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(Research Article)

Application of borehole data for groundwater flow modeling of the shallow Benin Formation in Adeje, Egbeleku and Effurun in Delta State

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Abstract

Groundwater modeling is an important tool for determining the optimal groundwater management strategies. The extensive use of groundwater in urban and semi-urban areas makes it useful for monitoring groundwater levels. It is critical for water resource management to estimate the direction of groundwater flow using readily available information. The goal of this study is to investigate the direction of groundwater flow within the study region using the finite difference-based numerical model MODFLOW. MODFLOW is graphical user interface software developed by the United States Geological Society (USGS). It is commercial software that is popular among hydrogeologists due to its user-friendly features. The program is primarily used to simulate groundwater flow and pollutant transfer under various situations. This study aims to examine the diversity of its uses in groundwater modeling. Agriculture, airfields, constructed wetlands, climate change, drought studies, Environmental Impact Assessment (EIA), landfills, mining operations, river and flood plain monitoring, salt water intrusion, soil profile surveys, watershed analyses, and other areas have reportedly used the software till date. The study will provide light on the extent of groundwater modeling and research tools. The Groundwater Modelling System (GMS) software was used to create a conceptual model. Four (4) wells data and well-logs were utilized to model groundwater flow direction. The model was calibrated in steady state for Adeje and Egbeleku in Okpe LGA and Effurun in Uvwie LGA. The model shows that groundwater flows from the northernmost section of the research area; Adeje and Egbeleku Area, to the research study's southernmost region; Effurun Area. This is identified because higher heads tend to form in the north, while lower heads tend to appear in the model's southern sections.

Keywords: GROUNDWATER; MODELING; MODFLOW; RECHARGE

1. Introduction

Water is necessary for both human and animal existence, and it is critical to our survival and well-being. Groundwater supplies 96% of the world's fresh water resources for residential, industrial, and agricultural usage. Because of the difficulties of accessing it once polluted, it becomes tough to rehabilitate.

Groundwater is an essential natural water resource that provides potable water to millions of people in most regions of Nigeria, particularly Delta State. However, its quality is determined not only by natural factors such as aquifer lithology, groundwater velocity, recharge water quality, and interaction with other types of water or aquifers; but also by human activities, which can alter these fragile systems, either by polluting them or modifying the hydrological cycle, to such an extent that groundwater use becomes very important to study (Helena et al, 2000).

Groundwater may flow both vertically and horizontally (Ophori 2007). Groundwater flow may be described and simulated using models. Groundwater Modeling System (GMS) is a finite difference software application that visualizes

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groundwater flow and incorporates several modules, including Modular Finite-Difference Flow (MODFLOW) and Modular Three-Dimensional Transport (MT3DMS).

1.1. Groundwater Occurrence

Groundwater is water that exists in the pore spaces and fractures in rocks and sediments beneath the Earth's surface. Groundwater makes up about 1% of the water on the Earth (most water is in oceans). Groundwater makes up to 35 times the amount of water in lakes and streams. Groundwater occurs everywhere beneath the Earth's surface, but is usually restricted to depth less than about 750 meters. Groundwater is a renewable resource. Adequate time is needed to allow replenishment of underlying groundwater reservoirs (aquifers); also, such areas must be properly managed in order to prevent water-soluble waste products stored in these areas from infiltrating and polluting the underground supply. The hydrological cycle is the most fundamental principle of groundwater hydrology.

There are basically four types of geological formations in relation to groundwater; (i) Aquifers (ii) Aquitard (iii) Aquiclude (iv) Aquifuge

1.1.1. Aquifers:

An aquifer is a groundwater reservoir composed of geologic units that are saturated with water and sufficiently permeable to yield water in a usable quantity to wells and springs. Examples: Sand and gravel deposits, sandstone, limestone, and fractured crystalline rocks. The amount of water a material can hold depends upon its porosity. However, only groundwater storage that exists in connected pores/ openings/ fractures is accessible for use.

Aquifers provide two important functions, which are; they transmit ground water from areas of recharge to areas of discharge; and they provide a storage medium for useable quantities of groundwater. Generally, there are two types of aquifers: Unconfined and confined aquifers. Aquifers are also referred to as Groundwater Reservoir or Water Bearing Formation (Todd et al 2005).

1.1.2. Aquitard:

An aquitard is a partly permeable geologic formation. It transmits water at such a slow rate that the yield is insufficient. Pumping by wells is not possible. For example, sand lenses in a clay formation will form an aquitard.

1.1.3. Aquiclude:

An aquiclude is composed of rock or sediment that acts as a barrier to groundwater flow. Aquicludes are made up of low porosity and low permeability rock/sediment such as shale or clay. Aquicludes have normally good storage capacity but low transmitting capacity.

1.1.4. Aquifuge:

An aquifuge is a geologic formation which doesn't have interconnected pores.

1.2. Groundwater Flow

Some of the precipitation that falls onto the land infiltrates into the ground to become groundwater. If the water meets the water table (below which the soil is saturated), it can move both vertically and horizontally. Water moving downward can also meet more dense and water-resistant non-porous rock and soil, which causes it to flow in a more horizontal fashion, generally towards streams, the ocean, or deeper into the ground.

If groundwater wants to be a member in good standing of the water cycle, then it can't be totally static and stay where it is. As Figure 1 shows, the direction and speed of groundwater movement is determined by the various characteristics of aquifers and confining layers of subsurface rocks (which water has a difficult time penetrating) in the ground. Water moving below ground depends on the permeability (how easy or difficult it is for water to move) and on the porosity (the amount of open space in the material) of the subsurface rock. If the rock has characteristics that allow water to move relatively freely through it, then groundwater can move significant distances in a number of days. But groundwater can also sink into deep aquifers where it takes thousands of years to move back into the environment, or even go into deep groundwater storage, where it might stay for much longer periods.

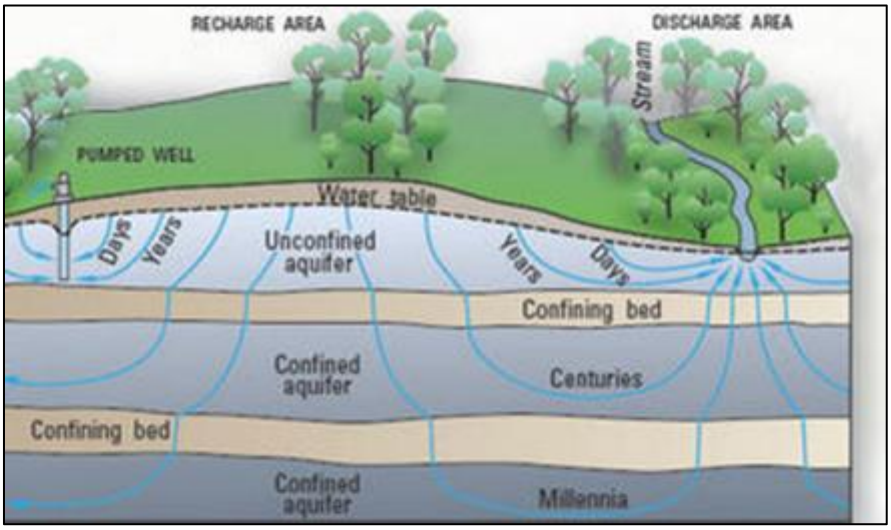

Figure 1 Conceptual Groundwater-flow Diagram. (Water Science School)

1.3. Statement of Problem

Models are used to try to reflect reality without damaging the environment or spending enormous amounts of money determining how the real-life situation will be and mitigating against a worst-case scenario because it is extremely expensive to duplicate real-life events in analysis and study.

