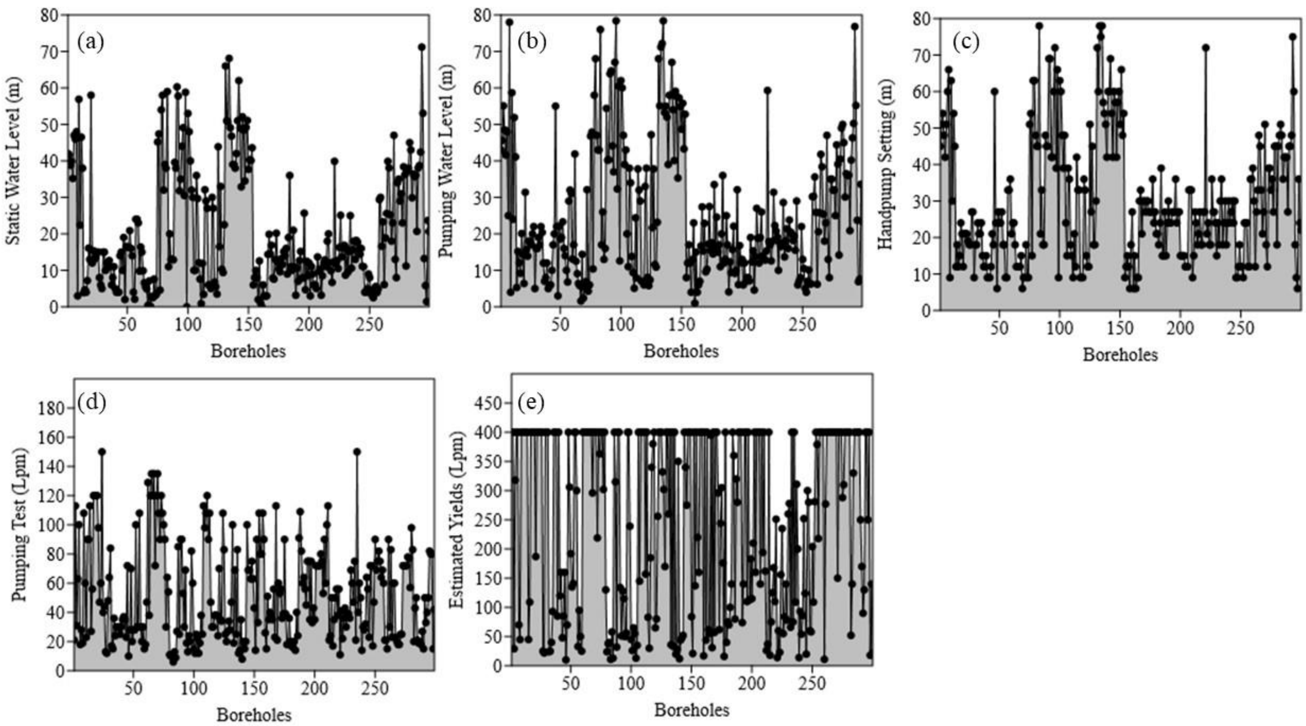

Figure 3: Hydrogeological variables (**a**) Static water level, (**b**) Pumping water level, (**c**) Handpump Setting, (**d**) Pumping test, and (**e**) Estimated yields.

4.1. Gwandu Formation

The Gwandu Formation is the most prolific aquifer in the Sokoto basin. Concerning groundwater, the most significant part of the Gwandu Formation is a sandy region in the basal section that, delineated at depth, forms the most widespread and productive artesian aquifer hitherto known in the Sokoto basin [32, 33]. This sandy zone thickens from only 4 meters in the central and northern parts of the basin to several hundred meters at Balle and in the Niger Republic. Boreholes at four sites from southwest to northeast and about 25 km west of the eastern limit of the Gwandu Formation have exposed the nature and stratigraphic position of the confined sand aquifer downdip [33]. The confined aquifer of the basal Gwandu rises in thickness toward the northwest from 12 meters to more than 60 meters and dips to the northwest at about 3 meters per kilometre.

Fig. (**4**) illustrates the type section of boreholes in the Gwandu Formation. Fig. (**4a**) summarises the lithology of the borehole (Badariya 49-NW-17) at Birnin kebbi. The lithology (0-4 red sand, 4-9 red sand & laterite, 9-14 yellow clay, 14-29 yellow sandy clay, 29-36 fine sand, 36-41 clay with coarse sand, 41-64 lateritic clay with coarse sand, 64-85 clay with coarse sand, 85-91 coarse sand), revealed the dominance of sandy formations with intercalated clays. The borehole was screened at 45 meters. The static water level (Swl) was 36.2 meters, the pumping test (Pt) was 57.0 litre per minute (Lpm), the pumping water level (Pwl) was 39.1 meters, and the estimated yield was 400 (Lpm). The borehole can produce 24000 litres per hour.

A similar condition was reported by Offodile [33] at Janzomo (Borehole G.S.N. No. 3502) southwest of the Sokoto basin. The aquifer was 13 meters thick and mainly contained fine to very coarse sand. It is underlain by 15 meters of grey elastic clay, which lies in the Kalambaina Formation. In borehole, G.S.N. No. 3072, 51 km to the northeast, at Sabia, the grey clay, 19 meters thick, also forms the Gwandu Formation base and is superimposed by about 22 meters of the aquifer material. At Janzomo and Sabia, the aquifer's uppermost is approximately 23-26 meters below the ground surface and lies below a 9-meter-thick layer of confining clay. At Tangaza, about 76 km northeast of Sabia in borehole GSN 3058, the basal clay is absent, and the aquifer of fine to coarse sand lies directly on the Kalambaina Formation. About 41 km north of Tangaza at Ruawuri, near the Niger border in the borehole (G.S.N. No. 3070), the aquifer is 34 meters thick. It is also, for the most part, the basal bed of the Gwandu Formation. Thin lignite and peat horizon at the Gwandu Formation base mark the Kalambaina contact at Tangaza and Ruawuri [32, 33].

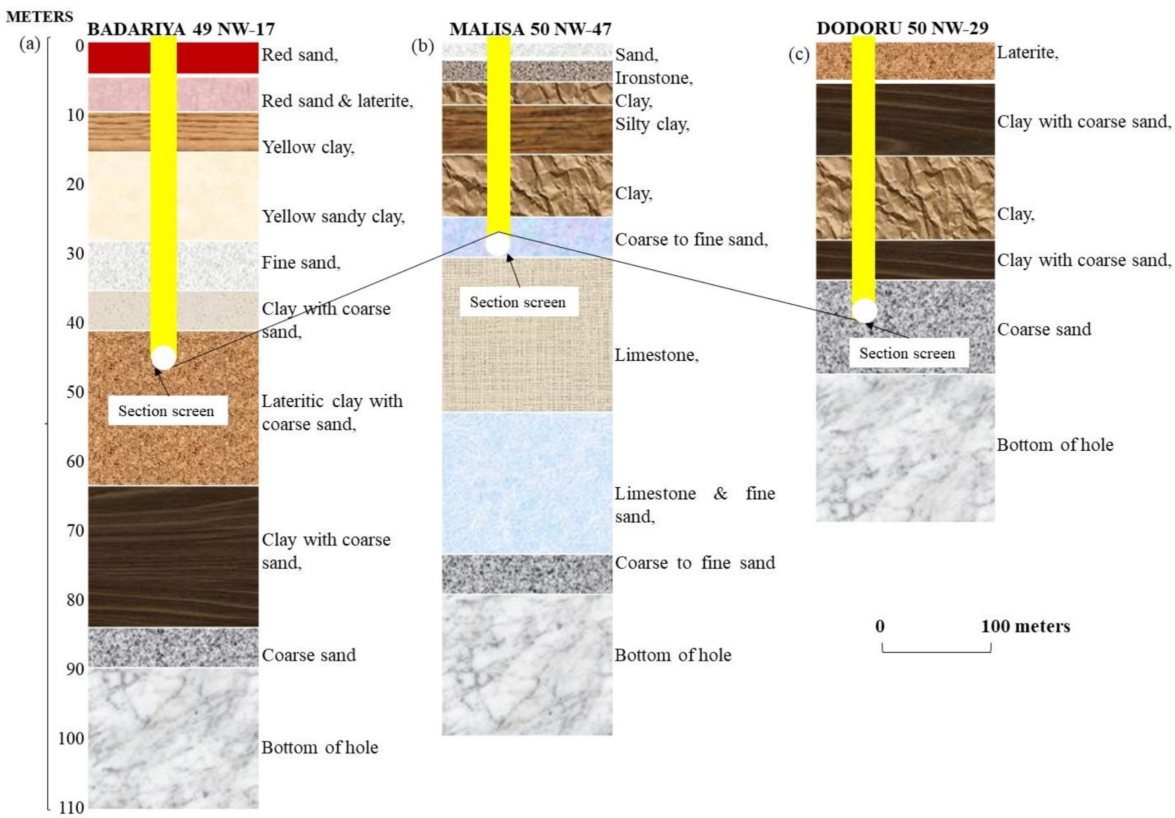

Figure 4: The type section of boreholes penetrating the Gwandu Formation (**a**) Badariya, (**b**) Malisa, and (**c**) Dodoru.

4.2. Kalambaina Formation

The Kalambaina limestone aquifer is probably best suited for developing small domestic supplies from dug wells and springs and for small-scale Irrigation from springs and spring-fed streams [32]. Should future water development in the Sokoto area deplete the Rima aquifer, some recharge from the Kalambaina could be induced by penetrating shafts or wells through the Dange Formation and allowing the suspended water to flow downwards. However, if proper measures for pollution control are not employed, the Kalambaina aquifer can be contaminated permanently. Fig. (**5**) shows the lithological section of boreholes penetrating the Kalambaina Formation.

Based on lithological features illustrated in Fig. (**5**), this formation could be said to be more or less an aquiclude or aquitard. It is of hydrogeological significance only as a confining layer capable of forming artesian conditions in the underlying aquifers [33]. The lower calcareous clay shales are extraordinarily continuous in lithology and depth in the formation over a large expanse. These lithological components hold considerable perched water, which feeds most of the hand-dug shallow wells, usually less than 19.7 meters deep (Fig. **5a**). The lithology showed the dominance of clay formations, as illustrated in Fig. (**5**). The borehole was screened at 45 meters. The Swl was 38.05 meters, Pwl was 40.22 metres, Pt was 15.0 (Lpm), and Ey was 250.0 (Lpm). The borehole was located in Kwannawa (Sokoto suburb). Fig. (**5b**) summarises the type section of the borehole at Gumara. The limestone occurred between 2-6 meters below the ground surface. The borehole was screened at 45 meters, and the Swl was 38.73 meters. Pwl was 46.30 meters, Pt was 50 (Lpm), and Ey was 170 (Lpm). The limestone formation was encountered 5-18 meters below the ground surface at Gwatsu (Fig. **5c**). The borehole was screened at 48 meters. Swl was 42.43 meters, Pwl was 50.27 meters, Pt was 33.0 (Lpm), and Ey was 90.0 (Lpm).

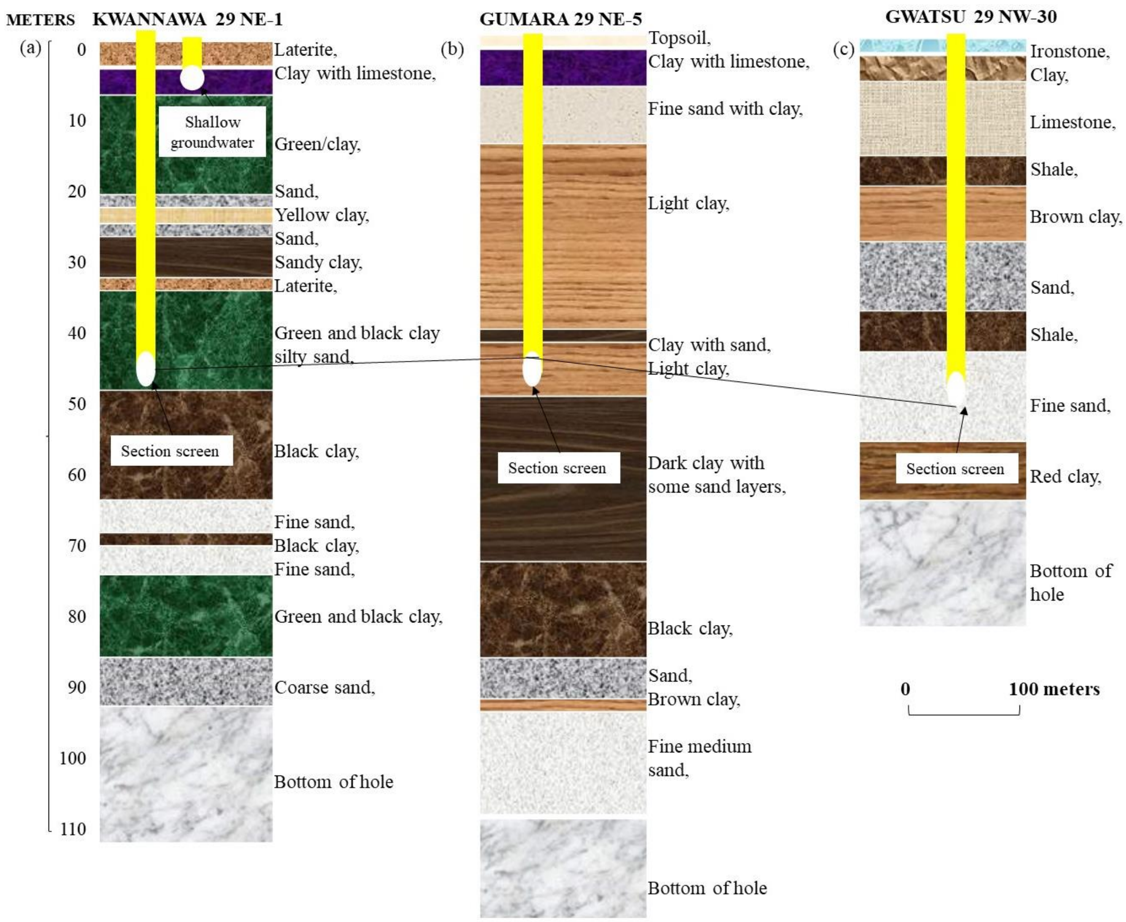

Figure 5: The type section of boreholes penetrating the Kalambaina Formation (**a**) Kwannawa, (**b**) Gumara, and (**c**) Gwatsu.

