TIME SERIES ANALYSIS AND MODELLING OF GROUND WATER FLUCTUATION IN OTUNJA, IKOLE-EKITI, EKITI STATE, NIGERIA.

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A PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE BACHELOR OF ENGINEERING, (B.ENG) DEGREE IN CIVIL ENGINEERING, FEDERAL UNIVERSITY OYE EKITI, EKITI STATE NIGERIA.

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ABSTRACT

Groundwater modelling is an important tool that can be used to determine appropriate management strategies for groundwater conditions. This study is relevant considering the extensive use of groundwater for both agricultural and domestic purposes as is presently done in the Otunja area of Ikole Ekiti, Ekiti State, Nigeria. Eight months (8) months ground water level data was obtained (day and night) from two wells located in Holy Apostolic Primary School Otunja Ikole Ekiti. 9 month rainfall and other relevant climatic data were collected from the department of Water Resources Management and Agro-Meteorology of Federal University Oye Ekiti.

A conceptual model based on 3-dimensional equation of Darcy permeability law was used for the modelling of groundwater recharge. The modelling of water head across the boundary domain was accomplished using MODFLOW, ArcGIS and Google Earth software. Classical Decomposition model of time series was used for determination of groundwater recharge and discharge rates. Estimates for missing data were derived using the quadratic equation.

The model was calibrated both in steady and transient states. The steady state calibration was done for 3rd of February, 2017 aquifer performance data while the model was set under a transient run from 3rd of February, 2017 to 28th of July, 2017 aquifer data using a hydraulic conductivity of value of $1.12*10^{-4}$cm/sec while the recharge rates were obtained from the time series.

Model predictions for the months of September and October were done and calibrated using observed groundwater data for the months of September and October. A predictive run was done from August 2017 to October 2017 where the model examined the response of the aquifer to abstractions under two schemes. Model prediction for the months of September and October and it indicated no clear difference of hydraulic head for the aquifer for these two months. Groundwater modelling is a useful tool for groundwater managers.

DEDICATION

This project is dedicated to Almighty God

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The timely and successful completion of the book could hardly be possible without the help and supports from a lot of individuals. I will take this opportunity to thank all of them who helped me either directly or indirectly during this important work.

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CERTIFICATION

This is to certify this project was carried out by ADALUMO, Kolapo Olatunbosun (CVE/12/0824) of the department of Civil Engineering, Federal University Oye-Ekiti, Ekiti State, Nigeria in partiall fulfillment for the award of Bachelor degree in Civil Engineering.

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LIST OF ABBREVIATION

ASTM	American Standard Testing Machine
I.I.D	Independent and Identically Distributed
GMS	Groundwater Modelling System
SS	Sum of Square
GIS	Geographic Information System

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CHAPTER ONE

INTRODUCTION

1.1 General Background

Water resources in any part of the world are subject to change due to meteorological and climatolo1gical impact all the year long. Impact of these factors on water resources has been extensively studied (Chen and Osadetz, 2002; Gleick, 1989; Maathuis and Thorleeifson, 2000; Lewis, 1989). Increased temperature, plant water requirements, demand for human and animal drinking water and industrial usage, limited rainfall on one hand and artificial ground water recharge on the other hand, requires more water resource development and planning activities in the future. Dealing with variations of ground water resources in relation to effect of rainfall and temperature on water table fluctuations is an important factor which plays a media role in sustainable ground water development. Physical relationships between meteorological factors, unsaturated and saturated zones of phreatic ground water resources, as is the case in the region's conditions, is cited elsewhere (Aflatooni, 2011). The long term historical and meteorological data ,among all, temperature and rainfall can be used to assess the future surface water, ground water table and storage variations in order to have a better insight into the problem posed in the future. In general, if the statistical parameters such as mean and variance of a long term meteorological time series changes steadily, it can be said that the climate change is inevitable, so using these historical times series and their effects on water resources, mainly ground water, may have a similar future impact. Analysis of time series as related to ground water table seeks two objectives; modelling of random variables to have an understanding of historical data and forecasting future data behaviour based on the past data (Ahn, 2000). We should understand the significant statistical characteristics between metrological data and those of say ground water table variations separating them into deterministic components or the ones that can be modelled.

1.2Basic Concepts of Time Series Modeling

1.2.1 Definition of a time series

A time series is a sequential set of data points, measured typically over successive times. It is mathematically defined as a set of vectorsx(t), t= 0,1,2, ... where t represents the time elapsed. The variable x(t) is treated as a random variable. The measurements taken during an event in a time series are arranged in a proper chronological order. A time series containing records of a single variable is termed as univariate. But if records of more than one variable are considered, it is termed as multivariate. A time series can be continuous or discrete. In a continuous time series observations are measured at every instance of time, whereas a discrete time series contains observations measured at discrete points of time. For example temperature readings, flow of a river, concentration of a chemical process etc. can be recorded as a continuous time series. On the other hand population of a particular city, production of a company, exchange rates between two different currencies may represent discrete time series. Usually in a discrete time series the consecutive observations are recorded at equally spaced time intervals such as hourly, daily, weekly, monthly or yearly time separations.The variable being observed in a discrete time series is assumed to be measured as a continuous variable using the real number scale. Furthermore a continuous time series can be easily transformed to a discrete one by merging data together over a specified time interval.