Polluted groundwater is dangerous since it is challenging to predict the direction of groundwater flow at the research area.

Because of a lack of knowledge on the direction of groundwater flow, some wells have been abandoned.

In order to forecast groundwater movement, aquifer management, well field design, recharge enhancement, optimal yield determination (safe yield), well interference study, groundwater-stream flow interaction, and other things, we may need utilize the Groundwater Modeling System (GMS). The use of GMS has been investigated and verified in this setting. GMS may also be used to enhance groundwater quality by avoiding contamination, reducing its impacts, developing alternative remediation procedures, and assessing their success, among other things. Despite the fact that GMS has only been studied in a small number of areas, further research in this area is highly recommended.

Aim and objectives of study

- It will depict the flow and direction of groundwater in the research area.
- It will assess the effect of groundwater flow direction on pumping and recharging rates.
- It will help to raise awareness about the need of utilizing a groundwater modeling system (GMS) when finding and managing waste dumps and water projects.

1.4. Significance of study

In terms of groundwater resources, this research will demonstrate how to employ groundwater modeling tools to address difficult regional and basin-wide environmental concerns. The importance of this research includes, but is not limited to, gaining an understanding of complex processes that operate in nature without harming the environment (SENSITIVITY ANALYSIS), determining the relative importance of various processes occurring in a given situation (WORST CASE), examining "WORST CASE," "SPECIAL CASE," or "WHAT IF" scenarios, and assisting in the making of probabilistic predictions for future purposes.

1.5. Scope of the study

My study scope is to collect field data from four wells with accurately characterized lithology, as well as to use computer interpretation software and online mapping tools such as ArcMap and Google Earth Map. The static water level (SWL) or hydraulic head were determined using a dip-meter gadget. A handheld Global Positioning System (GPS) was used to record precise locations. All of the essential parameters were gathered from the field and academic sources using the Aquaveo 10.7 Groundwater Modeling System software. The direction in which groundwater flows will be evaluated in order to determine if groundwater in the semi-urban and urban (Adeje, Egbeleku, and Effurun Areas) is been recharged by adjacent streams, peninsulas, and rivers or by rainfall. It also seeks to determine whether the rate of pumping has an influence on recharge using the Groundwater Modeling System (GMS).

1.6. Study Area

As indicated in Figure 2, the study region for this research project encompasses portions of the Uvwie and Okpe LGA and is located between latitudes $5^0$44'24.0"N and $5^0$50'42.0"N and longitudes $5^0$42'18.0"E and $5^0$33'54.0"E. It consists of four separate borehole locations; which are two boreholes in the Uvwie LGA, one each at PTI Housing Estate and PTI Junction Public Motor Park, Effurun, and one borehole in Adeje Town and the other one at the Egbeleku Landfill Site on Umiagwa Road in Okpe LGA.

The rivers that drain these areas include the Adeje Stream, Okuovo Tributaries, and Egborode River in Okpe LGA, which flows into the Warri River, as well as the Effurun River, Etajeruo Stream and Ugbomro River in Uvwie LGA.

The study area is a tropical environment with high rainfall for most part of the year. The average annual temperature is 26.7^{o}C, and there is generally 2768mm of precipitation. It is found in the Benin Formation of the Niger Delta Basin. The region is low-lying, with an average elevation of 15 meters above sea level.

The area rests mainly on the Sombreiro –Warri Deltaic Plain (SWP) one of the distinguishable physiographic landforms resulting from Recent and modern delta top deposition in the Niger Delta. The others being the Brackish Water and Mangrove Swamps (BMS) and the Fresh Water Swamps (FWS). The city is bound on its western edge by the BMS, swamp terrain that has so far limited city expansion in that direction (Akpoborie et al 2014).

1.7. Relief and Drainage

The surface area of the study area is relatively flat, with elevation ranging from 6m to 10m, and some places sometimes below the sea level. The area is sometimes affected by flooding and erosion especially around July to September.

1.8. Climate and Vegetation

The surrounding region is predominantly rainforest, tending to swamplands in some areas. The vegetation is rich in timber trees, palm trees, plantain trees and numerous fruit trees.

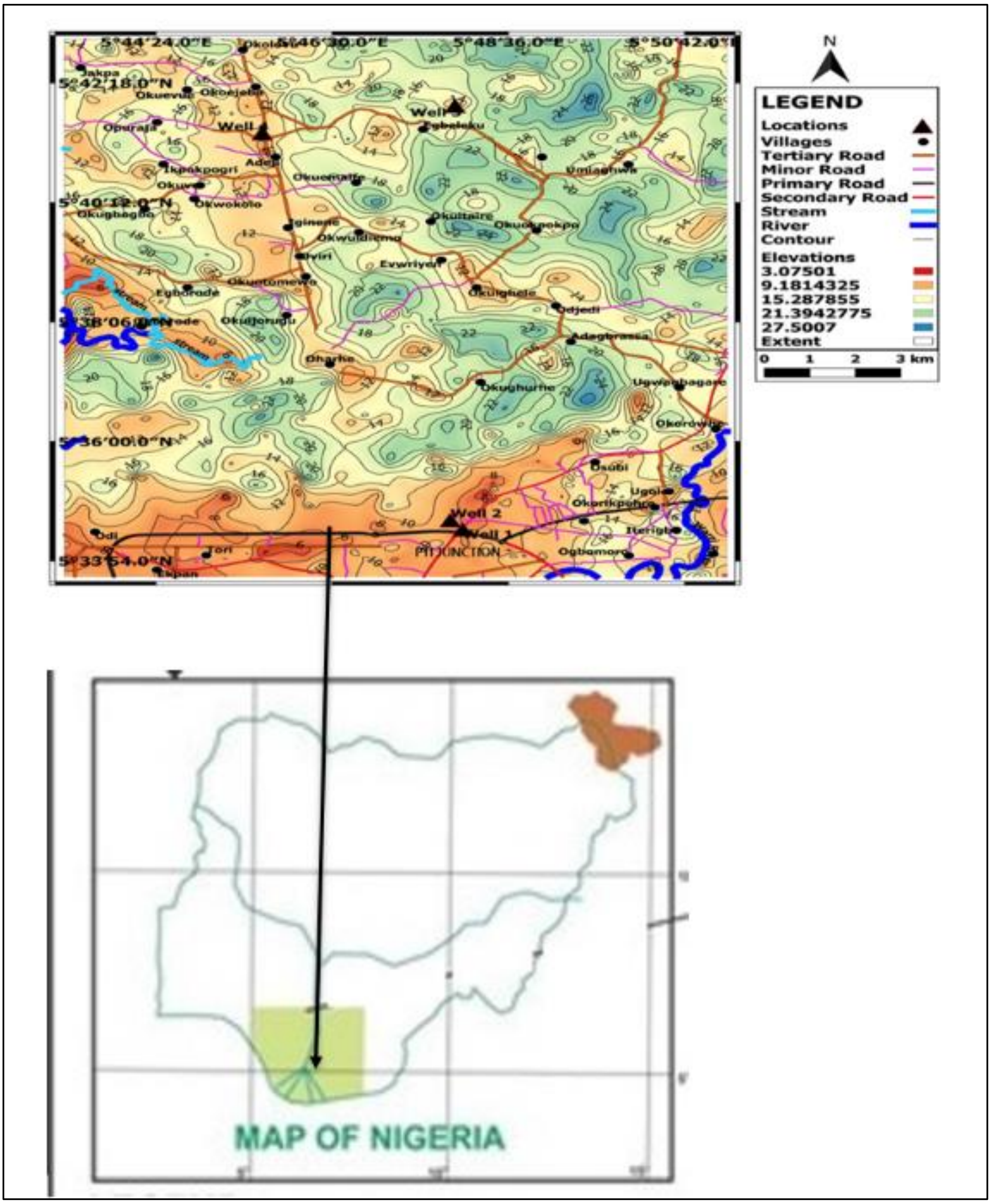

Figure 2 Map of the research area (Author)