4.3. Taloka Formation

The type section of a borehole penetrating the Taloka Formation is illustrated in Fig. (**6**). Fig. (**6a**) summarises the type section of the borehole at Dogon Daji. The lithology (0-6 laterite, 6-20 white clay, 20-36 yellowish clay, 36-42 limestone, 42-97 clay with silt, 97-103 fine sand) showed a mixture of clay and sandy formations. The borehole was screened at 60.0 meters, Swl at 46.0 meters, Pwl at 28.0 meters, Pt at 28.0 (Lpm), and Ey at 70.0 (Lpm). At Birnin Mala, the Wsl was 71.19 meters, Pwl was 76.82 meters, Pt was 40 (lpm), and Ey was 75.0 (Lpm), as illustrated in Fig. (**6b**). The Ey was 130 (Lpm), and the well was screened at 75 meters. The lithology (0-2 ironstone, 2-6 lateritic clay, 6-12 shaley clay, 12-16 yellowish clay, 16-24 coarse sand with ironstone, 24-26 pinkish clay, 26-109 coarse sand) revealed a mixture of sands, iron sones, and clays).

The borehole (TAMAJE SE-2) is more water-yielding (>400 Lpm). It yielded more than 24000 litres per hour (Fig. **6c**). The lithology (0-6 laterite, 6-20 white clay, 20-36 yellowish clay, 36-42 limestone, 42-97 clay with silt, 97-103 fine sand) showed the dominance of clay formations. The borehole was screened at 60 meters, Swl was 53.05 meters, Pwl was 55.2 meters, Pt was 50 (Lpm), and Ey was >400 (Lpm). Borehole yield in the Taloka Formation is highly variable, with a shallow water table and steep drawdown (Table **2**). The recharge area is believed to be adjoining the frontier with the Gundumi Formation. Some aquifers are confined in places by clay members within the formation, giving rise to artesian and sub-artesian conditions [33].

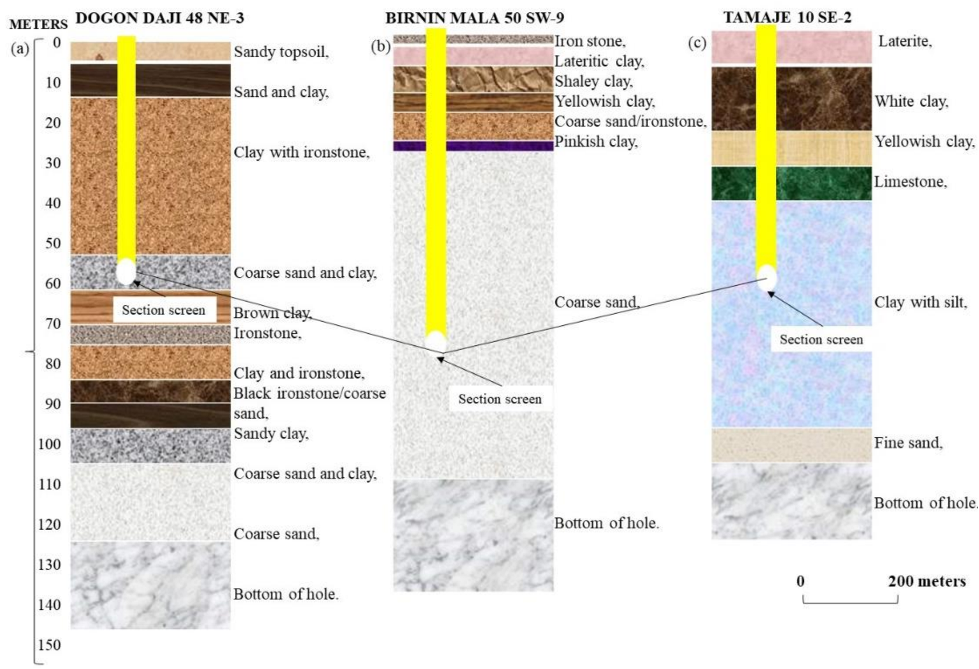

Figure 6: The type section of boreholes penetrating the Taloka Formation (**a**) Dogon daji, (**b**) Birnin Mala, and (**c**) Tamaje.

Table 2: Borehole yields in Taloka Formation.

Location	Estimated Yields
Dogon daji	1125 to 4500 litres per hour
Sokoto	3500 – 22500 litres/hr.
Kware	22300 litres/hr. drawdown 280m
Kware	41400 litres/hr. drawdown 235m
Waura	1400 – 2700 litres/hr
Illela Vet. Station.	4500 litres/hour drawdown 10m

After Offodile [33].

4.4. Wurno Formation

Fig. (**7**) summarises the type section of boreholes penetrating the Wurno Formation. The groundwater table is relatively shallow under the Wurno Formation. The type section at Tantarkwai (Fig. **7a**) showed clay dominance in the upper layers. Sandy formation occurred at the base of the borehole (0-6 laterite, 6-13 sandy clay, 13-125 clay with some silty layers, 125-136 sand). Despite the recorded depth, the borehole was screened at 18 meters. The Swl was 13.24 meters, Pwl was 23.73 meters, Pt was 82 (Lpm), and Ey was >400 (Lpm). The section screen was set at 6 meters at Awakala (Fig. **7b**), indicating a too-shallow aquifer. Sandy formations are apparent with clay intercalations (0-3 sand, 3-11 hard and clay, 11-26 sandy clay, 26-44 clay, 44-56 silty clay, 56-72 clay, 72-84 fine sand). The Swl was 1.45 meters, Pwl was 7.60 meters, Pt was 80 (Lpm), and Ey was >400 (Lpm). The groundwater table at Kudakuda is also shallow. The type section (0-6 fine sand, 6-16 coarse sand, 16-18 coarse sand with clay) primarily comprises sands. The borehole was screened 9 meters, Swl 5.83 meters, Pwl 6.89 meters, Pt 80 (Lpm), and Ey 250 (Lpm). The Wurno aquifer, like other aquifers in the basin, inclines to the northwest under the younger formations and has been run into as far north as Girawsi and Balle by the deep exploratory borehole of the Geological Survey of Nigeria (GSN BH No. 3053). Conversely, at Balle, about 80 kilometres northwest of Sokoto, the

Wurno Formation was encountered at 356 meters. Likewise, at Girawsi, 7.5 kilometres west of Sokoto, in GSN BH No. 3704, it was discovered 50 meters below the ground surface.

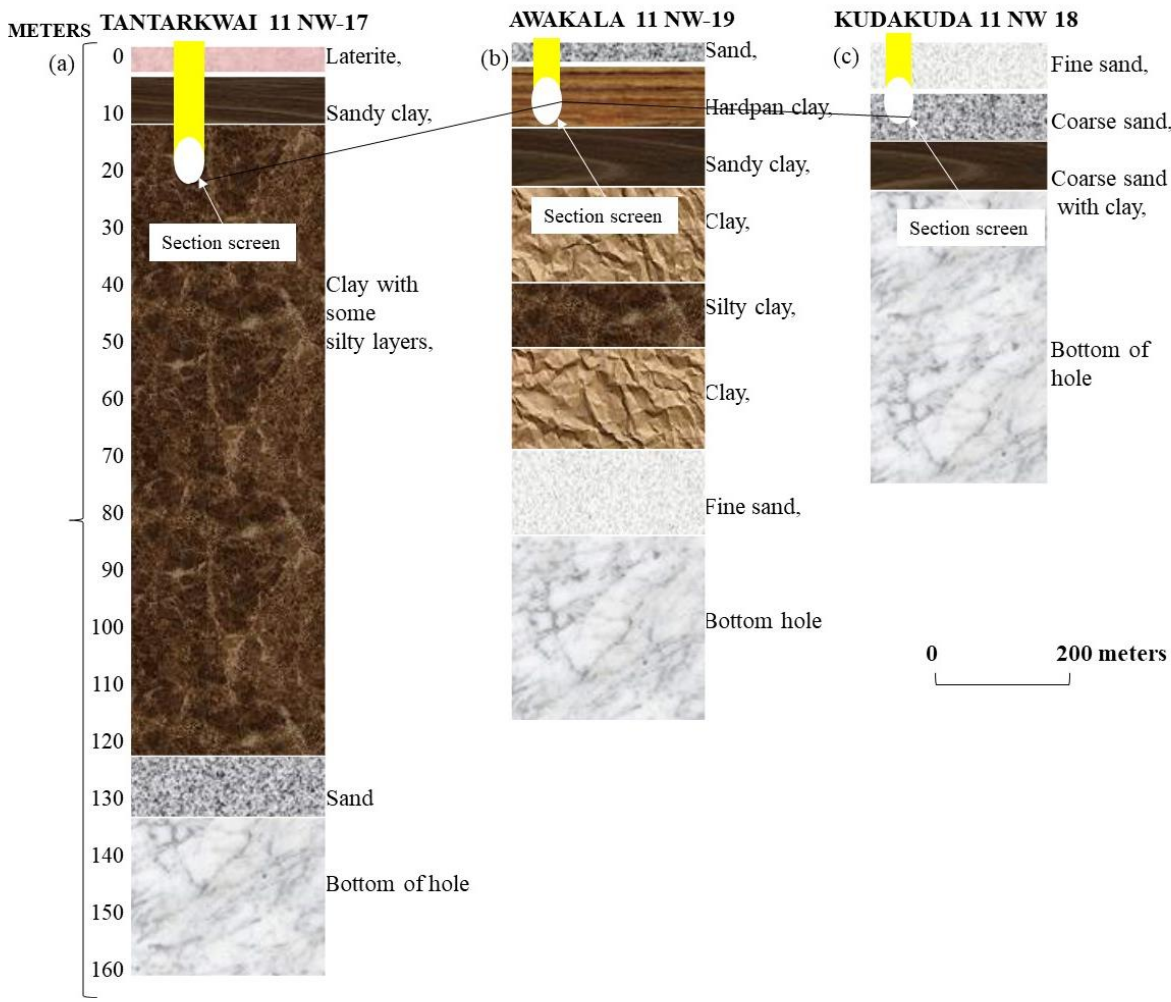

Figure 7: The type section of boreholes penetrating the Taloka Formation (**a**) Tantarkwai, (**b**) Awakala, and (**c**) Kudakuda.

Fig. (**8**) further shows the type section of Nigeria Geological Survey Boreholes (GSN. BH 3511 and GSN No. BH 3512), penetrating both Kalambaina and Wurno Formations: the borehole, GSN No. BH 3511(Fig. **8a**) penetrated the Wurno Formation along the Sokoto-Gusau road and yielded 233.33 lit/sec. The borehole screen was set between 66-81 meters. Just after Sokoto, at Dange, a borehole in the village seems to have passed through the overlying calcareous Kalambaina and the argillaceous Dange Formations (Fig. **8b**) into the older Wurno Formation. The well yielded about 4000 daily gallons (300 litres/sec). The screen was set between 200 and 205 meters. The water rose to 92 meters, indicating sub-artesian conditions [33].

4.5. Gundumi Formation

The type section of boreholes penetrating the Gundumi Formation is depicted in Fig. (**9a**-**c**). All three boreholes were located in Gundumi Town. The borehole (GUNDUMI 12 SW-1) has been screened at 36 meters. The Swl was 23.68, Pwl was 33.61.0 meters, Pt was 15.0 (Lpm), and Ey was 18.0 (Lpm). The formation log (0-6 laterite and ironstone, 6-12 laterite, ironstone with sand, 12-26 sand, 26-40 sandy clay with sand, 40-47 coarse sand) comprises laterite, ironstone, sand, and clay. The borehole (GUNDUMI 12 SW-2) had a relatively shallow groundwater table (Fig. **9b**). The formation log (0-6 sand and laterite, 6-24 coarse sand and clay, 24-36 sandy clay with coarse sand, 36-41 coarse sand, 41-42 clay) is comparable to GUNDUMI 12 SW-1. The screen was set at 24 meters, Swl was 20.66 meters, Pwl 23.45 meters, Pt was 42.0 (Lpm), and Ey was 140 (Lpm).