1.2.2 Components of a Time Series

A time series in general is supposed to be affected by four main components, which can be separated from the observed data. These components are: Trend, Cyclical, Seasonal and Irregular components. A brief description of these four components is given here. The general tendency of a time series to increase, decrease or stagnate over a long period of time is termed as Secular Trend or simply Trend. Thus, it can be said that trend is a long term movement in a time series. For example, series relating to population growth, number of houses in a city etc. show upward trend, whereas downward trend can be observed in series relating to mortality rates, epidemics, etc. Seasonal variations in a time series are fluctuations within a year during the season. The important factors causing seasonal variations are: climate and weather conditions, customs, traditional habits, etc. For example sales of ice-cream increase in summer, sales of woolen cloths increase in winter. Seasonal variation is an important factor for businessmen, shopkeeper and producers for making proper future plans. The cyclical variation in a time series describes the medium-term changes in the series, caused by circumstances, which repeat in cycles. The duration of a cycle extends over longer period of time, usually two or more years. Most of the economic and financial time series show some kind of cyclical variation. For example a trend/seasonal cycle consists of four phases, viz.

i. Prosperity
ii. Decline
iii. Depression and
iv. Recovery.

Schematically a typical business cycle can be shown as below:

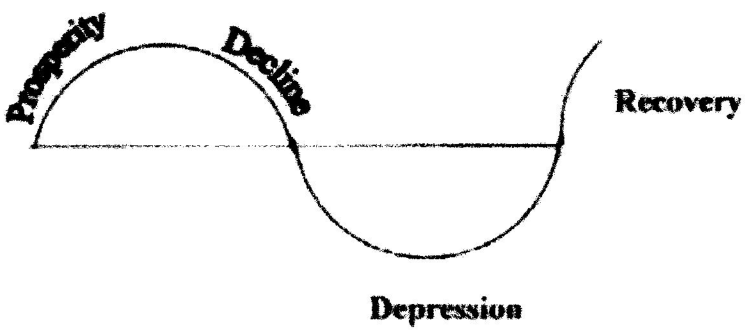

Fig.1.1: A four phase trend/seasonal full cycle

Irregular or random variations in a time series are caused by unpredictable influences, which are not regular and also do not repeat in a particular pattern. These variations are caused by incidences such as war, strike, earthquake, flood, revolution, etc. There is no defined statistical technique for measuring random fluctuations in a time series.

1.2.3 Time Series and Stochastic Process

Considering the effects of these four components, two different types of models are generally used for a time series viz. Multiplicative (Equation 1) and Additive models (Equation 2).

Multiplicative Model:

$Y(t)=T(t)\times S(t)\times C(t)\times I(t)$..(1)

Additive Model:

$$Y(t)=T(t)+S(t)+C(t)+I(t) \qquad (2)$$

Here Y(t) is the observation, T(t), S(t), C(t) and I(t) are respectively the trend, seasonal, cyclical and irregular variation at time . From the addictive model in Equation (model adopted for this study) the summation of the trend, seasonal and error component will sum up to the original time series data (i.e groundwater table data). Multiplicative model is based on the assumption that the four components of a time series are not necessarily independent and they can affect one another; whereas in the additive model it is assumed that the four components are independent of each other. A time series is non-deterministic in nature, i.e. we cannot predict with certainty what will occur in future. Generally a time series $\{x(t), t = 0,1, 2,...\}$ is assumed to follow certain probability model which describes the joint distribution of the random variable x_t. The mathematical expression describing the probability structure of a time series is termed as a stochastic process. Thus the sequence of observations of the series is actually a sample realization of the stochastic process that produced it. A usual assumption is that the time series variables x_t are independent and identically distributed (i.i.d) following the normal distribution. However, an interesting point is that time series are in fact not exactly i.i.d; they follow more or less some regular pattern in long term. For example if the temperature today of a particular city is extremely high, then it can be reasonably presumed that tomorrow's temperature will also likely to be high. This is the reason why time series forecasting using a proper technique, yields result close to the actual value.

1.3 AIM

To model variation in groundwater table depth in relation to time.

1.4 OBJECTIVES

1. To do trend analysis of daily groundwater fluctuation.
2. To determine rate of recharge and discharge into and from the groundwater.
3. To use a model for forecasting groundwater fluctuation.