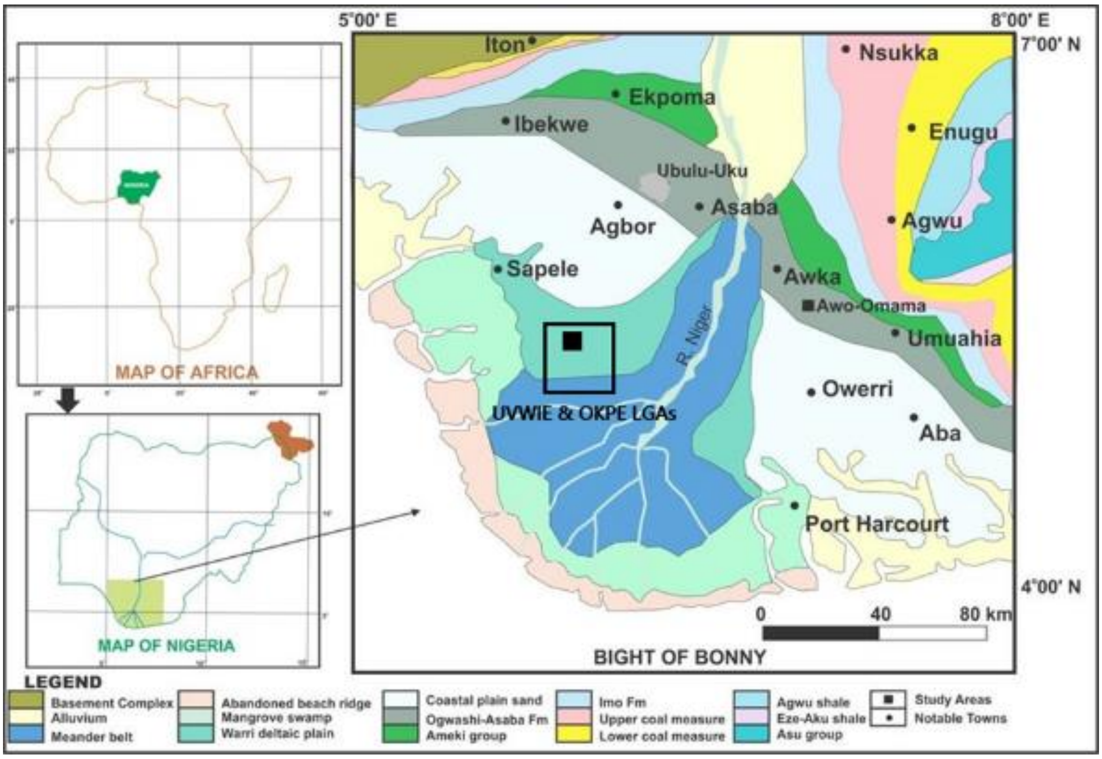

Figure 3 Map of the Niger delta showing the study area (modified from Olaonipekun 2018)

2. Review of Related Literature

Henry Darcy (1803-1858), a French hydraulic engineer, undertook research on the flow of water through sand, and his 1856 article established the connection that today regulates groundwater flow in the majority of alluvial and sedimentary formations, commonly known as Darcy's Law (Todd et al 2005). Because of advancements in numerical modeling techniques such as MODFLOW, analyzing groundwater flow has become easier (McDonald and Harbough, 1988). Ophori et al. developed a 3-D groundwater flow model for many regions in Owerri. Water normally travels in the subsurface from a recharge point to a discharge point. The locations of the recharge zone and the discharge zone in a basin must be identified. The sustainable management of a region's groundwater resources may rely largely on numerical groundwater flow models, which have the ability to solve real-world groundwater-related difficulties (Anderson et al). Water quality fluctuates as groundwater flows from the point of recharge to the point of discharge due to lithologic properties (naturally) as well as human activities (Puranik 2009). A conceptual model and a mathematical model are required for a groundwater model. The conceptual model depicts how water enters, flows through, and exits a groundwater system based on current hydrogeological understanding (Abdelaziz et al 2012).

While developing a groundwater model, we select the Domain (Region) of interest so that conditions along its boundaries may be properly characterized. We will most likely determine the boundary conditions through fieldwork. We continue by characterizing geologic units and their hydrogeologic properties as exactly as possible, including but not limited to permeability k, hydraulic conductivity of the rock K, transmissivity T, storability S, specific storability Ss, porosity n, recharge rate, pumping rate, and so forth. 2020 (Ophori)

Omo-Irabor, Olobaniyi, Oduyemi and Akunna (2008) have also stressed the influence of anthropogenic factors in the determination of water chemistry in the Niger Delta region

3. Materials and Methods

3.1. Methodology

Four shallow boreholes were drilled using the manual rotary technique and their lithology were recorded, their coordinates were also recorded. After some weeks, their static water level were recorded using the dip-meter. The data collected were computed in the groundwater modeling system software.

Simply put, the inverse problem is the task of estimating a set of relevant flow parameters from a set of measurements, which include: 1) point measurements of the flow parameters; 2) some hydrological data collected during a flow experiment; and 3) any additional (possibly transient) measurements that are sensitive to flow processes, such as geophysical data. A solution to this in-verse challenge is the parameter distribution for which the simulated and observed observational data match while keeping parameter measurements.

The current study is based on the assumption that hydraulic conductivity and recharge are unidentified flow characteristics. We assume that only hydraulic conductivity is a randomly variable field, despite the fact that both recharge and hydraulic conductivity are geographically variable. The Pilot point approach is used to parameterize such geographically distributed random variables. Even if we utilize zonation as a parameterization approach to turn its geographical heterogeneity into zones of uniform values, the recharge is believed to be spatially variable.

The careful selection and application of optimization strategies is required for the proper execution of any inversion. Gradient-based techniques are commonly used in parameter inversion approaches (e.g., Levenberg- Marquardt technique). In GMS, which stands for Groundwater Model System, the MODFLOW pre- and post-processor used in this work, there are several approaches to deal with the inverse problem. PEST, which stands for Parameter Estimation, performed this job satisfactorily in this circumstance. PEST is one of the model-independent parameter optimizers. While PEST has certain properties with existing nonlinear parameter estimation software, it was designed to be interfaced with any model without the requirement for modification. Doherty [8] recommended using regularized in-version techniques with beneficial tools like as PEST. PEST typically employs nonlinear parameter estimation and optimization models. Ramadan and Mahmoud 2012.

3.2. Modeling

Modeling: This is the abstract mathematical representation of a real-world event, system, behavior or natural phenomenon. The computer model is designed to act as a real-life situation. There is conceptual and numerical/mathematical modeling.

To begin modeling, follow the procedures outlined below in the sequence illustrated in Figure 5.

- Break the domain down into cells and nodes.
- Using algebraic equations, estimate PDEs at a FINITE number of domain points (NODES).
- Determined solution: Solve the sets of algebraic equations that are generated
- Solve thousands of problems repeatedly
- The Groundwater Modeling System (GMS), on which this work is based, is a COMPUTER CODE that represents the entire solution process directly.