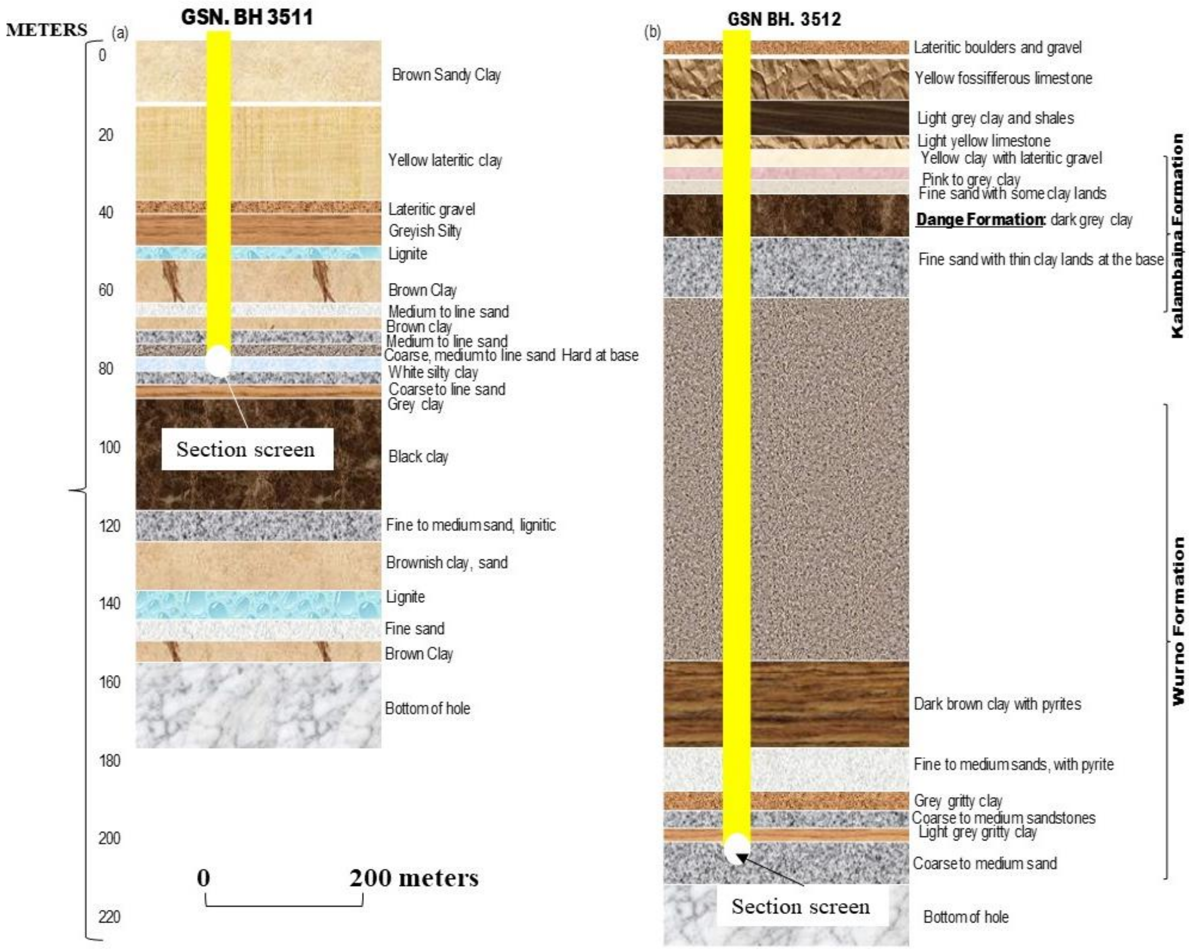

Figure 8: Lithologic section of boreholes penetrating Wurno Formation.

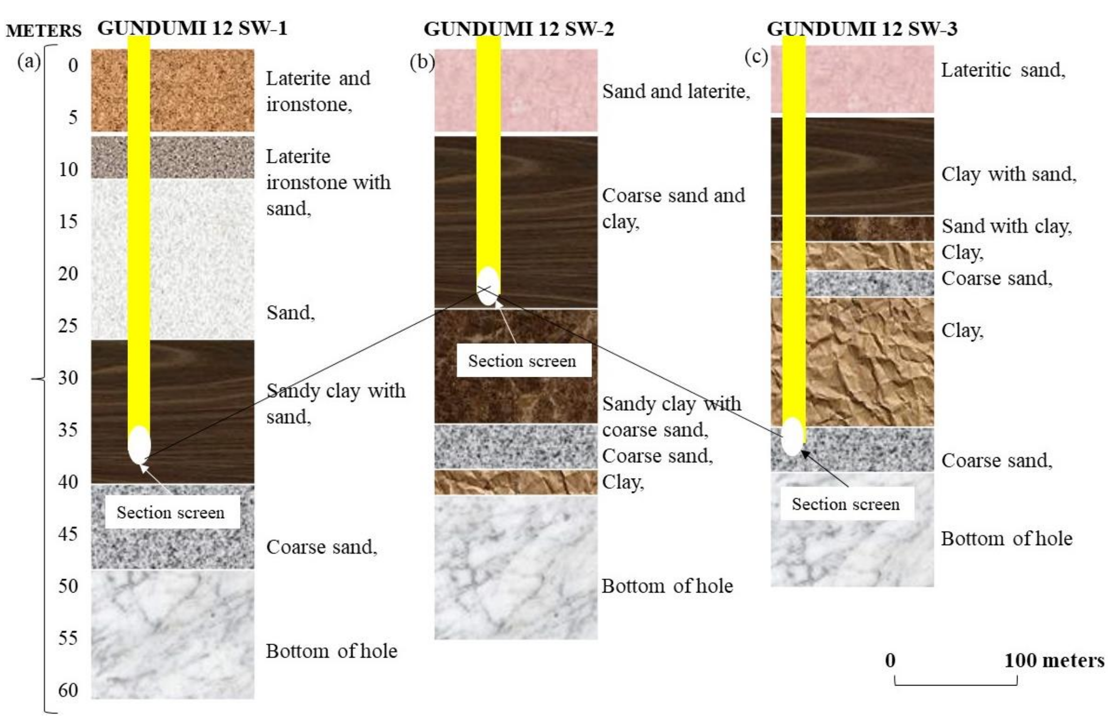

Figure 9: The type section of boreholes penetrating the Gundumi Formation at Gundumi Town.

In the borehole (GUNDUMI 12 SW-3), the section screen was set at 36 meters, Swl was 22.20 meters, Pwl was 29.31 meters, Pt was 15.0 (lpm), and Ey was 22 (lpm). The formation log (0-5 lateritic sand, 5-16 clay with sand, 16-18 sand with clay, 18-21 clay, 21-25 coarse sand, 25-36 clay, 36-42 coarse sand) was comparable to GUNDUMI 12 SW-2 and 3. The hydrogeological condition is highly variable, even under the same geological setting. This condition was concurrent with previous results [32, 33]. Along the Gusau-Sokoto road, many boreholes are screened in fine to coarse sand beds ranging from 4.57-30.58 meters deep, the profuse beds in the upper part of the Gundumi Formation [32]. Borehole GSN No. 3521, close to kilometre 167 along Gusau-Sokoto road, produced 6600 gph. In contrast, borehole GSN No. 3526, at 124 km, yielded about 1300 gph near the basement-rock contact. At Sabon Birni and Isa, boreholes GSN No. 3513 and 3514, correspondingly, marked off in gravel beds, which are very common in the Gundumi Formation in the northern portion of the Sokoto basin; transmissivities were generally low [32].

Boreholes tapping the Gundumi aquifer can give flowing water at lower elevations within the Sokoto region. In the River Sokoto floodplain (Fadama), exploratory borehole GSN 3704 at Girawsi poured 2500 gph with a pressure head of <6.55 meters from a 275.84-280.41 meters' depth. More yielding artesian aquifers overlie the Gundumi Formation in the western Sokoto basin [33]. However, with its boundless deepness and moderately low water-yielding capacity, the Gundumi aquifer is not attractive for groundwater development in the Sokoto basin. Fig. (**10**) shows the geohydrologic section through the NW and SE Sokoto basin, Northwestern Nigeria, indicating major aquifers and confining beds. Recharge into the Gundumi aquifer occurs, primarily on its outcrop zone, directly by infiltration from rainfall and seepage from rivers while in flooding during the rainy season. Groundwater in the Gundumi usually travels westward, then southward into the Illo Group; it finally discharges into the River Niger at the lower ranges of the River Sokoto system in the southern part of the Sokoto basin [32, 33]. The Gundumi Formation has more potential than the Illo Formation, though the latter has not been thoroughly investigated.

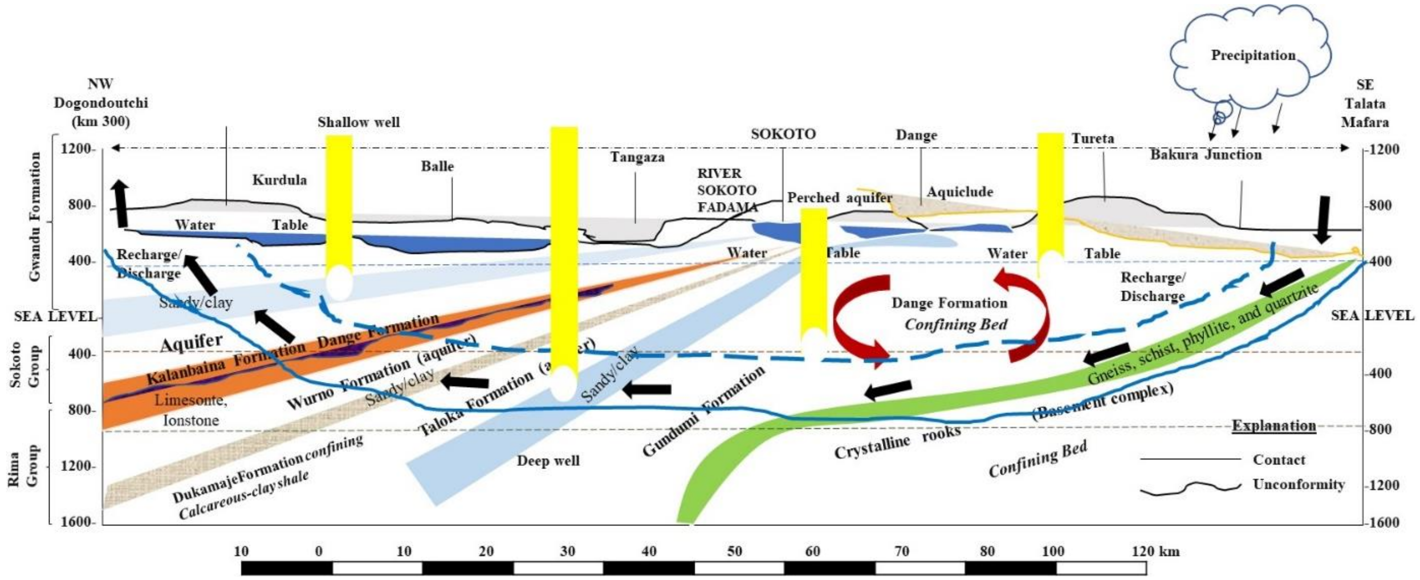

Figure 10: Geohydrologic section through the Northwestern and Southeastern Sokoto basin, Northwestern Nigeria, indicating major aquifers and confining beds.

4.6. Illo Formation

Fig. (**11a**-**c**) summarise the formation logs of boreholes piercing the Illo Formation at Illo Town. Sands' dominance is apparent and concurred with previous investigations [32, 33]. The borehole (ILLO 71 SW-4) was screened at 30 meters. The Swl was 16.9 meters, Pwl was 22.9 meters, Pt 21.0 (lpm) and Ey were 57.0 (lpm). The borehole (ILLO 71 SW-7) was equally screened at 30 meters and yielded more water (296 Lpm). The Swl was 13.0 meters, Pwl was 17.2 meters, and Pt was 56 (Lpm). The borehole (ILLO 71 SW-14) was screened at 27 meters. The Swl was 13.0 meters, Pwl was 17.2 meters, Pt was 36.0 (Lpm), and Ey was 40.0 (Lpm). Groundwater conditions varied even in the exact location. The variability of groundwater conditions was reported by previous studies [32, 33].

Exploration borehole, GSN No. 3704, at Girawsi, pierced through the Dange, Wurno, Dukamaje, and Taloka Formations, otherwise described as the Rima Group, and termination in the Gundumi Formation [33]. However, exploratory borehole GSN No. 3707 at Mungadi, the Illo, seemed to be hydraulically continuous with the artesian aquifer in the Rima Group at Birnin kebbi. The potentiometric analysis suggests that water moves south from the Rima aquifer into the Illo Group's aquifer, discharging into the lower reaches of the River Sokoto and the River Niger. About 32- 48 km west of River Rima towards the north of the zone where the confining bed of the Dange Formation is non-existent, it is likely also that even the Gwandu artesian aquifer is hydraulically continuous with the Rima-Illo aquifer [32].