1.5 STUDY AREA

The study area is Holy Apostolic Primary School located in Ootunja, Ikole Local Government Area (L.G.A.) of Ekiti State Southwestern Nigeria and it is accessible through Oye-Ilupeju-Itapa-Osi-Ikole and Ado-Ijan-Iluomoba-Ijeshalsu-Ikole route. Ikole is located between 7^0 47'$0^0$$5^0$31'$0^0$E and 7.78333^{0}N5.51667^{0}E. Two hand-dug wells were selected for this study, and groundwater table depths were measured on a daily basis. Most of the indigenes depend on groundwater as their only source of portable water supply. The Basement rocks show great variations in grain size and in mineral composition. The rocks are quartz gneisses and schists consisting essentially of quartz with small amounts of white micaceous minerals. In grains size and structures, the rocks vary from very coarse grained pegmatite to medium grained gneisses. (Adeyeri, et al 2016).

1.6 JUSTIFICATION

This study will help in the planning of the efficient use of groundwater and act as a guide to users of groundwater as the study will show when water will be sufficient enough and when it will not be sufficient in a particular time of the year because farming and marketing are the major work of the residence of Otunja Ikole Ekiti. Water is essential for the survival of mankind. Over the last years, the demand for water for agricultural, industrial and municipal usage has been on the increase. To meet these demands, surface and groundwater sources are required (Rastogi, 2007). In many regions, the groundwater resource is so huge that its occurrence and hydrological significance cannot be overlooked in the planning and management of water resources (Zakir et al., 2011). Groundwater modelling is an important tool that can be used to determine appropriate management strategies for groundwater conditions particularly in the areas where the hydrological cycles is predicted to be accelerated because of climate change (Mall et al., 2006).

1.7 SCOPE OF STUDY

This study covers modelling of groundwater table, groundwater trend analysis, seasonal variation in groundwater, boundary and initial conditions in groundwater. The study was carried out through daily observation of groundwater profile and the observation of daily rainfall. Rainfall data was obtained from Federal University Oye-Ekiti Metrological Station. Two different wells were selected for this purpose. Daily groundwater table depth and rainfall data from February to August was used for this study, and some assumptions were made.

Assumptions are:

1. The adjoining sidewall boundary was assumed to be a constant head boundary and flow through boundary.
2. The aquifer base stratum was assumed to be underlain with impermeable rock. This is based on study by Adeyeri et al., (2016).
3. The layouts of the boundary dormain cover the whole of the Holy Apostolic Primary School which is only a sub-set of the entire aquifer.
4. There is no source discharge from groundwater to adjoining streams.
5. The recharge and discharge rates were based on groundwater table fluctuation and observations at the site of the wells.

CHAPTER TWO

LITERATURE REVIEW

2.1 Time Series Analysis

Adeloye et al. (2002), defined a time series as observation made over a period of time. He stated that four fundamental assumptions form the base of hydrologic time series; homogeneity of the series, non-periodicity with no persistence, stationarity and freedom from trends or shifts. Homogeneity implies that the data in the series belong to one population, and therefore have a time invariant mean. Example is the groundwater table depth data obtained in this study. The wells are close-by and the series is likely to be homogenous in nature. Fernando et al. (1994) stated that Non-homogeneity arises because of changes in the method of data collection and the environment in which it is done. Example include time series data collected from two different locations which are far from each other. Stationarity implies that the statistical parameters estimated for different samples of a series do not change except due to sampling variations. Chen et al. (2002) established that a time series is said to be strictly stationary if its statistical properties do not vary with changes of time origin. In nature, strictly stationary time series does not exist. According to Kite (1989), Periodicities in natural time series are because of astronomical cycles such as earth's rotation around the Sun. Periodicity effect is not discernible in annual time series. O'Connel (1977), argue that persistence is relevant to hydrologic time series analysis, which is defined as the tendency for the magnitude of an event to be dependent on the magnitude of previous event(s).

2.1.2 Concept of Stationarity

Shumway and stoffer (2016) discussed that the concept of stationarity of a stochastic process can be visualized as a form of statistical equilibrium. The statistical properties such as mean and variance of a stationary process do not depend upon time. It is a necessary condition for building a time series model that is useful for future forecasting. Further, the mathematical complexity of the fitted model reduces with this assumption. There are two types of stationary processes which are defined below:

process $\{x(t), t = 0, 1, 2, \ldots\}$ is Strongly Stationary or Strictly Stationary if the joint probability distribution function of $\{x_{t-s}, x_{t-s+1}, \ldots, x_t, \ldots x_{t+s-1}, x_{t+s}\}$ is independent of t for all s. Thus for a strong stationary process the joint distribution of any possible set of random variables from the process is independent of time. However for practical applications, the assumption of strong stationarity is not always needed and so a somewhat weaker form is considered. A stochastic process is said to be Weakly Stationary of order k if the statistical moments of the process up to that order depend only on time differences and not upon the time of occurrences of the data being used to estimate the moments. For example a stochastic process $\{x(t), t = 0, 1, 2, \ldots\}$ is second order stationary if it has time independent mean and variance and the covariance values $Cov(x_t, x_{t-s})$ depend only on s. It is important to note that neither strong nor weak stationarity implies the other. However, a weakly stationary process following normal distribution is also strongly stationary. Some mathematical tests like the one given by Dickey and Fuller (1979) are generally used to detect stationarity in a time series data. The concept of stationarity is a mathematical idea constructed to simplify the theoretical and practical development of stochastic processes. To design a proper model, adequate for future forecasting, the underlying time series is expected to be stationary. Unfortunately it is not always the case. As stated by Hipel and McLeod (2005) in their work on time series modelling of water resources and environmental sysytems, the greater the time span of historical observations, the greater is the chance that the time series will exhibit non-stationary characteristics. However for relatively short time span, one can reasonably model the series using a stationary stochastic process. Usually time series, showing trend or seasonal patterns are non-stationary in nature. In such cases, differencing and power transformations are often used to remove the trend and to make the series stationary.

2.1.3 Model Parsimony

Adhikari and Agrawal (2013) in their work in Introductory Study on Time Series Modelling and Forecasting stated that, while building a proper time series model we have to consider the principle of parsimony. According to this principle, always the model with smallest possible number of parameters is to be selected so as to provide an adequate representation of the underlying time series data. Out of a number of suitable models, one should consider the simplest one, still maintaining an accurate description of inherent properties of the time series. The idea of model parsimony is similar to the famous Occam's razor principle. As discussed by Hipel and McLeod (2005), one aspect of this principle is that when face with a number of competing and adequate explanations, pick the most simple one. The Occam's razor provides considerable inherent informations, when applied to logical analysis. Moreover, the more complicated the model, the more possibilities will arise for departure from the actual model assumptions. With the increase of model parameters, the risk of overfitting also subsequently increases. An over fitted time series model may describe the training data very well, but it may not be suitable for future forecasting. As potential overfitting affects the ability of a model to forecast well, parsimony is often used as a guiding principle to overcome this issue. Thus in summary it can be said that, while making time series forecasts, genuine attention should be given to select the most parsimonious model among all other possibilities.

2.2 Classification of Hydrologic Time Series

2.2.1 Trend and seasonality

A time series is said to have trends, if there is a significant correlation (positive or negative) between the observations and time. Salas (1993) concluded that trends and shifts in hydrologic time series occur because of natural or artificial changes. Natural changes in hydrologic variables are usually gradual and are caused by several reasons. Global or regional climate change and urbanization are reasons for gradual change in hydrologic parameters over the period of study. Australian Bureau of Statistics (2008) discussed that artificial change (step change) in stream flow pattern may occur after a major regulation upstream of the monitoring site. An observed time series can have three components: (i) the trend (longterm direction) (ii) the seasonal (systematic calendar related) movements, and (iii) the irregular (unsystematic short-term) changes. Trend and seasonality are two basic components of a time series. The former represents a general systematic linear or (most often) nonlinear component that changes over time and does not repeat or at least does not repeat within the time range captured by the data. The latter may have a similar nature, but repeats itself at systematic intervals over time. In hydrology, time series analysis is done for achieving two major goals; to identify the nature of the hydrologic process represented by the sequence of observations, and to forecast future values of the time series hydrologic variable. For achieving these goals, the pattern of time series data is to be identified and described, which can be interpreted and integrated with other data.In practice a suitable model is fitted to a given time series and the corresponding parameters are estimated using the known data values. The three procedures (model identification, parameter estimation and diagnostic checking) of fitting a time series to a proper model is termed as Time Series Analysis. It comprises methods that attempt to understand the nature of the series and is often useful for future forecasting and simulation. In time series forecasting, past and present observations are collected and analyzed to develop a suitable mathematical model which captures the underlying data generating process for the series. The future events are then predicted using the model. This approach is particularly useful when there is not much knowledge about the statistical pattern followed by the successive observations or when there is a lack of a satisfactory explanatory model. Time series forecasting has important applications in various fields. Often valuable strategic decisions and precautionary measures are taken based on the forecast results. Thus making a good forecast, i.e. fitting an adequate model to a time series is very important. Over the past several decades many efforts have been made by researchers for the development and improvement of suitable time series forecasting models.

2.2.2 Parametric and Non-Parametric Analysis

Walsh (1962), Conover (1980) stated that method used for time series analysis fall into two classes: (i) parametric analysis, and (ii) non-parametric analysis. Parametric and non-parametric are two broad classification of statistical procedures. Parametric methods rely on assumptions about the shape of the distribution. The method assumes a normal distribution in the underlying population and considers the means and standard deviations of the assumed distribution. The most common parametric assumption is that data are nearly normally distributed. If the data deviate strongly from the assumptions of a parametric procedure, using the parametric procedure could lead to incorrect conclusions. Non-parametric methods rely on no or a few assumptions about the shape or parameters of the population distribution. Although assumptions about the distribution of measurements are less in non-parametric tests, they have two main drawbacks. (i) They are less statistically powerful than the similar parametric procedure when the data are nearly normal; and (ii) their results are often less easy to interpret compared to parametric tests. A non-parametric test will need a slightly larger sample size to have the same power as the matching parametric test. Many non-parametric tests use rankings of the values in the data rather than using the data. Even though non-parametric procedures are useful in many cases and necessary in some, they are not perfect solutions. Ramesh et al. (2000) concluded that parametric methods assess significance of trend by employing pre-specified model sand associated tests. Rank tests are generally applied in non-parametric methods.