In constructing a groundwater model; we select the Domain (Region) of interest, such that conditions along its boundaries can be defined unambiguously. We define the boundary conditions probably from field work. We go further to define geologic units and their hydrogeologic properties as closely as possible, which include but not limited to; permeability k, hydraulic conductivity of the rock K, transmissivity T, storability S, specific storability Ss, porosity n, recharge rate, pumping rate, etc. Ophori 2020.

Physical processes in groundwater systems are controlled by physical laws, expressed mathematically in terms of the governing equations, usually: PARTIAL DIFFERENTIAL EQUATIONS (PDEs). To do this, we are to select relevant equation governing flow in the domain of interest. By doing these simple steps, we have defined a BOUNDARY VALUE PROBLEM (BVP) or constructed a CONCEPTUAL MODEL as shown in Figure 4.

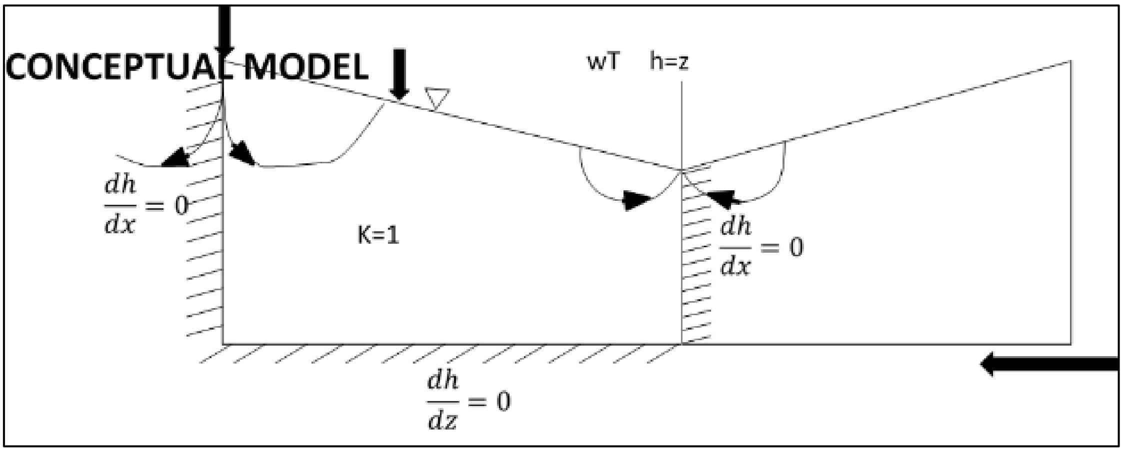

Figure 4 Conceptual Model or Boundary Value Problem (BVP) (Ophori 2020)

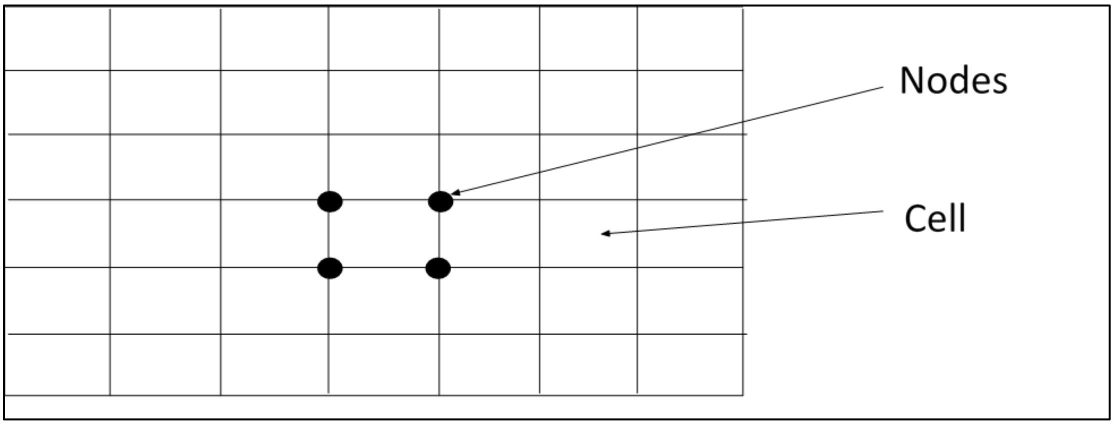

Figure 5 Domain is griddled into cells and nodes (Ophori 2020)

4. Model Verification, Validation, and Calibration

Verification: Before being applied to a real system, a model must be validated to ensure that equations are correctly solved. This is performed by contrasting your model's output with the analytical solutions to the equations (in domain with simple geometry).

Model validation is comparing model output to real field or laboratory observations to ensure that the physical system is, in fact, the one expected.

Calibration: Due to inadequate data, measurement inaccuracy, imperfect knowledge of the physical system, and other factors, field observations and model conclusions may not agree. Then, after adjusting certain model parameters, we rerun and compare. Models have been calibrated when field and model findings closely match.

4.1. Digital Elevation Model

The landscape of a planet, moon, or asteroids is often represented using a digital elevation model, which is a 3D computer visual representation of elevation data. A discrete worldwide grid is referred to as a "global DEM." The most popular starting point for digitally created relief maps is DEMs, which are often used in geographic information systems, GIS. (Wikipedia)

Digital elevation data are 3D representations of the earth's surface that are often saved in pixel grid (raster) format, with each cell containing the average elevation value of its coverage region. Digital elevation models (DEMs) can be in one or two formats:

Digital surface models with average heights for all surface elements, such as buildings and plant canopies, represented by each pixel value. Image pictures from satellites or photographs are frequently used to create digital surface models.

The height of the ground surface is represented by the value of each pixel in digital terrain models. This information is often generated by RADAR imaging devices.

Contour maps, also known as digital elevation models, were constructed for the research area using the following programs: Google Earth Pro, ArcMap, QGIS, and gpsvisualizer.com. Google Earth Pro, while not a comprehensive GIS, is a free tool that allows for the display, assessment, overlay, and generation of geographical data. It may also be used to see its extremely high-resolution satellite photos, transfer or receive geographical data in its native interoperable file format (KML), and find locations (e.g., for simple geocoding). In addition to Earth navigation, the desktop edition of Google Earth includes a path tracer and measure distance features. The research tool used was path tracing, the research region was zoomed in using the search area, and the path of interest was followed before being saved as a.kmz file type. The file is then put into GPS visualizer using the search up elevation option. GPS Visualizer is an online program that produces maps and profiles using geographic data. The website generates heights at different Co-ordinates along the path traced using Google Earth Pro, and the defined text is saved. The delineated text is loaded into the Quantum Geographic Information System (QGIS), as a layer. Using the QGIS application, data scientists can create custom maps and conduct geographic investigations. It is used to create a variety of geophysical maps. The contour map of the research region is created using the imported text file, which depicts the main road network and local water features. The program was used to grid the groundwater modeling system's research area.