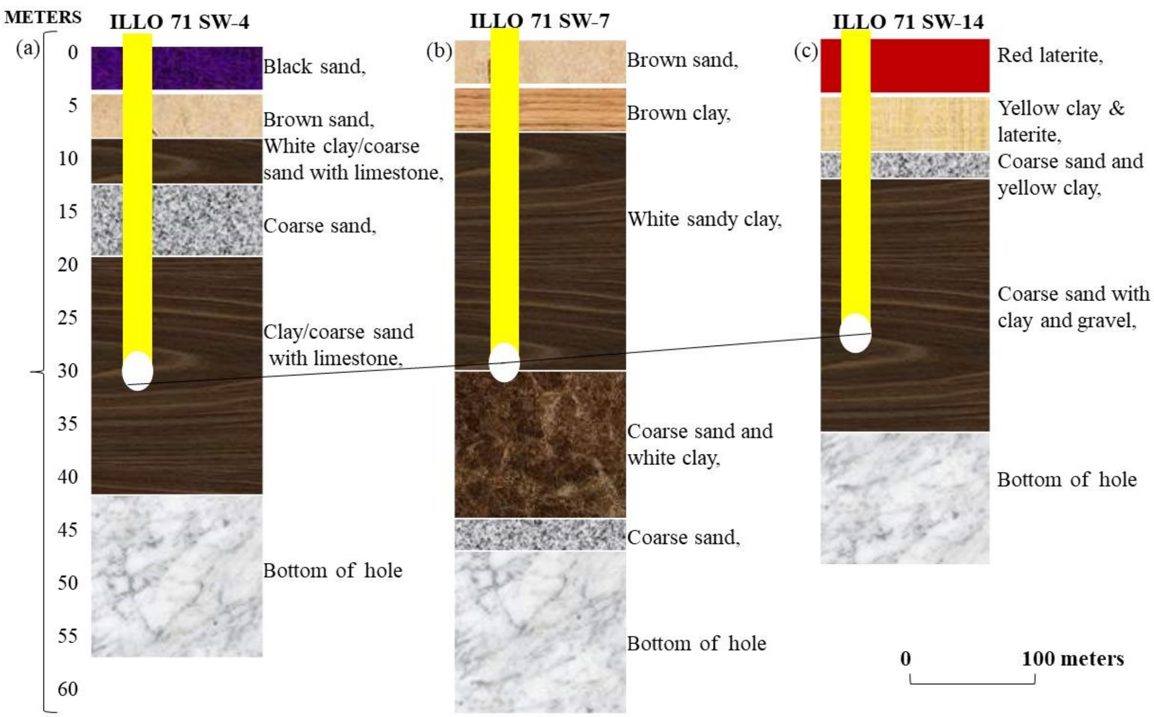

Figure 11: The type section of boreholes penetrating the Illo Formation at Illo Town.

Fig. (**12**) summarises the hydrogeological conditions of the sedimentary aquifers of the Sokoto basin. The groundwater conditions of the Sokoto basin are comparable to Nigeria's sedimentary aquifers. Hydrogeological analysis of 153 boreholes sited in southwestern Nigeria's sedimentary basin (Dahomey Basin) showed that the

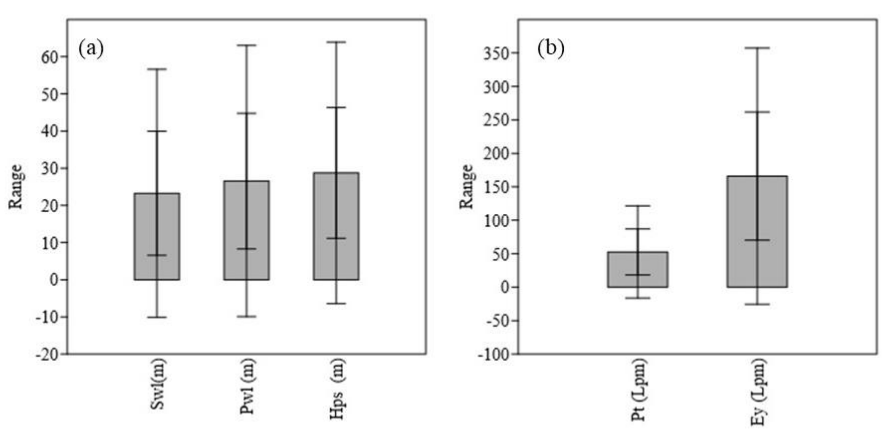

Figure 12: Box plot of hydrogeological variables.

groundwater occurred in five major sedimentary formations. The annual groundwater recharge was 1.55 x 109m^3 [78]. Similarly, high-yielding sandy aquifers were delineated in Southeastern Nigeria's sedimentary terrain [79]. The electrical resistivity curves over the sedimentary terrain of the Obaretin-Iyanomon area indicated enormous groundwater potential [80]. Interpretation of electrical resistivity over Nanka Sands (Anambra Basin) revealed high groundwater potentials [81]. Transmissivity values varying from 37.54 to 95.5 m^2/day and estimated borehole yields of about 5 litres per second were detected in the Ogwashi-Asaba Sedimentary Formation [82]. In the deltaic formation of the Niger Delta, Nigeria, the mean estimated yields of boreholes are greater (30056 lit/m) than values obtained from the Sokoto basin [83]. In the sedimentary terrain of Simawa, southwestern Nigeria, the mean borehole yield was 2820.0 Lpm [84]. The mean borehole yield in the Lower Niger Basin (Ilorin) was 81.0 Lpm [85]. Borehole yields varied from 28 to 44 Lpm in the regoliths aquifer of Kano, Northwestern Nigeria [86]. Similar conditions were reported from sedimentary aquifers within Africa and elsewhere worldwide.

4.7. Hydrogeological Conditions of Sokoto Basin Compared to other Basins

Groundwater load in Africa was valued to be 0.66 million km^2. Not all groundwater reservoirs can be harnessed, but the estimated volume is 100 times bigger than annual continental renewable freshwater resources. The natural distribution of groundwater is exceptionally capricious, and the utmost quantity is stored in the sedimentary aquifers of North Africa [87]. Borehole yields can sustain handpumps yielding 6.0 to 18.0 Lpm in most countries. These aquifers have sufficient groundwater to withstand withdrawals through inter-annual variations in recharge [87]. Regions having greater yields (more than 3060 Lpm) are limited. Comparison with other sedimentary basins in Africa showed that mean borehole yield in the Sokoto basin was greater than values obtained from the Voltaian sedimentary aquifers in Northern Ghana (0.3 to 72 5–1200 Lpm) [88]. In Ghana's alluvial province, the estimated borehole yield ranged from 1 to 15 m^3/h [89].

The Swl ranged from 3 to 19 meters within shallow alluvial aquifers of eastern Ethiopia. Estimated yields ranged from 42.0 to 180.0 Lpm [90]. The high-potential aquifers are the fluvial-lacustrine deposits and the rhyolites. Basalts underlie these in Sunuta Sub-Basin, Northeast Ethiopia. The estimated yields ran from 1320 to 4800 Lpm for domestic and Irrigation discharges [91]. In the Cretaceous and Tertiary aquifers of the Kalahari Basin, the calcareous sands and sandstones formed the principal aquifer with greater groundwater yields [92]. It is comparable to the Cretaceous and Tertiary aquifers of the semiarid Sokoto basin. In East Africa, the depths of water-bearing alluvial aquifers ranged from 50 to 150 meters. The projected borehole yields in eastern Kenya fluctuated from 1 to 5 m3 per hour [93]. Alluvial aquifers in the Mzingwane Catchment, Zimbabwe, have much groundwater storage. The projected groundwater potentials varied from 175000 to 5 430000 m^3. Such larger volumes of groundwater can support large irrigation schemes.

Outside Africa, in Cheju Volcanic Island, Korea, viable yields of about 0.66 billion m^3, built on water budget analysis, were projected in alluvial aquifers. It represents 41.6 % of annual recharge [94]. The oceanic sediments developed the most significant hydrogeologic frontiers and groundwater water incidence within the basin. In sedimentary aquifers of Northeastern Wasit Governorate, Iraq, the estimated yields of boreholes were relatively higher (4860 Lpm) despite the desert conditions [95]. Excellent groundwater potentials typify the global sedimentary aquifers. However, they are pressured by increased groundwater mining with its resultant consequences of lowering the water table and further depletion propelled by climate change and uncontrolled anthropological activities [96-103].

4.8. Statistical Modeling

4.8.1. CABFAC Factor Model

Factor analysis (FA) classifies hydrogeological data and portrays it in a way that fairly explicates the aspects of the data matrix that produced the perceived hydrogeological conditions [104-108]. Four factors were extracted to irradiate the relationship between hydrogeological variables (Table **3**). Factor 1 accounted for 86.490 % of the total variance and is anecdotally related to the estimated yield (Ey). Factor 1 had a high positive correlation (≥0.65) on Ey and correlated weakly with Pt. It correlated negatively with the remaining variables. Factor 2 explained 35.102 % of the total variance and is weakly correlated with all the variables. Factor 3 demonstrated that 4.593 %

of the total variance is weakly related to the Swl, Pwl, Ey, and Hps. It correlated negatively with Pt. Factor 4 explained that 0.655 % of the total variance connected significantly with Hps and Pwl. It is weakly correlated with Ey and negatively correlated with Swl and Pt.

Table 3: CABFAC factor analysis.

Variables	Factor 1	Factor 2	Factor 3	Factor 4
Swl	-0.114	-0.938	*0.340*	-1.986
Pt	0.130	-0.424	-2.184	-0.182
Pwl	-0.247	-1.339	0.206	*0.502*
Ey	2.203	-0.327	0.190	0.058
Hps	-0.236	-1.428	0.189	0.875
Eigenvalue	**259.470**	**35.102**	**4.593**	**0.655**
% variance	**86.490**	**11.700**	**1.530**	**0.220**

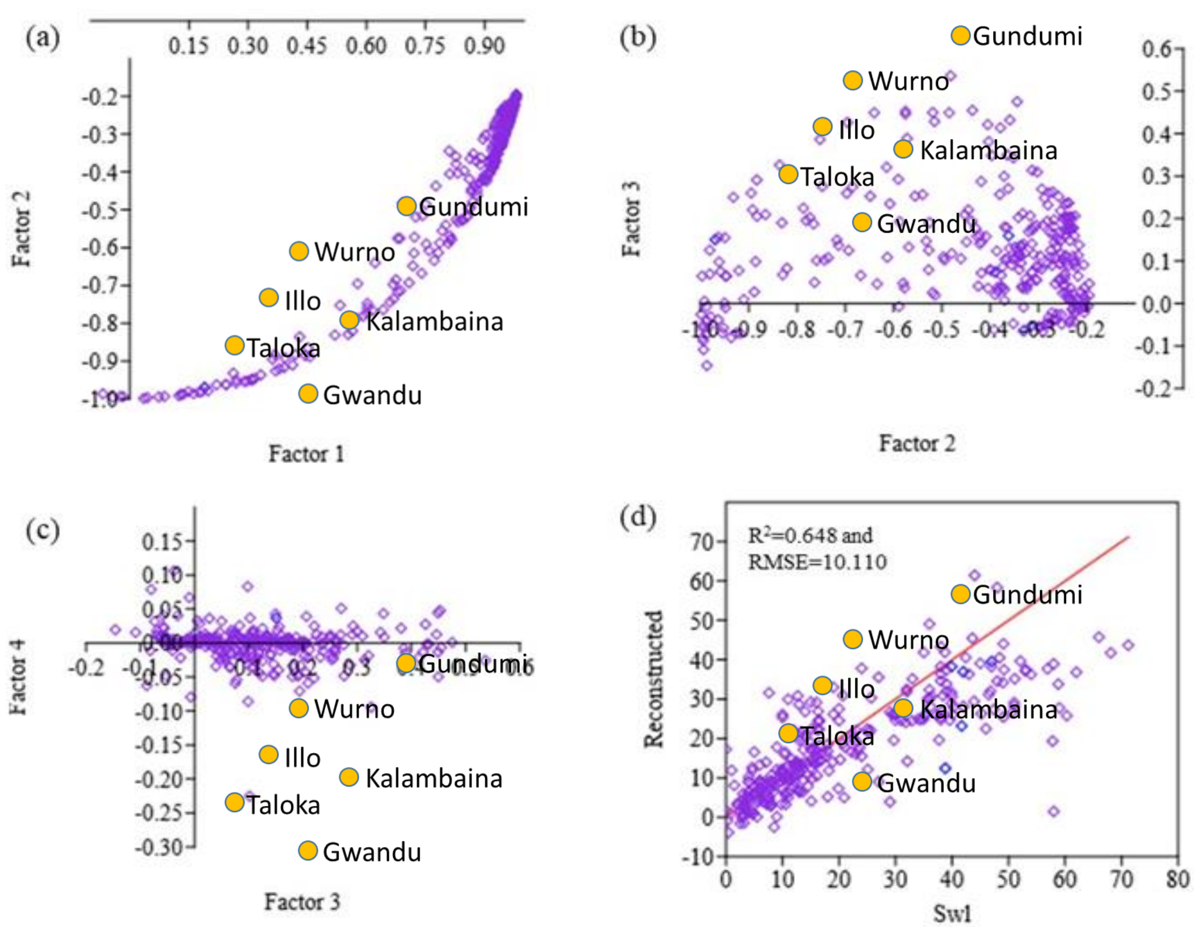

Figure 13: Scatter plots for extracted Factors (**a**) Factor 1 vs Factor 2, (**b**) Factor 2 vs Factor 3, (**c**) Factor 3 vs Factor 4, and (**d**) Reconstructed residual plots of the CABFAC Factor Model.

Fig. (**13**) presents a Biplots of the four factors. Negative correlations of factor loadings are noticeable (Fig. **13a**). There are more positive values in Factors 2 and 3 and Factors 3 and 4 (Fig. **13b**-**c**). Based on factor analysis, it can be inferred that all the variables, to some degree, have influenced groundwater variability in the study area. The scatter and reconstruction plots are depicted in Fig. (**13d**). Based on residual plots, the R^2=0.648 and RMSE=10.110.

As summarised in Fig. (**13d**), the model showed a high dispersity of Swl from the mean Swl. Various factors can account for the variation of Swl in boreholes. Boring tests in rock blocks exposed to predominant actual triaxial far-field pressures feigning real in situ settings often lead to poor local yields or collapse of boreholes and can cause borehole breakouts [109, 110].