2.3 Trend Analysis in Hydrologic Time

Yue et al. (2003) insisted that Mann-Kendall test is a commonly used non-parametric test for trend detection. It does not take into account whether the trend is linear or nonlinear. Studies show that the effectiveness of the test depends on the magnitude of trend, sample size, and the variation within a time series. Thus, the bigger the absolute magnitude of trend or larger the sample size, the more powerful are the tests. As the amount of variation in a time series increases, the power of the tests decreases. When a trend is present, the power is also dependent on the distribution type and skewness of the time series. Several studies on application of Mann-Kendall statistics for detecting trends in hydrologic data are available in literature (Fanta et al. 2001, Donald et.al2002, 2004). These studies show the strength of Mann-Kendall non-parametric trend test in bringing out trends in hydrologic data. This test is useful in the analysis of major flow regulations, since the absolute magnitude of trend in such cases will be larger.

2.4 Groundwater Movement

University of California (2003) expatiated that a geologic formation from which significant amounts of ground water can be pumped for domestic, municipal, or agricultural uses is known as an *aquifer*. In some cases, aquifers are vertically separated from each other by geologic formations that permit little or no water to flow in or out. A formation that acts as such a water barrier is called *aquitard* if it is much less permeable than a nearby aquifer but still permits flow (e.g., sandy clay). If the water barrier is almost impermeable (e.g., clay) and forms a formidable flow barrier between aquifers, it is known as an *aquiclude*. Aquifers can be of two major types: *unconfined* or *confined*. An unconfined aquifer has no overlying aquitard or aquiclude. Where there are multiple levels of aquifers, the uppermost aquifer typically is unconfined. Vertical recharge of an unconfined aquifer by rainwater or irrigation water that filters downward through the soil is not restricted. The water table at the top of the unconfined aquifer can migrate freely up and down within the sediment formation, depending on how much water is stored there, the water level in a borehole drilled into an unconfined aquifer will be at the same depth as the water table in the aquifer.A confined aquifer, on the other hand, is sandwiched between an aquitard above and an aquiclude or aquitard (e.g., bedrock) because the water table in the recharge area of the confined aquifer is much higher than the top of the confined porous sediment rock fractures aquifer itself, water in a confined aquifer isPressurized. This pressurization means that the water level in a borehole drilled into a confined aquifer will rise significantly above the top of the aquifer. A *flowing artesian well* occurs where the pressure is so high that the water level in a well drilled into the confined aquifer rises above the land surface— in other words, an open well flows freely with no pumping. Sometimes ground water is forced into a spring because a low permeable layer of rock or fine sediments (clay) keeps the water from percolating deeper. A spring may also occur where subsurface pressure forces water to the surface through a fracture or fault zone that acts as a conduit for water movement from a confined aquifer

2.4.1 Hydraulic Head and Gradient

University of California (2003), on water quality and technical assistance program for California Agriculture elucidated that groundwater movement is always in the downward direction of the hydraulic head gradient. The hydraulic gradient is often but not always similar to that of the land surface. Groundwater movement in gravel, confined aquifer, aquitard and sands is relatively rapid, whereas it is exceedingly slow in clay or in tiny rock fractures. The ability of geologic material to allow ground water movement is called unconfined, semi-confined, and confined aquifers in a typical alluvial basin. Dark-colored sediments indicate fine-grained clay or predominantly clay materials *(aquitard)*. Light-colored materials indicate coarser-grained aquifer materials. Ground water moves from higher elevations to lower elevations and from locations of higher pressure to locations of lower pressure. Typically, this movement is quite slow, on the order of less than one foot per day to a few tens of feet per day. In groundwater hydraulics (the science of groundwater movement), water pressure surface and water table elevation are referred to as the *hydraulic head*. Hydraulic head is the driving force behind groundwater movement. Groundwater movement is always in the downward direction of the hydraulic head gradient. If there is no hydraulic head gradient, there is no flow. The hydraulic gradient is often but not always similar to that of the land surface. In most areas of California's val- leys and basins the hydraulic gradient is in the range of 0.5 to 10 feet per thousand feet (0.05 to 1.0 percent).