4.2. Flow Simulation

Using the theoretical framework, a grid approach was used to build the groundwater-flow model, which comprises geography, climate, geology, groundwater domain geometry, physical hydrologic characteristics, and hydrologic boundary conditions. This assignment was completed using the MODFLOW software. MODFLOW (previously known as the Modular Three-Dimensional Finite-Difference Groundwater Flow Model) is a 3D, cell-centered, finite difference, saturation flow model developed by the United States Geological Survey USGS (McDonald & Harbaugh, 1988). MODFLOW, which can do both steady-state and transient analysis, offers a variety of boundary conditions and input options. MODFLOW is compatible with the 3D Grid and 3D UGrid modules in GMS. The steady state flow is used in the modeling, which assumes that the groundwater level (water table in the unconfined aquifer or piezometric level in the confined aquifer) remains constant throughout time. The groundwater level is a spatial function only when the flow is steady-state. The law of conservation of mass, which dictates that the rate at which groundwater enters and exits a system must be equal, serves as the basis for steady state flow. The two most often used approaches are the Finite Difference Method (FDM) and the Finite Element Method (FEM).

The flowchart for creating the model using the MODFLOW Model is shown in Figure 6.

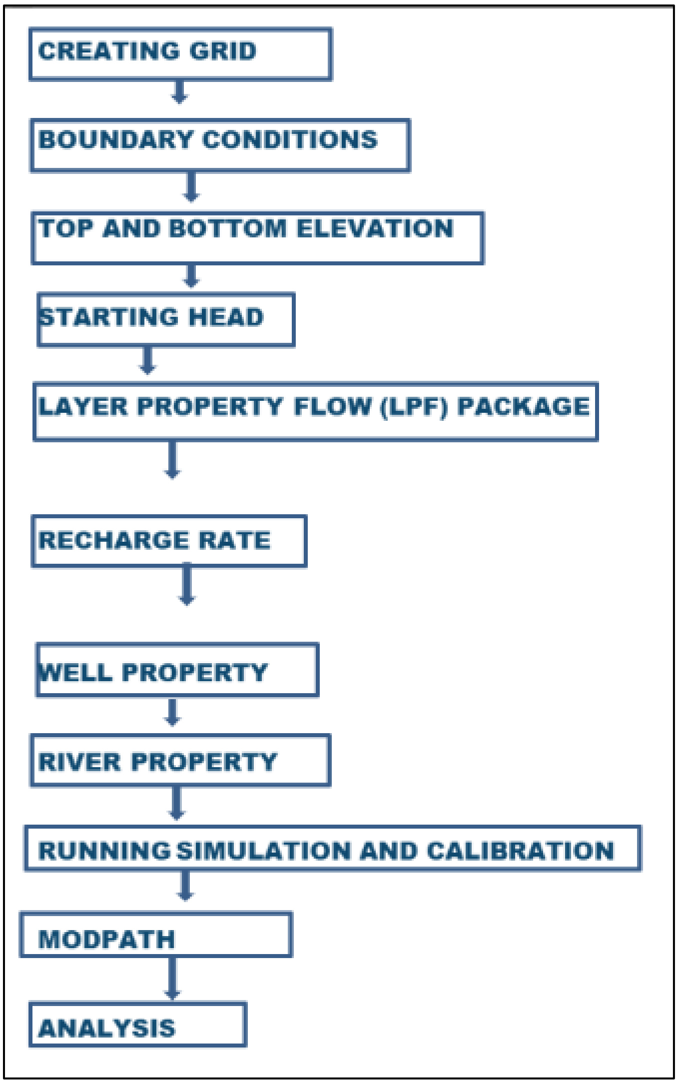

Figure 6 Modelling flowchart

4.3. Creating the Grid

The grid approach made use of the x, y, and z axes, which stand for width, length, and depth, respectively. According to the drilling records, the grid on the map was utilized for 17 cells in the x axis, 20 cells in the y axis, and 4 cells in the z axis. The map's scale was utilized to calculate the x, y, and log lengths for the simulated aquifer's z length depth.

4.4. Assigning ibound Array

Using the IBOUND array, each cell may be classed as active (IBOUND>0), inactive (IBOUND=0), or constant head (IBOUND<0). The cells that are active are those in Wells 1, 2, 3, and 4. Because they are inactive, cells outside the Wells are assigned a value of 0, while those inside the Wells are assigned a value of -1.

4.5. Top and Bottom Elevation

The top and bottom elevations of the strata were derived using elevation data from the map's contours and drill logs. The top elevation is determined by the contour values, while the bottom elevation is determined by the thickness of the layers in the region. The overall thickness of the drilling logs is 55 meters.

4.6. Starting Heads

The Starting Heads array is used to provide a starting head value. Several water level data were collected from the four research area wells for this model. These figures were used to calculate the hydraulic head, which acted as the initial heads, as well as the elevation. The cells designated in the IBOUND array as constant head (-1) remain unchanged. Deducting the water levels from the height gives the hydraulic head.

4.7. Layer Property Flow (LPF) Package

The LPF program develops finite difference equations for cell-to-cell flow and computes conductance between grid cells. The LPF Package dialog was used to define the hydraulic conductivity data for each layer and layer type. A feature known as hydraulic conductivity assesses a material's capacity to transmit fluid via pores and fissures when a hydraulic gradient is supplied. The hydraulic conductivity requirements for various types of sediment were employed, as shown in Table 1.

Table 1 Hydraulic Conductivity Standards (Guideal, 2011)

Materials	**Range of K (m/day)**
Clay soils (surface)	0.2
Deep Clay Beds	10-8 -10-2
Loam soils (surface)	0.1-1
Fine sand	1-5
Medium sand	5-20
Coarse sand	20-100
Gravel	100-1000
Sand and Gravel mixes	5-1000
Clay, sand and gravel mixes (till)	0.001-0.1

4.8. Package Add-ons (recharge rate, well and river)

Optional Packages for this model include the Recharge Rate Package, Well Package, and River Package.

4.8.1. Recharge Rates Package

Water that seeps into the earth replenishes subsurface aquifers. The process of bringing water from the land's surface to an aquifer is known as groundwater recharge. The movement of water from the unsaturated zone into the saturated zone is another word for it. A set volume of water is pumped into a basin based on how much rain falls in it. Annual rainfall in Uvwie and Okpe LGAs is roughly 1056 mm/hr, which may be explained by coastline characteristics that allow wind-carrying precipitation to flow through (Gobo, 2008). The yearly rainfall in the Niger Delta ranges from 5000mm at the coast to around 3000mm in the Delta's northern portion (Etu-Efeotor and Odigi, 1983). Evapotranspiration of 1000mm results in effective rainfall of 2000mm. The subsurface aquifers are known to receive 37% of this effective rainfall, or 750mm, with the remaining 1250mm flowing straight into the streams (Akpokodje et al., 1996). The Warri Rainfall record is used with the data above since it is the nearest metrological station to the sample locations.

4.8.2. Well Package

The Well Package is critical in the model. The model was created using data from four wells.

4.8.3. River Package

Due to the two rivers that drain the study area—the Egborode River, which flows into the Warri River, and the Ugbomro River, which empties into the Warri River in a south-eastern direction—the River Package was utilized.

4.9. Stimulation and Calibration of Model

After the model had been run, the MODFLOW was used to check for errors after all of the parameters had been entered. The model is iterated again and over until it converges. The vectors are combined to establish the flow direction of MODFLOW.

Following that, the model was calibrated. Any groundwater modeling project must incorporate a model calibration method. Before a groundwater model can be utilized for forecasting, it must be shown that it can correctly imitate observed aquifer activity. To calibrate a model, model parameters such as recharge and hydraulic conductivity are often changed, and the model is then run until the predicted output matches the field-observed data as closely as feasible. GMS includes a number of tools to assist in model calibration. A collection of observed heads was collected in the field at various sites around the research region for the model's steady state calibration.