This study has demonstrated how Factor Analysis (FA) can be used to examine the hydrological conditions of a particular basin. FA is a robust tool applied in hydrogeological studies. For instance, Liang [111] performed a comprehensive impact assessment of hydrogeological and land use properties on groundwater using multivariate analysis (i.e. Factor Analysis and Cluster Analysis). The study identified geological (i.e., seawater intrusion) and human activities (i.e., over-pumping), as depicted by Factor, as the foremost variables affecting groundwater availability in Taiwan. Using multivariate analysis by Kazakis *et al*. [106], groundwater assessment over different hydrological regimes revealed that the three factors derived from PCA aligned with geological influence. Hence, MA offers a user-friendly tool for hydrogeological analysis, especially in resource and data-poor environments.

4.8.2. Generalised Regression Model

Regression analysis is widely used in hydrogeological investigation to understand subsurface unit hydrogeologic and geohydraulic properties [112-115]. A general regression model was produced to identify the significant hydrogeological parameter(s) influencing the estimated yields of boreholes in the Sokoto basin. Estimated yields (Ey) were selected as a response variable, while the remaining 4 variables (Swl, Pwl, Pt, and Hps) are predictors. Ey is an excellent indicator of boreholes' overall productivity, which is influenced by other hydrogeological parameters. It provides estimates of borehole productivity [116-118]. Consequently, it enables a hydrogeologist or water engineer to make suitable water pumping decisions and the accompanying water uses.

Table 4: Coefficients.

S = 115.055 R-Sq = 44.94% R-Sq(adj) = 44.19%						
PRESS = 4210952 R-Sq(pred) = 40.63%						
Term	**Coef**	**SE Coef**	**T**	**P**	**95% CI**	**VIF**
Constant (Ey)	142.058	21.4451	6.6243	0.000	(99.8533, 184.263)	
Swl	7.400	1.1227	6.5912	0.000	(5.1905, 9.610)	7.5809
Pt	11.0014	2.337	0.2124	0.000	(1.9191, 2.755)	1.1201
Pwl	-9.010	1.3609	-6.6205	0.000	(-11.6882, -6.332)	13.9287
Hps	1.932	1.4560	1.3266	0.186	(-0.9339, 4.797)	14.2864

A significant relationship between Ey and certain hydrogeological variables is an indicator of boreholes' overall productivity, which can be an indicator of groundwater potential. Based on the coefficients: S = 115.055, R-Sq = 44.94%, and R-Sq (adj) = 44.19%. PRESS = 4210952, R-Sq (pred) = 40.63%. The P-value (<0.001) obtained, in addition to a high percentage R^2 (44.94%), indicated that the entire predictors are significant except Hps (Table **4**). It can be inferred that estimated yields from boreholes depend on aquifer properties in addition to these variables.

In the model summary (Table **5**), all four variables (predictors) are significant (P-value <0.001). The residual plots are summarised in Fig. (**14**). It is used to verify the hypothesis that residuals are normally distributed. The normal probability plot of the residuals approximately follows a straight line (Fig. **14a**). The overall P-value is <0.001. The observed relative normality in this analysis confirmed the model's accuracy. The hydrogeological variables with a P-value <0.001 are considered significant. Swl, Pwl, Pt, and Hps have P-value <0.001. In addition to geology, these variables represented the most critical parameters affecting the groundwater potentials in the study area. Also, it can be inferred that the variability of groundwater conditions is a product of the geological configurations in the Sokoto basin [32, 33, 37, 119] and elsewhere worldwide [120-123].

Table 5: Model summary.

Regression Equation: Ey = 142.058 + 7.40009 Swl + 2.33724 Pt - 9.00991 Pwl + 1.93155 Hps						
Source	**DF**	**Seq SS**	**Adj SS**	**MS**	**F**	**P**
Regression	4	1387244	1387244	796811	60.192	0.000
Swl	1	68566	575094	575094	43.443	0.000
Pt	1	2225181	1602184	1602184	121.032	0.000
Pwl	1	870198	580228	580228	43.831	0.000
Hps	1	23298	23298	23298	1.760	0.000
Error	295	3905132	3905132	13238		
Lack-of-Fit	294	3904332	3904332	13280	16.60	0.193713
Pure Error	1	800	800	800		
Total	**299**	**7092376**				

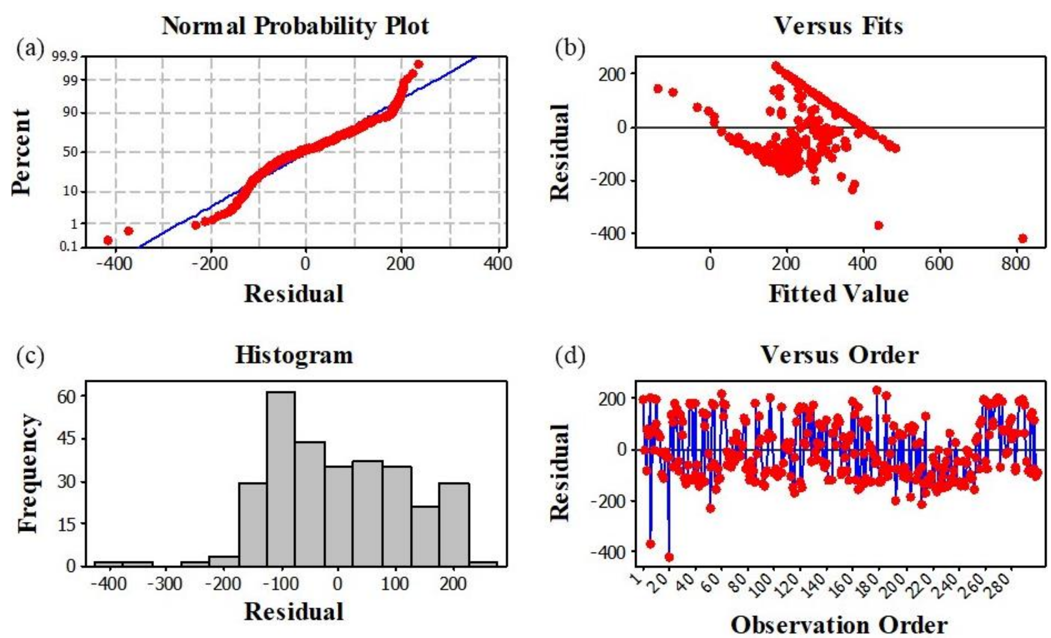

Figure 14: Residuals plot for Estimated yields.

4.9. Implications for Sustainable Groundwater Development

Although the annual groundwater use in the world is below 1000 km^3, it represents 1.5% of the renewable water resource and supports a more significant share of water-persuaded human welfare [124-128]. The overall groundwater usage has distended during the last five decades; man undoubtedly never needed to advance and handle groundwater usage at such a great scale. Sustainable economic development requires sustainable groundwater use [129]. It represents a global critical water development task [124, 130, 131]. While studying this task, there was considerable research concentrating on the factors controlling the occurrence of groundwater; there are fewer exertions on sustainable groundwater development and usage in arid and semiarid regions as a result of drops in precipitation (climate change) and population pressure with its sprawling climatic vagaries in addition to enlarged dry season farming and municipal supplies.

This study has revealed the hydrogeological details and groundwater potentials of the Sokoto basin. While variation in estimated yields has been spotted, the basin is consecrated with rich groundwater aquifers that can be exploited for different uses. Sustainable groundwater development is a startling environmental problem in semiarid regions [8, 132-134]. The comprehensive applications of these findings offer an unnerving task that has been raised in developing nations such as Nigeria. In these nations, dry season farming has evolved into enormous chaos, supporting hundreds of millions of rural livelihoods and consequently pressuring groundwater resources. The over-exploitation of aquifers is often trailed by exhaustion or lessening of groundwater storage. Hence, operative control measures must be applied to address evolving problems relating to groundwater depletion [5, 135, 136].

Sustainable groundwater development entails a better performance of irrigation projects in semiarid areas [137-140] and improved municipal supplies [141-143]. Communities depending on groundwater resources and natural ecological services must acclimate to climatic vicissitudes. Moreover, the dramatic fluctuations in expected global warming costs are anticipated to adversely affect income and livelihood resources in arid and semiarid areas [144-147]. Small groups have typically bent intensive groundwater development, and individual farmers often want public subsidies. It epitomises a silent social revolution. Since groundwater is a constrained resource, there is a need to evade unlimited access problems [148, 149].

Presently, there are no restrictions on groundwater development in the Sokoto basin. Therefore, water use policy is necessary to move towards the sustainable development of groundwater in the basin and elsewhere in global arid and semiarid regions. The exertion of dealing with a significant number of stakeholders at the basin scale necessitates an amalgamation of the local management institutions and government, regulations, stakeholders, and means, involvement, and co-responsibility [150-153]. It epitomises the challenge due to inadequate skill and the need to establish awareness, knowledge, and data on the significance of effectively managing an indispensable and vital universal asset. Joint stakeholder institutions assembled on the individualities of every local condition seem to be an essential component. Even under various economic and social settings, such as those predominant when groundwater development started, sustainable groundwater development is possible. It can be achieved using unified water resources development and management strategies, reflecting the uniqueness of semiarid eco-regions and suitable resolutions by all opposing interests.

5. Conclusion

The increasing groundwater mining consequence of increased irrigation farming, industrial and municipal demands, and the drying up of surface water in arid and semiarid regions (climate change) have led to more groundwater development. These, coupled with land-use changes (increased urban paved sources), resulting in reduced recharge, posed a threat to groundwater. While human activities can alter aquifers' hydrogeological conditions, understanding aquifers' natural potential is also essential. Sokoto basin represents the most irrigated region in Northwestern Nigeria. Thus, a detailed analysis of groundwater potentials is necessary. Results obtained from this analysis led to the following remarks:

i. Gwandu Formation is the most prolific aquifer. An estimated yield of up to 24000 litres per hour (L/h) can be obtained from a borehole.

ii. The Kalambaina limestone aquifer is best suited for developing small domestic supplies in Sokoto and surrounding villages. Boreholes can yield about 15000 (L/h).

iii. Poor aquifers characterise the Taloka Formation; however, Tamaje boreholes can yield more than 24000 (L/h). The aquifer is more prolific along the Jega-Dogon Daji axis.

iv. The Wurno Formation is a reasonable water-yielding aquifer. Over 24000 (L/h) can be obtained from boreholes.

v. The Gundumi Formation is also good water-yielding aquifer. Estimated yields from the borehole are less than 1500 (L/h). However, at Rabah, the Gundumi aquifer produces artesian flows of 60 to 500 gallons per hour (gph) from individual wells with pressure heads ranging from 0.3 to 3.65 meters above the ground surface.

vi. The Illo Formation is the southern lateral equivalent of the Gundumi Formation. The highest estimated yields were 17760 (L/h) at Illo town.

vii. The Dange Formation is aquiclude; thus, it needs no further analysis.

viii. Statistical modelling (CABFAC Factor Model and Generalized Regression Model) indicated that all the variables influenced groundwater potentials (i.e., estimated yields) in the study area to some degree.

ix. Consequently, the observed variability in groundwater potentials is a geological configuration of the Sokoto basin since all the analysed hydrogeological variables are statistically significant.

Even though the Sokoto basin has productive groundwater aquifers, the lack of control on groundwater development driven by increased irrigated agriculture, urbanisation, industrialisation, increased municipal water demands, and other water-related activities have presented a significant challenge to the sustainable development of groundwater resources. Therefore, a policy guideline to regulate groundwater development is required to ensure sustainable development and management of groundwater resources. Hence, this study will have both theoretical and practical implications.

5.1. Theoretical Implications

This study has shown how Multivariate Analysis (MA) and Regression Analysis (RA) can benefit hydrogeological analysis. Hence, findings will enrich the literature on how MA and RA can be employed for hydrogeological analysis. The specific implications are as follows:

i. Theoretically, this study lays the foundation for hydrogeological analysis using regression and multivariate statistical modelling with acceptable accuracy.

ii. This study's regression and multivariate analysis can be used to develop groundwater monitoring at the basin scale, especially in data-poor environments with associated cost reductions regarding hydrogeological analysis.

iii. Regression and multivariate analysis can further enrich the literature concerning a methodical approach to monitoring, evaluating, and managing hydrogeological variabilities, particularly in arid and semiarid regions. Consequently, the current result could have many practical implications.

5.2. Practical Implications

This study employed regression and multivariate statistical analysis to increase 8understnading of the hydrogeological conditions of Sokoto Basin, Northwestern Nigeria. The practical implications are as follows:

i. This study provides baseline data that could aid the detection of future variations regarding hydrogeological conditions of the Sokoto Basin.

ii. It will enable the classification of groundwater development projects or schemes and the identification of prolific aquifers for sustainable groundwater use.

iii. The study will offer policymakers the needed data for proper groundwater resource management planning.

iv. The current methodological approach could be used in similar data-poor regions where time series data is lacking to increase understanding of hydrological conditions of underlying aquifers and geological factors that could affect groundwater availability.

v. Lastly, current findings are expected to provide the basis for groundwater depletion through future estimation of borehole yields.

Therefore, future research concerning hydrogeological characteristics of basins, especially those in arid and semiarid regions, can adopt regression and multivariate analysis. These statistical tools offer a user-friendly method for researchers needing more precise results while considering multiple hydrogeological parameters.

Conflict of Interest

The authors declare that no competing interest(s) is associated with this article.

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Supplementary Material

The supplementary Table (**S1**) is available below to this article.