2.4.2 Hydraulic Conductivity

University of California (2003), on water quality and technical assistance program for California agriculture noted that hydraulic conductivity is measured in gallon per day per square foot (gpd/ft) or in feet per day (ft/day). The amount of groundwater flow is greater with higher hydraulic conductivity, even if the hydraulic gradient is the same. The hydraulic conductivity of sandy or gravelly aquifers typically ranges from 100 to 10,000 gallons per day (gpd) per square foot (approximate equivalent: 10 to 1,000 ft/day). On the other hand, the hydraulic conductivity of clays, which consist of tiny particles that stick together and block water movement, is a tiny fraction of the hydraulic conductivity of a sandy aquifer: 0.001 gallon per day per square foot or less. The hydraulic conductivity of fractured rock depends greatly on the degree of fracturing. It may be as high as 10 to 100 gpd per square foot (approximately 1 to 10 ft/day).

The groundwater velocity is the product of hydraulic conductivity and hydraulic gradient, with adjustments for the porosity of the soil material (usually from 5 to 20 percent):

$$\text{Groundwater velocity} = \frac{\text{hydraulic conductivity} \quad \text{hydraulic gradient}}{\text{Porosity}}$$

2.5 Selection of Modelling Software

An important step in the modelling process is the selection of modelling software in which all possible options are considered (Kumar, 2013). In many cases, researchers have adopted the use of MODFLOW, developed by the US Geological Survey (Harbaugh et al., 2000). Ahmed and Umar (2009) used Visual MODFLOW to simulate the behaviour of the flow system and evaluate the water balance of Yamuna-Krishni interstream. The principle of finite difference method and its applications in groundwater modelling was discussed by Igboekwe and Achi (2011). Their study used finite difference method to solve the equations that govern groundwater flow to obtain flow rates, flow direction and hydraulic heads through an aquifer. Rodr'lguez et al. (2006) developed a groundwater/surface water interaction model for the shallow alluvial aquifer of the Choele Choel Island in Patagonia, Argentina. The model utilized MODFLOW and its stream package, and was successfully calibrated for a historical irrigation season. Their modelling results indicated that drainage through streams is significantly higher than drainage through artificial drains. Inverse modelling of groundwater flow was the approach used by Abdelaziz and Baker (2012) to evaluate the potential of groundwater resources for the development of the Sinai Peninsula. GMS was used for the numerical modelling, and parameterisation, PEST was used in GMS. A steady state calibration of the model was done and the results used as initial values for a transient run. The model assumed the calibrated recharge was constant over the transient simulation from 1988 to 2006. At the end of their study, they came to the conclusion that the water balance is in a critical situation and needs an improved management to exploit the water resources.

2.6 Groundwater Flow Modelling

Groundwater flow modelling at the source of River Ethiope, Delta State, Nigeria was undertaken by Okocha and Atakpo (2013). The watershed was modelled with a grid of 40 rows by 15 columns with 2 layers. Recharge from rainfall served as input while abstraction from boreholes served as output. A steady state groundwater simulation was carried out and calibrated using six target heads. The model converged after 150 iterations. The results from the modelling showed that abstraction was much more less than recharge. Therefore, further exploitation of the groundwater is possible. Igboekwe and Udoinyang (2011) carried out a study aimed at assessing the extent of the interaction between the Kwa Ibo River and the viable groundwater wells located within the premises of Michael Okpara University of Agriculture, Umudike. The watershed was modelled with a grid of 50 rows by 40 columns with two layers. Computed heads and porosity were used to compute groundwater velocity. The maximum groundwater velocity was 0.44m/d along the Kwa Ibo River. The predominant groundwater flow was found to be towards the south, but it was mostly towards Kwa Ibo River on both sides. Ujile (2013) used the principles of mass transfer to evaluate groundwater contaminants flow model in Yenagoa, Nigeria. The application of the model was carried out with the MATHCAD software systems. The model solution showed that the concentration levels of iron pollutants in the groundwater depends on the distance from source of pollution, time, process of transfer and flow regime. Overexploitation of the aquifers in Lagos Area, Nigeria led Abiola and Agbede (2012) to study and ascertain the extent of sea water intrusion in the area. The study used the two dimensional solute-transport in an incompressible porous medium and transport in the absence of sources and decay reactions. A computer program was developed to solve the 2-D dispersion problems. The model was calibrated in two steps, with the transient runs modelling chloride concentration for three aquifers. The results indicated that the area of chloride concentration increased from 13Km2 in 1996 to 38Km2 for the upper coastal plain sands, while the concentration increases from 68mg/L to 83mg/L . Edet et al. (2014), quantified the amount of exploitable aquifer in Akwa Ibom by a regional numerical groundwater flow modelling using MODFLOW. The model was calibrated under steady state conditions to determine the aquifer's hydraulic conductivity and recharge characteristics. Groundwater modelling system (GMS) software, MODFLOW-based software was also used for this study

2.7 Diurnal Cycle of the Groundwater Table

Maidment (1993) stated that water levels in piezometers fluctuate on time scales ranging from a few minutes to hundreds of years, depending upon the nature of the processes that initiate the fluid pressure variations. Short-term fluctuations in confined aquifers can be caused by changes in barometric pressure of the atmosphere, earth tides, and seismic events. Earth tides can lead to water-level changes of 1 or 2 cm; atmospheric pressure changes may cause fluctuations of several tens of centimeters, depending upon elastic properties of the aquifer and the magnitude of change in atmospheric pressure. These types of water-level changes are damped in unconfined aquifers. However, fluctuations can occur in response to time-varying rates in consumptive use of water by plants whose roots penetrate to the water table.