A calibration target emerges at the grid's observation wells after running MODFLOW. The target's center is aligned with the observed value. The observed value plus the interval makes up the top of the goal, while the observed value minus the interval makes up the bottom. The mistake is indicated by the coloured bar. Green is painted on the colour bar if it completely meets the aim. If the bar deviates from the target but the mistake is less than 200%, it is highlighted in yellow. A red line is drawn on the bar if the mistake is more than 200%, Watero (2014).

4.10. Materials

The material used was a GPS Device, a dip-meter used to measure hydraulic heads and GMS 10.6 (64-bit) Aquaveo Software, installed in a computer to run the model.

5. Results

Four (4) boreholes' data, as well as their positions and hydraulic heads, were collected in the field. The GMS software was used to plot, calibrate, and validate the parameters derived from fieldwork and previously published literature. Table 2 shows the locations of the several wells and their hydraulic heads.

Table 2 The locations of boreholes and their hydraulic heads. (Author)

S/N	LATITUTDE (N)	LONGITUDE (E)	HYDRAULIC HEAD (m)
BH 1	5^{0}34’26.76”	5^{0}48’3.24”	3.3
BH 2	5^{0}34’31.08”	5^{0}48’1.08”	3.2
BH 3	5^{0}41’53.52”	5^{0}47’57.84”	3.1
BH 4	5^{0}41’22.56”	5^{0}45’41.04”	3.1

The bottom elevation for the model is generated using lithology data received from borehole drilling activities. Figure 7 displays the lithology of the boreholes as well as the depth at which the model parameters for the research region were applied.

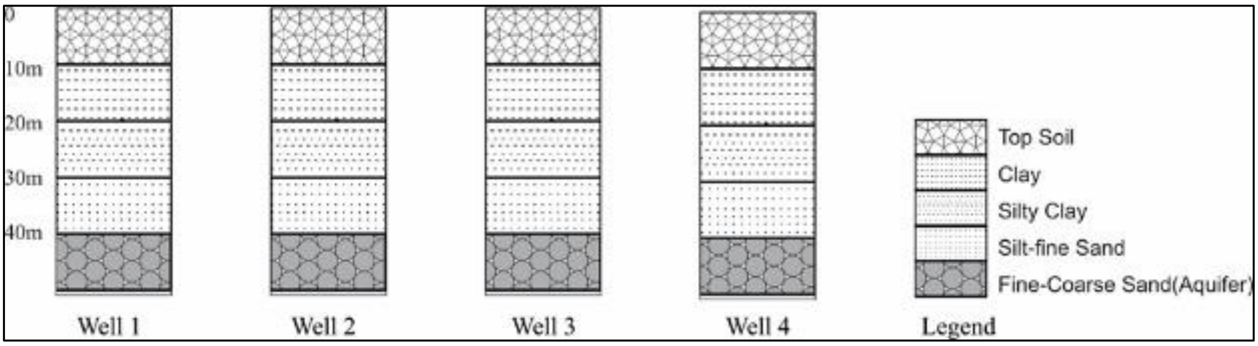

Figure 7 Borehole lithology for Wells 1, 2, 3, and 4

Table 3 displays the yearly rainfall for the research region, i.e. Warri and surrounding areas, from 2005 to 2015. Precipitation and runoff are largely important for recharging the aquifer in the study region, which receives a lot of rain.

Table 3 The monthly and annual rainfall in Warri (Oyeleke, 2021)

Months													
YEARS	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**ANNUAL TOTAL**
2005	37.3	21.7	191.2	104.1	315.1	216.4	592.4	146.7	432.5	203.6	68.6	39.0	2368.6
2006	111.0	171.9	177.6	149.2	453.9	259.4	368.4	305.6	525.3	493.2	25.0	17.7	3058.2
2007	TR	60.3	34.5	44.4	286.6	58.18	364.2	140.2	493.9	448.9	65.9	33.5	2030.58
2008	20.4	10.0	172.6	337.8	295.1	467.4	501.9	635.4	428.5	214.2	72.5	23.8	3179.6
2009	13.0	86.1	66.9	138.2	209.2	383.4	407.1	414.5	117.5	368.8	76.0	15.7	2296.4
2010	8.2	118.4	89.5	218.9	379.8	250.1	192.4	302.4	536.6	296.4	157.7	21.8	2572.2
2011	TR	136.4	67.0	143.0	366.6	332.5	671.6	458.2	254.8	119.1	131.0	3.7	2763.9
2012	20.7	174.2	46.9	130.0	358.6	470.1	678.1	133.4	313.1	339.6	166.4	72.0	2903.1
2013	107.0	15.7	151.6	209.3	174.3	458.6	497.5	183.8	185.2	483.6	203.1	37.3	2707.0
2014	89.3	17.9	190.0	225.5	348.0	304.9	194.2	349.4	374.9	474.9	250.7	128.2	2947.9
2015	TR	118.4	138.5	238.1	359.6	479.1	187.5	417.5	489.0	524.1	227.4	4.4	3183.6
Month Total	406.9	931.0	1326.3	1938.5	3546.8	3680.08	4655.3	3487.1	4151.3	4046.4	1444.3	397.1	30011.1

Average Rainfall = 2728.28mm/yr

Evapotranspiration = 1000mm/yr

Effective Rainfall (EF) = 1728.28mm/yr

Recharge (37% of EF) = 638.46mm/yr = 0.001749m/day

Run off = 1088.82mm/yr

5.1. Groundwater Flow Model

The movement of groundwater is controlled by a hydraulic head. The hydraulic head is the height to which water will normally rise in a well. The hydraulic gradient is the difference in hydraulic heads between any two places. When there is a hydraulic gradient from higher to lower, groundwater will flow. A steady state flow was used to represent groundwater in the research area. Figure 8 shows the 3D presentation of the model for the study region with the appropriate parameters. The study area model is depicted from various side angles in Figures 9, 10, and 11.