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Table S1. Hydrogeological Data of Sedimentary Section of Sokoto basin

S/no.	Location and Borehole Number	Casing and Screen	Si (m)	Swl(m)	Pt (Lpm)	Pwl (m)	Ey (Lpm)	Hps (m)
BN001	UNGUWAR HASSAN 48 SW-1	PVC and 0.50 mm wire	67.0-68.5	42	21	43	400	45
BN002	UNGUWAN DAMBO 48 SW-2	PVC and 0.50 mm wire	82.5-84.0	41.7	113	45.6	400	51
BN003	GUMKI 48 SW-3	PVC and 0.50 mm wire	60.5-62.0	38.8	31	55.1	29	54
BN004	GUMKI 48 SW-4	PVC and 0.50 mm wire	101.5-103.0	39.9	63	48.5	318	48
BN005	GUMKI 48 SW-5	PVC and 0.50 mm wire	131.5-133.0	35.2	100	41.6	400	42
BN006	ADAKAKA 48 NE-2	PVC and 0.50 mm wire	125.0-126.5	47	18	48	400	51
BN007	DOGON DAJI 48 NE-3	PVC and 0.50 mm wire	116.0-117.5	46	28	25	70	60
BN008	DOGON DAJI 48 NE-6	PVC and 0.50 mm wire	120.5-122.0	48	19	78	45	66
BN009	UNGUWAR MAIGUZAYE 48 NE-8	PVC and 0.50 mm wire	82.5-84.0	3	108	4	400	9
BN010	MARAKE (S.H.P.) 48 NE-17	PVC and 0.50 mm wire	103.5-105.0	56.9	60	58.7	400	63
BN011	UNGUWAN ALI 48 NE-18	PVC and 0.50 mm wire	64.5-66.0	22.4	23	24	400	30
BN012	RAFIN TSAKA (SHP) 48 NW-1	STEEL and 0.50 mm wire	90.0-91.5	46.5	90	51.9	400	54
BN013	RAYA 48 NW-2	STEEL and 0.50 mm wire	154.5-156.0	38	90	41.1	400	45
BN014	TUNGAR NOMA MADO 71 SW-1	PVC and 0.50 mm wire	27.0-30.0	3.9	113	5.3	400	12
BN015	BUMA 71 SW-2	PVC and 0.50 mm wire	30.0-33.0	4.7	27	15.2	45	18
BN016	BUMA 71 SW-3	PVC and 0.50 mm wire	26-5-29.5	4	56	12.1	109	12
BN017	GWAZANGE 28 SW-24	STEEL and 0.25 mm wire	72.5-74.0	7.2	120	9.2	400	15
BN018	TUNGAN NOMA 28 SW-25	STEEL and 0.25 mm wire	131.5-133.0	16.1	120	20.1	400	24
BN019	UNGUWAR DARAKWAI 28 SW-26	PVC and 0.50 mm wire	63.5-65.5	13	120	14.4	400	21
BN020	GWAZANGE 28 SW-29	STEEL and 0.25 mm wire	70.5-72.0	58	120	6.4	400	12
BN021	U/NOMA GYADA 28 SW-31	PVC and 0.50 mm wire	65.0-67.0	12	98	31.4	187	21
BN022	KUNKURU 28 SW-33	PVC and 0.50 mm wire	56.0-58.0	15.4	47	15.7	400	21
BN023	FULANIN KISAWA ELA 28 SW-34	PVC and 0.50 mm wire	51.0-53.0	13.1	60	13.9	400	21
BN024	ARGUNGU (FORESTRY II) 28 SW-35	PVC and 0.50 mm wire	54.5-56.0	13.6	150	18	400	19
BN025	BABBAR KADUBA 28 SW-5	STEEL and 0.25 mm wire	65.0-66.5	15	40	18	400	18
BN026	BABBAR KADUBA 29 SW-6	STEEL and 0.25 mm wire	65.0-66.5	15	44	17	400	18
BN027	BADARIYA 28 SW-7	STEEL and 0.25 mm wire	51.5-53.0	8	13	20	25	27
BN028	BADARIYA 28 SW-8	STEEL and 0.25 mm wire	57.5-59.0	6	12	22	22	27
BN029	BADARIYA 28 SW-9	STEEL and 0.25 mm wire	65.0-66.5	5	48	5	400	9
BN030	GIJIYA 28 SW-11	PVC and 0.50mm PVC	24.5-30.5	15	64	16	400	18
BN031	GIJIYA 28 SW-12	PVC and 0.50mm PVC	27.0-33.0	15	84	16	400	18
BN032	TUNGAR ALKASUN 28 SW-13	PVC and 0.50mm PVC	30.0-36.0	10	17	19	24	24
BN033	GARIN KARANGIYA 28 SW-14	PVC and 0.50mm PVC	27.0-33.0	12	15	17	25	21
BN034	KISAWA 28 SW-15	PVC and 0.50mm PVC	29.5-33.5	11	36	22	40	21
BN035	U/MALLAM HASSAN 28 SW-20	PVC and 0.50mm PVC	55.0-58.0	12.7	24	20.4	93	24
BN036	BANGAREJI 28 NW-2	PVC and 0.50 mm wire	54.0-60.0	11	30	12	400	15
BN037	JABAKA 28 NW-3	PVC and 0.50 mm wire	16.0-22.0	6	30	7	400	12
BN038	JABAKA 28 NW-4	PVC and 0.50 mm wire	19.0-22.0	8	30	8	400	12
BN039	JABAKA 28 NW-5	PVC and 0.50 mm wire	20.5-23.5	11	25	12	85	15

BN040	KWARKWARI 28 NW-6	PVC and 0.50 mm wire	32.5-35.5	5	30	5	400	9
BN041	TUBA KAINA 28 NW-7	PVC and 0.50 mm wire	17.0-20.0	4	35	6	120	9
BN042	TUBA KAINA 28 NW-8	PVC and 0.50 mm wire	17.5-20.5	4	37	6	160	9
BN043	TUBA KAINA 28 NW-9	PVC and 0.50 mm wire	15.5-18.5	4	35	10	48	12
BN044	ILLELAR AUGIE 28 NW-10	PVC and 0.50 mm wire	36.5-39.5	14	23	17	85	21
BN045	ILLELAR AUGIE 28 NW-11	STEEL and 0.15 mm wire	38.5-41.5	15	72	20	160	18
BN046	ILLELAR RAFI 28 NW-12	PVC and 0.50 mm wire	64.0-65.5	10	10	55	10	60
BN047	ILLELAR RAFI 28 NW-13	PVC and 0.50 mm wire	32.0-35.0	19	28	22	70	24
BN048	TUNGAR NOMA 28 NW-14	STEEL and 0.25 mm wire	68.0-70.0	2	70	3	400	6
BN049	HAKIMAWA 27 SW-31	STEEL and 0.25 mm wire	137.5-139.0	16.6	20	22.1	306	27
BN050	ZAMAWA 27 SW-32	STEEL and 0.25 mm wire	34.5-36.0	16.4	28	18.6	192	24
BN051	ZAMAWA 27 SW-33	STEEL and 0.25 mm wire	34.5-36.0	16.3	28	19	135	24
BN052	BAGGA 27 SW-36	PVC and 0.50 mm PVC	117.5-119.0	20.9	100	23.3	141	27
BN053	DAFASI 28 NE-6	PVC and 0.50 mm PVC	32.5-35.5	16	30	16	400	18
BN054	DAFASI 28 NE-7	PVC and 0.50 mm PVC	32.5-35.5	14	30	14	400	18
BN055	YAKURUTU 28 NE-9	PVC and 0.50 mm PVC	14.5-16.0	4	108	10	300	9
BN056	KAURAR SANI (SHP) 27 SE-37	PVC and 0.50 mm PVC	9.5-12.5	2.1	30	6.8	33	9
BN057	UNGUWAR RAFI 27 SW-1	STEEL and 0.25 mm wire	72.5-74.0	24	20	29	95	33
BN058	KUKADU 27 SW-8	STEEL and 0.25 mm wire	49.0-50.5	24	30	32	50	33
BN059	KUKADU 27 SW-9	STEEL and 0.25 mm wire	44.5-46.0	23	15	31	25	36
BN060	UNGUWAN CHADI 27 SW-27	STEEL and 0.25 mm wire	150.0-151.5	9.8	18	13.1	400	21
BN061	DANGONGORA 27 SW-28	STEEL and 0.25 mm wire	172.0-173.5	16.4	47	17	400	24
BN062	TUNGAR TASHA 27 SW-29	STEEL and 0.25 mm wire	151.5-153.0	15	129	41.9	400	24
BN063	GIGANE 27 SW-30	STEEL and 0.25 mm wire	131.5-133.0	9.9	38	12.5	400	18
BN064	UNGUWAR FANDO 27 SE-15	STEEL and 0.50 mm wire	67.5-69.0	6.6	120	9.1	400	12
BN065	UMARA SABON GARI 27 SE-16	STEEL and 0.50 mm wire	62.5-64.0	5.5	135	6.4	400	12
BN066	GWAGWARE 27 SE-17	STEEL and 0.50 mm wire	65.5-67.0	4.9	120	5.8	400	12
BN067	GWABARAE 27 SE-18	PVC and 0.50 mm wire	34.0-36.0	0.4	135	1.6	400	12
BN068	GOTOMO DIKKO 27 SE-19	PVC and 0.50 mm wire	50.0-52.0	7.1	72	14.4	296	15
BN069	GOTOMO DIKKO 27 SE-20	PVC and 0.50 mm wire	46.0-48.0	0.2	120	2.4	400	6
BN070	UNGUWAR SHEHU 27 SE-24	PVC and 0.50 mm wire	39.0-41.0	2.8	135	5.4	400	9
BN071	ALWASA (SHP) 27 SE-30	PVC and 0.50 mm wire	58.0-60.0	2.5	108	6.9	400	9
BN072	MAINI KAINA 27 SE-31	STEEL and 0.25 mm wire	92.5-94.0	7.6	90	32.1	219	18
BN073	MABAWA 27 SE-32	PVC and 0.50 mm wire	15.5-17.0	3.1	120	4.3	400	9
BN074	MABAWA 27 SE-33	PVC and 0.50 mm wire	15.5-17.0	3.5	108	6	363	9
BN075	ZAZZAGAWA FULANI 27 SE-34	STEEL and 0.50 mm wire	135.0-136.5	45.2	100	46.8	400	51
BN076	ZAZZAGAWA FULANI 27 SE-35	STEEL and 0.50 mm wire	140.5-142.0	47.4	90	47.9	400	54
BN077	TUNGAN AMADU 27 SE-36	STEEL and 0.50 mm wire	87.0-88.5	4.6	30	10.4	302	15
BN078	JADADI 26 SE-1	STEEL and 0.50 mm wire	173.5-175.0	54	64	58	400	63
BN079	JADADI 26 SE-2	STEEL and 0.50 mm wire	83.0-84.5	58	54	68	130	63
BN080	UNGUWAN BARO 26 SE-3	STEEL and 0.50 mm wire	64.5-66.0	32	11	47	24	48
BN081	UNGUWAN KANTA 26 SE-4	STEEL and 0.50 mm wire	52.5-54.0	39	10	43	38	45