The difference between confined and unconfined aquifers is that confined aquifers are separated from the soil surface by a confining layer. This could be rock or a thick clay layer. The unconfined aquifer does not have this confining layer and water is able to move into the aquifer from the soil surface or river or lake.

Tromble (1977) explained the various components of the groundwater hydrograph. Groundwater fluctuations reflect varying rates of water use (evapotranspiration) and water movement through the soil. He pointed out there are several inflection points in the diurnal fluctuations.

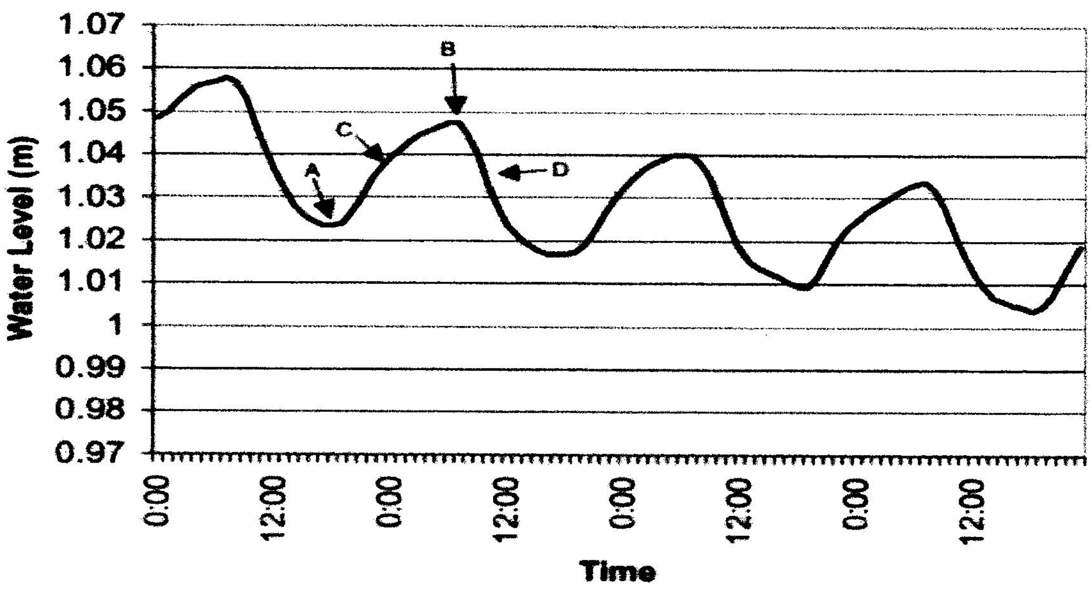

Fig.2.1: Diurnal fluctuations of groundwater table with inflection points (Tromble 1977)

At point (A) the inflow and outflow are about the same, at point (B) recharge and transpiration are at a minimum, at point (C) inflow is greater than outflow and at point (D) outflow is greater than inflow. In Figure 2.1, at the lowest point (A) on the curve, the inflow and outflow of water are about the same; both high, and at the highest point on the curve (B) recharge and transpiration are at a minimum. When outflow is greater than inflow (D) transpiration is high and when inflow is greater than outflow (C) transpiration rates are lower for the day. The recharge stopped at point (B) because the water level had reached the static head. The night time peak (B) and the daytime low (A) decrease over time due to water loss from evapotranspiration from the shallow water table or flow from the system.

Numerous researchers (White 1932, Croft 1948, Kittredge 1948, Gatewood et al. 1950, Heikurainen 1963, van Hylckama 1974, Tromble 1977, Anderson 1982, Gerla 1992, Sala et al. 1996, Rosenberry and Winter 1997, Caldwell et al.1998, Dulohery et al. 2000, and King and Bawazir 2000) have noted the diurnal trends in groundwater levels. Of these White (1932), Kittredge (1948), Gatewood et al. (1950), Heikurainen (1963), van Hylckama (1974), Tromble (1977), Rosenberry and Winter (1997), and Dulohery et al. (2000) investigated these fluctuations as a way to measure plant water use. Goodrich et al. (2000) noted in their study of riparian evapotranspiration that stream flow exhibits a distinct diurnal fluctuation prior to the first hard freeze and that this pattern dissipates after the freeze. They attribute this fluctuation to air temperature and riparian evapotranspiration. Laczniak et al. (1999) reported observing diurnal groundwater fluctuations in wells and attributed it primarily to local evapotranspiration. They noted that the "magnitude and timing of the fluctuation differs with well depth, vegetation and soil conditions, climate, and distance from a surface water source." Rosenberry and Winter (1997) in their investigations of groundwater fluctuations in prairie wetlands observed diurnal head fluctuations in groundwater monitoring wells and attributed it to daily evapotranspiration. White (1932) noted that diurnal groundwater fluctuations, in an alfalfa field, began in the spring when plants put on leaves and ceased in the fall after killing frosts. He also found that "generally the daily fluctuations vary directly with the temperature, wind movement, and intensity of sunlight and inversely with the humidity, and they 16 follow more or less closely the daily fluctuations in evapotranspiration from a free water source." He also found that the stage and vigor of plant growth influenced the amount of the daily groundwater fluctuation.