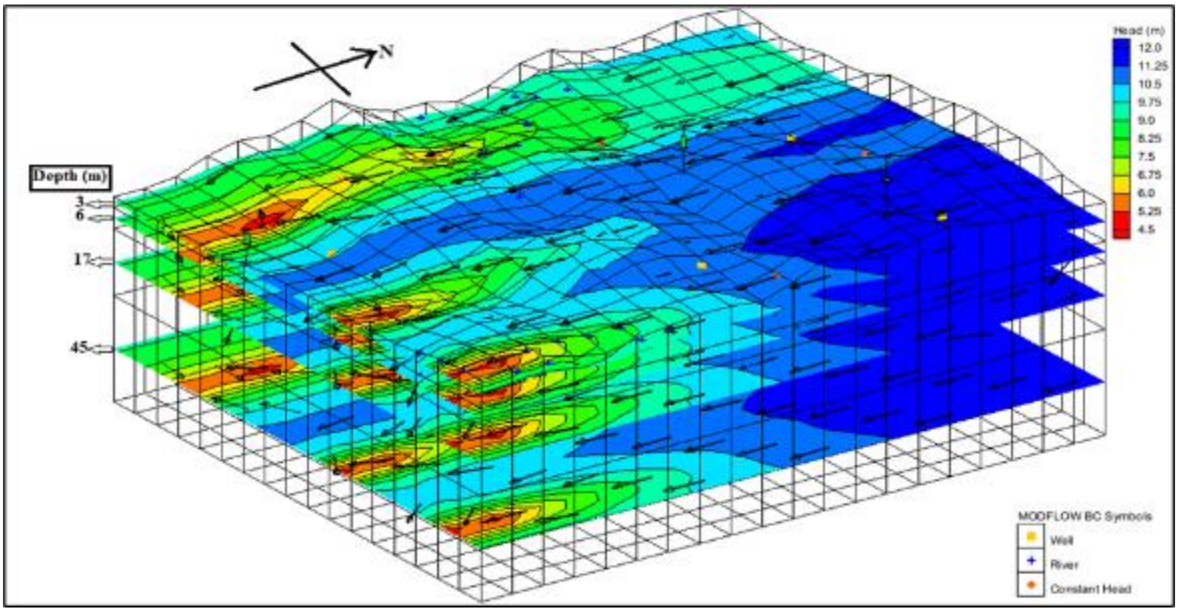

Figure 8 3D Groundwater Flow Diagram from GMS

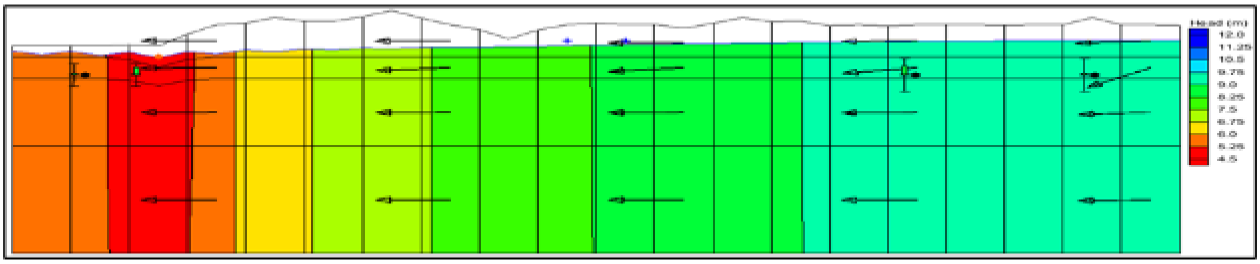

Figure 9 Down Side view of GMS Flow Direction

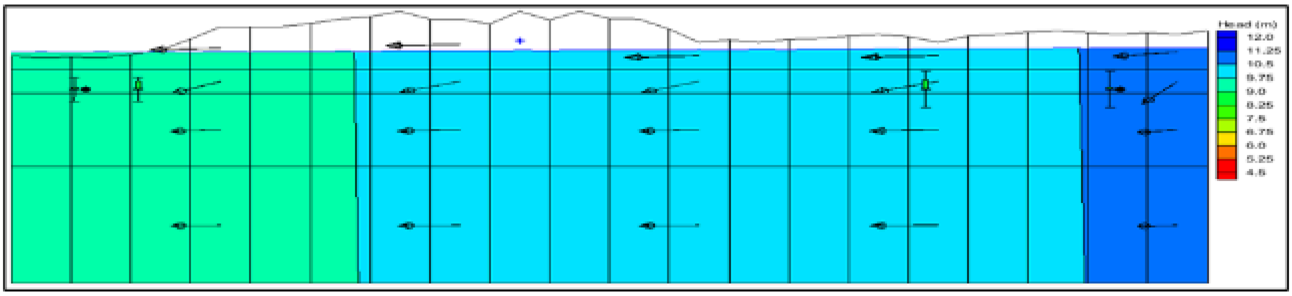

Figure 10 Left Side view of GMS Flow Direction

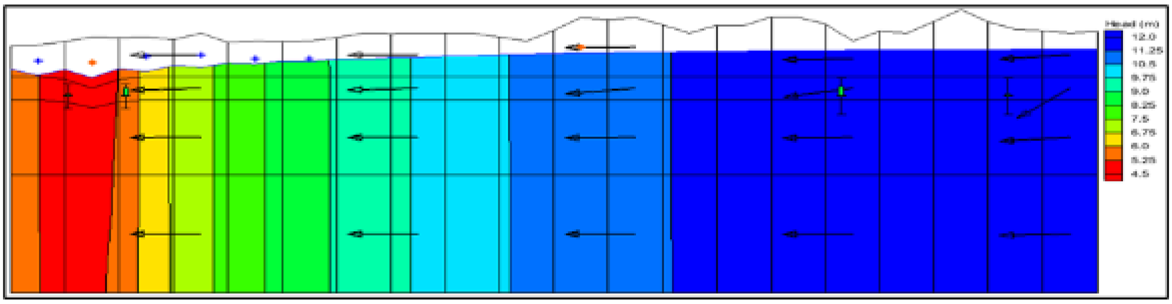

Figure 11 From the top, a view of the GMS Flow Direction

The model is calibrated to see if it properly represents the status of the groundwater. This is accomplished using the Calibration Graph. The calibration graph demonstrates if the model actually portrays the groundwater conditions in the research region. The 45º line completely matches the measured head in the field and the projected head from the model. The model depicts the status of the groundwater better as the spots get closer to the 45º line.

Because the points in the graph in Figure 12 are closer to the 45° line, this model might be utilized to manage groundwater in the study area.

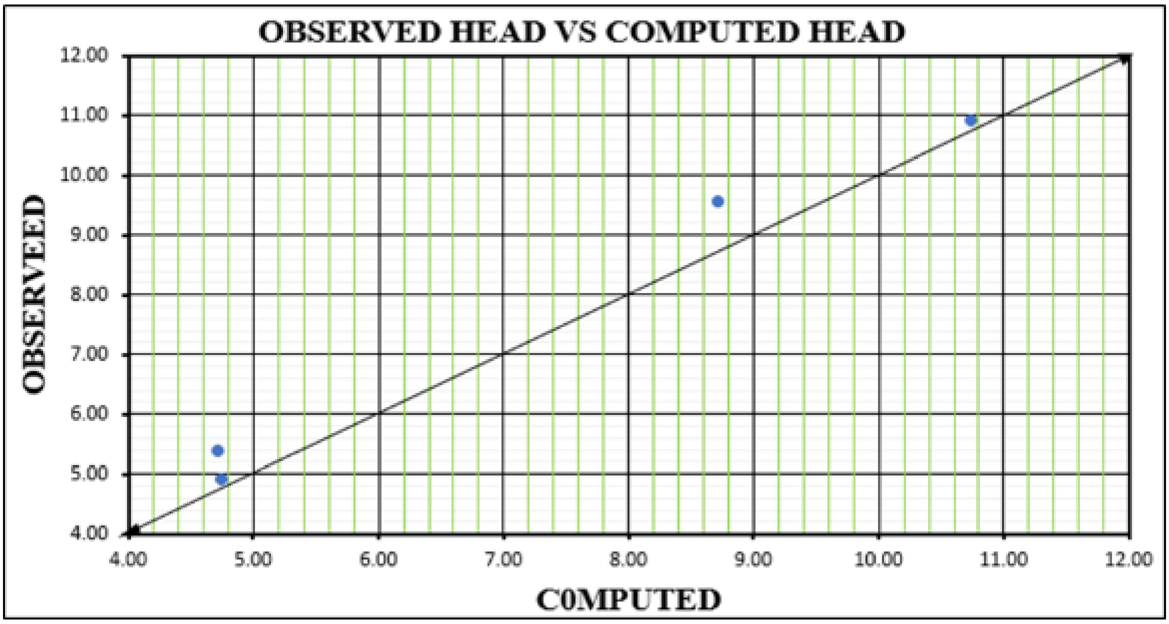

Figure 12 Displaying a calibration graph of the estimated and observed heads

We may simulate natural processes by modifying the model's parameters to the worst-case and best-case situations while it is running. It is feasible to analyze how the recharge affected the head by increasing the recharge. Figures 13 and 14 shows the negligible impact of increasing and decreasing the recharging rate by 80%.