BN082	UNGUWAN KANTA 26 SE-5	STEEL and 0.50 mm wire	58.5-60.0	38	10	43	40	45
BN083	FAWANGU 26 SE-6	STEEL and 0.50 mm wire	93.0-94.5	59	6	76	11	78
BN084	TUNGAN RAFI 9 SW-5	STEEL and 0.50 mm wire	76.5-78.0	11	13	17	58	21
BN085	TUNGAN RAFI 9 SW-6	PVC and 0.50 mm PVC	32.5-35.5	20	9	26	13	33
BN086	TUNGAN TUDU 9 SW-7	PVC and 0.50 mm PVC	35.0-39.0	13	27	13	400	18
BN087	TUNGAN TUDU 9 SW-8	PVC and 0.50 mm PVC	31.5-33.0	13	85	16	315	18
BN088	DIBONI 9 SW-11	PVC and 0.50 mm PVC	88.0-89.5	12.9	25	54.4	32	48
BN089	MULGU 26 SE-14	STEEL and 0.50 mm wire	149.5-151.0	39.6	90	40.2	400	45
BN090	MULGU 26 SE-15	STEEL and 0.50 mm wire	155.5-157.0	38	90	40.3	400	45
BN091	SHALWAI 26 SE-16	STEEL and 0.50 mm wire	73.5-75.0	60.3	53	63.9	134	69
BN092	SHALWAI 26 SE-17	STEEL and 0.50 mm wire	74.5-76.0	57.8	30	64.7	51	69
BN093	KORONGA GOGA 26 SE-18	STEEL and 0.50 mm wire	64.5-66.0	31.8	69	44.1	128	42
BN094	KORANGENGOGA 26 SE-7	STEEL and 0.50 mm wire	64.5-66.0	35	19	37	115	42
BN095	SABON GARIERI 26 SE-8	STEEL and 0.50 mm wire	136.5-138.0	44	13	67	50	60
BN096	KANGIWA (FASCO) 26 SE-9	STEEL and 0.50 mm wire	143.5-145.0	49.1	24	78.4	56	72
BN097	UNGUWAN CHUNA 26 SE-10	STEEL and 0.50 mm wire	136.0-137.5	30.5	20	32.3	400	39
BN098	FAWANGU 26 SE-11	STEEL and 0.50 mm wire	167.5-169.0	58.8	82	60.5	400	66
BN099	UNGUWAN KALGO 26 SE-13	STEEL and 0.50 mm wire	84.0-85.5	0	60	12.6	239	9
BN100	FULANI SARKA 27 NE-1	STEEL and 0.50 mm wire	95.5-97.0	53	15	62	45	63
BN101	FULANI SARKA 27 NE-2	STEEL and 0.50 mm wire	91.0-93.0	48	12	60	26	60
BN102	UNGUWAR SALIHU 27 NE-3	STEEL and 0.50 mm wire	77.5-79.0	40	25	47	65	48
BN103	TUNGAR MALAM MANU 27 NE-4	STEEL and 0.50 mm wire	58.0-59.5	32	22	39	55	39
BN104	TUNGAR MALAM MANU 27 NE-5	STEEL and 0.50 mm wire	49.0-50.5	30	12	43	13	48
BN105	KATANGAR AREWA 27 NE-6	STEEL and 0.50 mm wire	43.0-44.5	10	19	20	35	24
BN106	KATANGAR AREWA 27 NE-7	STEEL and 0.50 mm wire	41.0-42.5	10	38	11	400	15
BN107	DAN MARKE 26 SW-1	STEEL and 0.50 mm wire	49.5-51.0	36	25	38	145	39
BN108	GORUM GORA	STEEL and 0.50 mm wire	142.0-143.5	29.7	113	34	400	36
BN109	LAILABA (FASCO) 27 NE-15	STEEL and 0.50 mm wire	113.5-115.0	12.1	98	13.8	400	18
BN110	LAILABA (SHP) 27 NE-16	STEEL and 0.50 mm wire	106.0-107.5	7.6	108	9.4	400	15
BN111	BANIDAI 27 NE-18	STEEL and 0.50 mm wire	87.0-88.5	0.9	120	5.1	400	9
BN112	GYARSHE 27 NE-19	PVC and 0.50 mm wire	43.0-45.0	11.9	90	24.4	157	21
BN113	UNGUWAN LADAN 27 NE-20	STEEL and 0.50 mm wire	80.5-82.0	3.4	108	7.9	400	12
BN114	FAKARA GURUZA 27 NE-21	PVC and 0.50 mm wire	46.5-48.5	32.1	47	37.8	83	42
BN115	ZABARMAMA 27 NE-8	STEEL and 0.50 mm wire	32.5-34.0	29	30	32	30	33
BN116	ZABARMAMA 27 NE-9	STEEL and 0.50 mm wire	40.0-41.5	27	30	29	185	33
BN117	BAGUNI 27 NE-10	PVC and 0.50 mm wire	32.5-35.5	6	38	7	340	9
BN118	BAGUNI 27 NE-11	PVC and 0.50 mm wire	32.5-35.5	6	38	7	380	9
BN119	BAGUNI 27 NE-12	PVC and 0.50 mm wire	32.5-35.5	5	38	6	400	9
BN120	TUNGAR KIMBA 27 NE-13	PVC and 0.50 mm wire	44.5-47.5	30	24	33	65	36
BN121	TUNGAR ALLE 27 NE-14	PVC and 0.50 mm wire	46.0-48.0	27	70	38	80	33
BN122	KATAN. ZABARMAWA 27 NE-29	PVC and 0.50 mm wire	20.5-22.5	6.8	35	8.1	256	15

BN123	KATAN. ZABARMAWA 27 NE-30	PVC and 0.50 mm wire	21.5-23.5	5.5	34	5.8	400	12
BN124	ASAUKAKA GORU 27 NE-22	STEEL and 0.50 mm wire	125.0-126.5	3.5	108	7.4	400	12
BN125	SARKA TSAKA 27 NE-23	STEEL and 0.50 mm wire	80.5-82.0	43.9	83	47.2	400	51
BN126	SHAFA ZANE 27 NE-24	STEEL and 0.50 mm wire	116.5-118.0	16.5	25	21.7	332	27
BN127	FULANI KOKOSHE 27 NE-25	STEEL and 0.50 mm wire	136.0-137.5	33	20	37.8	302	45
BN128	KATANGA AREWA 27 NE-26	PVC and 0.50 mm wire	22.0-24.0	10.3	27	11.6	170	18
BN129	ZAGABU 27 NE-27	STEEL and 0.50 mm wire	149.5-151.0	9.4	34	10.9	400	18
BN130	ZAGABU 27 NE-28	PVC and 0.50 mm wire	46.0-48.0	22.5	28	23.2	400	30
BN131	MASAMA GOJE 27 NW-8	STEEL and 0.50 mm wire	84.5-86.0	66	47	68	260	72
BN132	U/ NOMA NAMAIWA 27 NW-9	STEEL and 0.50 mm wire	107.5-109.0	51	100	55.1	400	60
BN133	UNGUWAN SAINI 27 NW-10	STEEL and 0.50 mm wire	106.5-108.0	50.7	19	71.2	36	78
BN134	UNGUWAN SHAMAKI 27 NW-11	STEEL and 0.50 mm wire	130.5-132.0	68.1	69	72.2	400	75
BN135	KUKA BAKWAI JODI 27 NW-12	STEEL and 0.50 mm wire	105.0-106.5	49.1	25	78.4	33	78
BN136	DUKKI BABANI 27 NW-13	STEEL and 0.50 mm wire	92.5-94.0	46.8	83	53.3	400	57
BN137	DUKKI BABA 27 NW-1	STEEL and 0.50 mm wire	85.5-87.0	39	12	55	20	54
BN138	DUKKI BABA 27 NW-2	STEEL and 0.50 mm wire	83.0-84.5	39	14	52	28	51
BN139	AWASHAKA 27 NW-3	STEEL and 0.50 mm wire	80.5-82.0	38	35	39	350	42
BN140	AWASHAKA 27 NW-4	STEEL and 0.50 mm wire	79.5-81.0	42	8	58	12	60
BN141	SABON SARA GAIKA 27 NW-5	STEEL and 0.50 mm wire	80.5-82.0	51	20	58	44	60
BN142	KUKOKI 27 NW-6	STEEL and 0.50 mm wire	90.5-92.0	62	15	67	48	69
BN143	MARINA 27 NW-7	STEEL and 0.50 mm wire	75.5-77.0	49	20	54	52	54
BN144	GIRIN KAMZO 27 NW-21	STEEL and 0.50 mm wire	81.5-83.0	32.9	100	40.1	400	42
BN145	TUNGAN TOSITO 27 NW-22	STEEL and 0.50 mm wire	100.5-102.0	52.1	69	59.1	340	60
BN146	ALJANNA 27 NW-23	STEEL and 0.50 mm wire	100.5-102.0	48.4	69	57.6	275	57
BN147	UNGUWAN NAMATA 27 NW-14	STEEL and 0.50 mm wire	210.0-211.5	34.5	63	35.3	400	42
BN148	SABON GARI MAIKALI 27 NW-15	STEEL and 0.50 mm wire	122.5-124.0	49.2	75	57.3	400	57
BN149	SABON GARI MAIKAL 27 NW-16	STEEL and 0.50 mm wire	95.0-96.5	51.1	63	54.9	400	60
BN150	TUNGAN GOGE 27 NW-17	STEEL and 0.50 mm wire	68.0-69.5	37.7	43	48.7	84	51
BN151	DADIN KOWA 27 NW-18	STEEL and 0.50 mm wire	74.0-75.5	40.3	14	55.8	21	66
BN152	U/ MIYAKI RINDIMA 27 NW-19	STEEL and 0.50 mm wire	62.5-64.0	40.1	90	43.3	400	48
BN153	UNGUWAR NOMA GANJI27 NW-20	STEEL and 0.50 mm wire	98.0-99.5	43.6	33	52.8	137	54
BN154	TUNGAR MARINA 27 SE-8	STEEL and 0.50 mm wire	58.5-60.0	6	108	8	400	9
BN155	BANGOLA 27 SE-9	PVC and 0.50 mm wire	27.5-29.5	8	80	12	220	12
BN156	BANGOLA 27 SE-19	PVC and 0.50 mm wire	27.5-29.5	10	80	17	160	15
BN157	TUNGAR MARINA 27 SE-11	STEEL and 0.50 mm wire	51.5-53.0	8	108	12	400	12
BN158	TUNGAR MAIDAWA 27 SE-12	STEEL and 0.50 mm wire	51.5-53.0	2	90	4	400	6
BN159	UNGUWAR MALI 27 SE-14	STEEL and 0.50 mm wire	49.5-52.0	12.6	26	13	400	18
BN160	INDIRE 27 SE-1	PVC and 0.50 mm wire	37.0-41.0	1	15	23	17	27
BN161	INDIRE 27 SE-3	STEEL and 0.50 mm wire	41.5-43.0	0	51	1	400	6
BN162	T/ DAN DARE KOKWASHI 27 SE-4	STEEL and 0.50 mm wire	22.0-23.5	6	35	15	44	15
BN163	T/ DAN DARE KOKWASHI 27 SE-5	P.V.C. and 0.50 mm wire	15.0-18.0	3	40	4	400	6
BN164	TUNGAR RAIRAI 27 SE-6	PVC and 0.50 mm wire	13.0-16.0	3	38	6	62	9

BN165	TUNGAR RAIRAI 27 SE-7	PVC and 0.50 mm wire	12.5-15.5	3	35	7	55	9
BN166	GESHERO 71 SE-24	PVC and 0.50 mm wire	37.5-39.5	14.4	56	16.7	395	30
BN167	T/ BATURE GATAWINI 71 SE-25	PVC and 0.50 mm wire	34.5-40.5	19.9	23	27.4	31	33
BN168	KURU KURU 71 SE-26	PVC and 0.50 mm wire	21.5-24.0	14.5	113	15.3	400	21
BN169	ILLO 71 SW-4	PVC and 0.50 mm wire	36.0-39.0	16.9	21	22.9	57	30
BN170	GIRIS 71 SW-5	PVC and 0.50 mm wire	41.5-47.5	7.9	60	9.6	400	30
BN171	GIRIS 71 SW-6	PVC and 0.50 mm wire	42.0-48.0	7.6	53	10.3	400	27
BN172	ILLO 71 SW-7	PVC and 0.50 mm wire	44.5-47.5	13	56	17.2	296	30
BN173	TONDI 71 SW-8	PVC and 0.50 mm wire	38.0-40.0	20.2	36	27.5	62	30
BN174	TUNGAR BAGE 71 SW-9	PVC and 0.50 mm wire	42.0-48.0	12.2	39	15.5	244	27
BN175	TUNGAR BAGE 71 SW-10	PVC and 0.50 mm wire	45.5-51.5	10.4	90	17.6	305	27
BN176	TUNGAR FATI 71 SW-11	PVC and 0.50 mm wire	41.5-47.5	9.6	39	14.5	176	27
BN177	LOLO 71 SW-12	PVC and 0.50 mm wire	39.0-42.0	13.2	18	33.5	16	36
BN178	SARFU 71 SW-13	PVC and 0.50 mm wire	50.0-53.0	11.6	18	16.4	400	24
BN179	ILLO 71 SW-14	PVC and 0.50 mm wire	30.0-33.0	15.1	36	24.6	40	27
BN180	LANI 72 SE-5	PVC and 0.50 mm wire	21.0-27.0	14	20	15	75	21
BN181	LANI 72 SE-6	PVC and 0.50 mm wire	21.0-27.0	16	17	17	70	21
BN182	LANI 72 SE-7	PVC and 0.50 mm wire	35.0-41.0	9	16	11	100	18
BN183	DAN NIKI 72 SE-8	PVC and 0.50 mm wire	35.5-41.5	19	20	20	140	24
BN184	RAFIN TSA 72 SE-9	PVC and 0.50 mm wire	47.5-53.5	36	14	36	400	39
BN185	KUMBOGO 72 SE-10	PVC and 0.50 mm wire	29.0-35.0	11	40	12	360	15
BN186	KUMBOGO 72 SE-11	PVC and 0.50 mm wire	29.0-35.0	10	24	13	80	15
BN187	TUNGA ILLO DADA 72 SE-12	P.V.C. and 0.50 mm wire	46.0-48.5	21	91	25	320	27
BN188	TUNGAN LALLE 72 SE-13	PVC and 0.50 mm wire	37.0-39.0	11	109	17	280	15
BN189	KENDE (S.H.P.) 72 SE-14	PVC and 0.50 mm wire	25.5-28.0	3.2	82	4.1	400	24
BN190	DADA GABBAS 72 SE-15	PVC and 0.50 mm wire	33.5-35.5	10.6	60	12.3	400	30
BN191	DADA GABBAS 72 SE-16	PVC and 0.50 mm wire	28.5-30.5	7	64	9.4	400	24
BN192	DADA GABBAS 72 SE-17	PVC and 0.50 mm wire	30.0-32.0	12.7	56	15.7	74	24
BN193	LANI (S.H.P.) 72 SE-18	PVC and 0.50 mm wire	46.0-48.0	15.2	45	22.1	140	27
BN194	LANI BIRNI 72 SE-19	PVC and 0.50 mm wire	30.5-32.5	7.9	75	9.2	400	27
BN195	GARANDA 72 SE-20	PVC and 0.50 mm wire	33.5-35.5	7.9	75	10	400	27
BN196	TUNGAR ILLO 72 SE-21	PVC and 0.50 mm wire	54.0-56.0	25.7	35	32.1	110	36
BN197	MAINAKANTA 72 SE-22	PVC and 0.50 mm wire	27.5-29.5	4.7	75	6.1	400	24
BN198	SHIBA 72 SE-23	PVC and 0.50 mm wire	33.5-35.5	12.5	33	16.8	113	27
BN199	SHIBA 72 SE-24	PVC and 0.50 mm wire	30.0-32.0	8.5	43	12.1	183	27
BN200	KURUGU 72 SW-2	PVC and 0.50 mm wire	18.0-24.0	12	35	13	115	15
BN201	MAI SOKOTO 72 SW-3	PVC and 0.50 mm wire	20.0-23.0	3	72	6	210	15
BN202	SHARABI 72 SW-4	PVC and 0.50 mm wire	32.5-35.5	11	72	12	400	15
BN203	SHARABI 72 SW-5	PVC and 0.50 mm wire	32.5-35.5	9	72	7	160	15
BN204	SABON GARIN ZAGGA 72 SW-6	P.V.C. and 0.50 mm wire	33.5-35.5	6	72	8	400	12
BN205	SABON GARIN ZAGGA 72 SW-7	P.V.C. and 0.50 mm wire	33.5-35.5	6	80	8	400	12

BN206	ZAGGA (SHP) 72 SW-15	PVC and 0.50 mm wire	27.5-29.5	5	75	7.1	400	12
BN207	KWASARA 72 SW-16	PVC and 0.50 mm wire	33.5-36.0	13.7	53	19	140	33
BN208	KWASARA 72 SW-17	PVC and 0.50 mm wire	32.5-36.0	9.8	90	12.3	400	33
BN209	KWASARA 72 SW-18	PVC and 0.50 mm wire	33.5-36.0	10.4	60	15.4	194	33
BN210	TUNGAR DAKA 72 SW-19	PVC and 0.50 mm wire	27.5-29.5	3.2	100	4.6	400	9
BN211	TUNGAR DANIYA 72 SW-21	PVC and 0.50 mm wire	19.5-22.5	8.5	113	13.8	162	15
BN212	DOGON DAJI 94 NE-1	PVC and 0.50 mm wire	38.5-41.5	12	21	27	26	27
BN213	TUNGAR ARAWA 94 NE-2	PVC and 0.50 mm wire	26.0-32.0	12.9	24	18.8	37	24
BN214	KANGIWA 94 NW-1	PVC and 0.50 mm wire	28.5-31.5	11	50	12	400	18
BN215	BANI 94 NW-2	PVC and 0.50 mm wire	19.5-23.5	18	17	19	18	21
BN216	SAMBE 94 NW-3	PVC and 0.50 mm wire	43.0-49.0	20	35	26	75	27
BN217	SANJI 94 NW-4	PVC and 0.50 mm wire	20.5-23.5	12	50	14	125	18
BN218	GIDAN ZANA 94 NW-5	PVC and 0.50 mm wire	24.0-30.0	9.9	56	13.2	168	18
BN219	T/ MALLAM MAISHANU 94 NW-6	PVC and 0.50 mm wire	32.0-34.0	6.7	38	12.8	110	27
BN220	TUNGAR ALHAJI 94 NW-7	PVC and 0.50 mm wire	31.5-37.0	12.3	56	15.3	251	27
BN221	TUNGAR GWAYA 94 NW-8	PVC and 0.50 mm wire	75.0-78.0	39.9	11	59.3	14	72
BN222	KANGIWA 94 NW-9	STEEL and 0.50 mm wire	24.5-32.0	11.8	41	17.9	60	21
BN223	TUNGAR GONI 94 NW-10	PVC and 0.50 mm wire	19.0-25.0	12.7	22	16.9	23	24
BN224	TUNGAR GONI 94 NW-11	PVC and 0.50 mm wire	23.5-29.5	10.5	36	12.6	156	18
BN225	TUNGAR GUBI 94 NW-12	PVC and 0.50 mm wire	29.0-33.0	16.3	43	18	235	18
BN226	T/ MAIYARA KALI 94 NW-13	PVC and 0.50 mm wire	41.5-47.5	25.1	30	31.4	55	36
BN227	TUNGAR ANNASHAWA 94 NW-14	PVC and 0.50 mm wire	40.5-46.5	13.7	39	22.3	84	27
BN228	T/ TAFANNA T/SABO 94 NW-15	PVC and 0.50 mm wire	41.5-47.5	16.1	39	20.8	140	27
BN229	SEIN KABAKA 94 NW-16	PVC and 0.50 mm wire	24.0-30.0	16.9	36	19.2	78	24
BN230	BALA LANGU 94 NW-17	PVC and 0.50 mm wire	16.0-19.0	8.7	69	10	260	15
BN231	RUNTUWA MAMAGA 94 NW-18	PVC and 0.50 mm wire	26.5-29.5	16	60	17.6	278	24
BN232	SAMBA 94 NW-19	PVC and 0.50 mm wire	23.0-26.0	9.5	47	16.5	66	18
BN233	WAGA WAGA 94 NW-20	PVC and 0.50 mm wire	32.5-35.5	15.2	75	17.1	400	30
BN234	SANBI 94 NW-21	PVC and 0.50 mm wire	43.5-46.5	25	21	28.6	75	36
BN235	BULALANGU II 94 NW-22	STEEL and 0.50 mm wire	35.0-41.0	10.6	150	13.7	400	18
BN236	SANGI 94 NW-23	PVC and 0.50 mm wire	25.5-28.5	15.6	40	18.1	109	24
BN237	BANI 94 NW-24	PVC and 0.50 mm wire	43.0-46.0	18	60	21.4	311	30
BN238	DARANNNA 94 SE-1	PVC and 0.50 mm wire	40.0-46.0	13	50	16	200	18
BN239	BAKIN RUWA 94 SE-3	PVC and 0.50 mm wire	26.0-29.0	18.2	14	23.8	14	24
BN240	BAKIN RUWA 94 SE-3	PVC and 0.50 mm wire	30.0-36.0	17.7	30	20.5	93	30
BN241	NEW MAJE 94 SE-4	PVC and 0.50 mm wire	27.0-33.0	15.7	28	19.9	54	24
BN242	OLD MAJE 94 SE-5	PVC and 0.50 mm wire	29.0-33.0	14.4	32	18.2	86	27
BN243	TUNGAR SAMAILA 94 SW-1	PVC and 0.50 mm wire	35.0-41.0	16	64	19.4	252	30
BN244	TSAMIYA 94 SW-2	PVC and 0.50 mm wire	25.0-28.0	11.1	56	15.5	124	24
BN245	GWAMBA 95 NW-2	PVC and 0.50 mm wire	27.5-30.5	11	23	29	20	30
BN246	KALIEL 95 NW-3	P.V.C. and 0.50 mm wire	27.0-30.0	4	72	6	300	9
BN247	KALIEL 95 NW-4	PVC and 0.50 mm wire	23.0-26.0	4	72	7	280	9

BN248	KALIEL 95 NW-5	P.V.C. and 0.50 mm wire	21.5-24.5	5	17	8	60	12
BN249	BAHINDI 95 NW-6	PVC and 0.50 mm wire	32.0-34.0	9	47	22	58	18
BN250	BAHINDI 95 NW-7	PVC and 0.50 mm wire	28.0-30.0	8	90	13	204	12
BN251	BAKKI DOMA 95 NW-8	PVC and 0.50 mm wire	34.0-36.0	4.6	69	10.5	109	12
BN252	BAKKI DOMA 95 NW-9	PVC and 0.50 mm wire	14.0-17.0	3.1	75	5.1	281	9
BN253	BARGAWA 95 NW-10	PVC and 0.50 mm wire	27.5-30.0	2.5	82	4	400	24
BN254	ILLELA 95 NW-11	PVC and 0.50 mm wire	27.5-29.5	3.7	75	7	379	24
BN255	FARDA 95 NW-12	PVC and 0.50 mm wire	27.5-29.5	5.6	64	10.1	218	24
BN256	KASHIN GIWA 95 NW-13	PVC and 0.50 mm wire	24.0-26.0	3.9	69	6.3	400	12
BN257	TUNGAR GURUZA 96 NW-14	PVC and 0.50 mm wire	22.5-25.5	4.9	60	6.3	400	12
BN258	MALISA 50 NW-48	PVC and 0.50 mm wire	67.5-69.5	29.4	21	30.2	400	36
BN259	MALISA 50 NW-49	PVC and 0.50 mm wire	49.0-51.0	30	21	30.3	400	36
BN260	TAKARI FULANI HAUSA 50 NW-50	PVC and 0.50 mm wire	36.5-42.5	16.6	15	35.6	11	39
BN261	TAKARI FULANI HAUSA 50 NW-51	PVC and 0.50 mm wire	34.5-36.5	23.3	90	25.9	277	30
BN262	KOCI 50 NW-52	PVC and 0.50 mm wire	14.0-17.0	6.1	30	6.2	400	12
BN263	RAMBUKI 50 NW-53	PVC and 0.50 mm wire	45.0-47.0	18.9	83	20.6	400	27
BN264	RAMBUKI 50 NW-54	PVC and 0.50 mm wire	47.0-49.0	25.6	23	25.8	400	33
BN265	ILLELA MADADI 50 NW-55	STEEL and 0.25 mm wire	60.5-63.5	39.9	60	41.8	400	48
BN266	ILLELA MADADI 50 NW-56	STEEL and 0.25 mm wire	60.5-62.0	38.1	60	38.4	400	45
BN267	KWASGARA 50 NW-59	PVC and 0.50 mm wire	44.5-46.5	25.2	23	25.4	400	33
BN268	GORKOMODO 50 NW-14	PVC and 0.50 mm wire	32.0-35.0	18	20	18	400	21
BN269	GORKOMODO 50 NW-15	PVC and 0.50 mm wire	32.0-35.0	23	18	23	400	27
BN270	KALBANGO 50 NW-16	PVC and 0.50 mm wire	50.0-53.0	47	18	47	400	51
BN271	DAN MAIGIRO 50 NW-21	PVC and 0.50 mm wire	18.0-21.0	13	25	13	150	18
BN272	DAN MAIGIRO 50 NW-22	PVC and 0.50 mm wire	22.0-25.0	8	25	8	400	12
BN273	DODORU 50 NW-28	PVC and 0.50 mm wire	46.0-48.0	34	72	35	400	39
BN274	DODORU 50 NW-29	PVC and 0.50 mm wire	45.5-47.5	35	72	35	400	39
BN275	YOLE BIRNI 50 NW-30	PVC and 0.50 mm wire	46.5-48.0	29	72	32	288	33
BN276	YOLE BIRNI 50 NW-31	PVC and 0.50 mm wire	46.5-48.0	31	72	32	310	36
BN277	GUREL 50 NW-32	PVC and 0.50 mm wire	38.0-40.0	23	78	25	400	27
BN278	BADARIYA 49 NW-16	STEEL and 0.25 mm wire	100.5-102.0	38.4	77	44.4	400	45
BN279	BADARIYA 49 NW-17	STEEL and 0.25 mm wire	87.0-88.5	36.2	57	39.1	400	45
BN280	GORU 49 NW-18	STEEL and 0.25 mm wire	95.0-96.5	11.2	98	14.2	400	18
BN281	BADARIYA 49 NW-52	STEEL and 0.25 mm wire	84.0-85.5	37.3	83	40.5	400	45
BN282	DANGA 50 NE-11	STEEL and 0.25 mm wire	94.5-96.0	38	20	49	52	48
BN283	SABON BIRNI 50 NE-16	STEEL and 0.25 mm wire	72.5-74.0	45	43	50	140	51
BN284	SABON BIRNI 50 NE-17	STEEL and 0.25 mm wire	72.5-74.0	43	50	45	330	48
BN285	MARUDA 50 NE-19	PVC and 0.50 mm wire	45.0-47.0	29.9	21	30.1	400	36
BN286	MARUDA 50 NE-21	PVC and 0.50 mm wire	51.0-53.0	36.4	19	36.5	400	42
BN287	MARUDA 50 NE-22	PVC and 0.50 mm wire	45.0-47.0	35.7	19	36	400	42
BN288	NAMAN GOMA 50 NE-25	PVC and 0.50 mm wire	46.0-48.0	36	18	36.1	400	42

BN289	BAKANYADIYA	PVC and 0.50 mm wire	40.5-42.5	20.7	27	20.9	400	27
BN290	KWANNAWA 29 NE-1	STEEL and 0.25 mm wire	75-76.5	38.05	15	40.22	250	45
BN291	GUMARA 29 NE-4	STEEL and 0.25 mm wire	99.100.5	38.73	50	46.3	170	45
BN292	GWATSU 29 NW-30	STEEL and 0.25 mm wire	57-58.5	42.43	33	50.27	90	48
BN293	BIRNIN MALA 50 SW-9	STEEL and 0.25 mm wire	106.9-108	71.19	40	76.82	130	75
BN294	TAMAJE 10 SE-2	STEEL and 0.25 mm wire	101-102.5	53.05	50	55.2	400	60
BN295	TANTARKWAI 11 NW-17	STEEL and 0.25 mm wire	127-128.5	13.24	82	23.73	400	18
BN296	KUDAKUDA 11 N.W. 18	STEEL and 0.25 mm wire	12.-18	5.83	80	6.89	250	9
BN297	AWAKALA 11 NW-19	STEEL and 0.25 mm wire	79.5-81	1.45	80	7.6	400	6
BN298	GUNDUMI 12 SW-1	PVC and 0.50 mm wire	40.5-46.5	23.68	15	33.61	18	36
BN299	GUNDUMI 12 SW-2	PVC and 0.50 mm wire	38-41	20.66	42	23.45	140	24
BN300	GUNDUMI 12 SW-3	PVC and 0.50 mm wire	39.5-41.5	22.2	15	29.31	22	36

Note: Si= Screen interval, Swl= Static water level, Pwl = Pumping water level, Pt= Pumping test, Ey Estimated yield, Hps= Handpump setting. M=meters and Lpm= litres per minute.