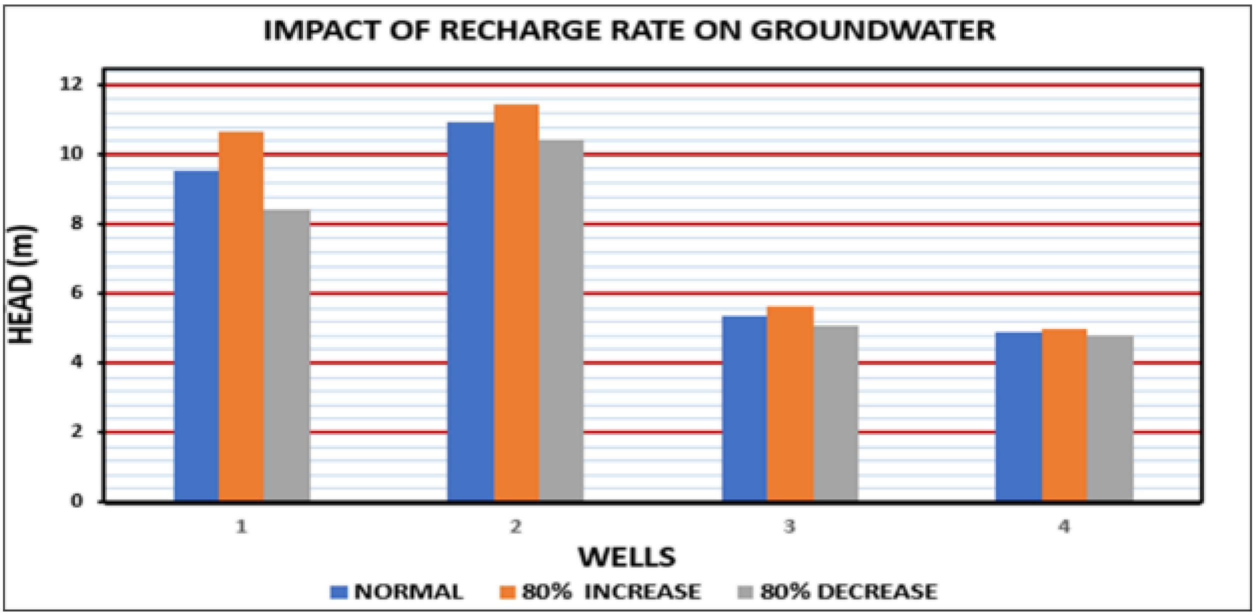

Figure 13 The impact of recharge rate on groundwater

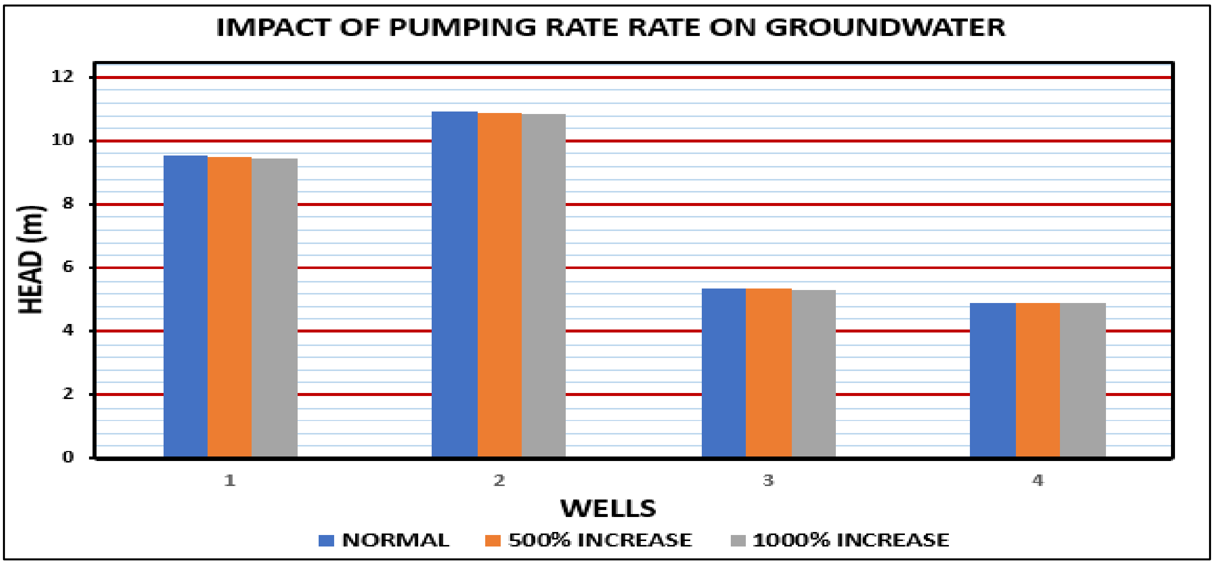

Figure 14 Depicting the pace of groundwater pumping

Once the model has run, the application will inform the user of how much water departs and enters the zone of interest. The model may be used for groundwater management in the research, as shown in Table 4, if the difference between what enters and departs the system is near to what really occurs.

Table 4 Parameters for GMS Simulation (Author)

S/n	Parameters	In	Out
1	Storage	0.0000	0.0000
2	Constant Head	13,731.0820	488,099.8125
3	Wells	0.0000	0.0000
4	River Leakage	20,248.5859	440.8163

5	Recharge	458,653.4375	0.0000
	Total	492,633.0938	492540.6250
	Difference	92.4688	
	Percent Discrepancy	0.02%	

6. Discussion

The hydraulic head from the model of the study area ranges from 3.0m-3.5m as shown in Table 2, this range is similar to the hydraulic head observed in some wells within the study area (Figure 12). This range of values differs with the ones observed by Oseji and Ofomula (2010) at Utagba-Ogbe, this is due to the fact that the elevations in Utagba-Ogbe is higher compared to the elevations of the study area which is lowland and flat. Since the hydraulic head governs the groundwater flow of an area and that it flows from higher to lower hydraulic gradient; the model shows that the groundwater flow in the area is from a higher to a lower hydraulic head. The groundwater is the study area flows from the northern to the southern part as reported by Akpoborie et al in 2014. The aquifer in the area is recharge mainly by rainfall, from the model, the groundwater infiltrates downward and changes its direction towards the Ugbomro River, Okuovo tributary, Adeje streams and the Effurun River.

The results from the steady state calibration are shown in Figure 12, the water level condition in the month of August as measured from wells in the field was used for the calibration. The calibration was successful due to correlation of the observed and calculated heads. Calibration of the model is done to check if the model represents the actual groundwater condition. This is done by using the Calibration Graph. Calibration graph indicates if the model represents the groundwater condition of the study area. The 45^o line represents a perfect correspondence between the observed head in the field and computed head from the model. The more closer the points are to the 45^o line the more the model represents the groundwater condition.

From the graph in Figure 12 the points are closer to the 45^o line, therefore this model can be used for groundwater management of the study area.

7. Conclusion

The study shows that the program has been used in a range of groundwater flow simulation settings. This shows that software-based research has a promising future. It is worth noting that the use of modeling software is slightly higher in North America, Europe, Middle East, and Asian countries (particularly China). An examination of the literature reveals that similar situations in other nations may be examined using the same research approaches. Some research have attempted to merge GMS with other applications like as QGIS, ArcMap, SWAP, SWAT, and so on (MODFLOW). These efforts inject new life into the research modeling.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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