2.7.1 Soils/Specific Yield

White (1932) noted that the fluctuations in groundwater monitoring wells varied in amplitude with the amount of water discharged from the zone of saturation by evapotranspiration. He also noted:

That the amount of the daily rise and fall is a function of the texture of the material in the belt of fluctuation, which controls the capacity of the material to give up water under the pull of gravity after being saturated. This capacity is the specific yield of the soil. The specific yield of a rock or soil with respect to water is the ratio of 1) the volume of water which after being saturated it will yield by gravity to 2) its own volume. It is the measure of the volume of pore space alternately emptied and filled during the daily fall and rise of the water table, or it may be defined as the depth of water that drains out of the soil as the water table declined or enters the soil as the water table rises, expressed as a percentage of the depth of soil alternately drained or resaturated. For example, if the removal of a quantity of water representing a depth of 0.1 inch on a given area causes the water table to decline 1 inch under the area, the specific yield of the soil in which the decline takes place is 10 [percent].

Specific yield is directly related to soil texture. Johnson (1967) developed a specific yield triangle to determine specific yields based on soil texture. The specific yield of the soil increases as the percent of sand in the soil increases, and the more clay in the soil the lower the specific yield.

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

The methodology adopted for this study can be grouped into two:

1. Time series analysis and
2. Groundwater modeling.

3.2 DATA COLLECTION AND REDUCTION

Data relating to groundwater table level from February to August was obtained through on-site observation for two different well. The metrological data used for this study was obtained from the Federal University Oye-Ekiti metrological station. The flowing are the data used for the groundwater modeling:

i. Rainfall: Rainfall data from February 2017 to August 2017 as obtained from Federal University Oye-Ekiti metrological centre was used for this study.
ii. Groundwater level: Groundwater level depths were obtained from two different well located in otunja-Ikole Ekiti.
iii. Pumping rate: A rough estimate of the pumping rate was obtained through on-site interview. The average water demand per day was obtained as 40 liters per day per capital.
iv. Hydraulic conductivity: Estimates for hydraulic conductivity was obtained from Adeyeri et al., (2016)
v. Ground elevation: Groundwater bedrock depth and elevation was obtained from Adeyeri et al., (2016)
vi. Location (Coordinates): Location coordinates was also obtained from Adeyeri et al (2016).
vii. Boundary (Study area):

Software packages

i. Google earth
ii. MODFLOW
iii. ArcGIS
iv. Minitab Statistical Software.

The Procedural Step for modelling of groundwater using time series approach are:

3.3CurveFitting

To make a realistic estimate of missing data a curve that gives a true reflection of the fluctuation pattern in the series was used. The suitability of a linear regression equation and the quadratic regression equation was compared. The polynomial curve give a better fitting to the groundwater table plot as shown in Table 3.1, having the lower value for sum of square error, and therefore was used for the fitting of missing data.

Table 3.1: Sum of Square Error

Source	DF	SS
Linear	1	0.279334
Quadratic	1	0.004161

The model was adopted for values at close range to the missing data. For example in 01/02/2017, the quadratic model $Y = 4.780 - 0.01748*(X) + 0.005600*(X)^2$ was used to obtain the missing data by considering data at close range to the missing data i.e groundwater level data for day 1, 2, 3, and 4. Similar procedure was used for the other missing data in the series.

3.4Addictive Model of Classical Decomposition

Trend analysis involves the analysis of the below stated addictive decomposition model (Equation 3.1):

The addictive model is $Y_t = S_t + T_t + E_t$ 3.1

Where

Y_t = Time series value (actual value) at period t

S_t = Seasonal component (index) at time t

T_t = Trend cycle component at time t

E_t = The irregular (remainder) component at period t

3.3.1 Trend analysis

This will be achieved using least square estimation of the model parameter. The linear trend model is shown in Equation 3.1

$$T_t = \alpha t + \beta \tag{3.1}$$

Where α and β are the least square estimator

This will entail the following procedure for the determination of the trend component. The seasonal component of the series was neglected considering that the groundwater table depth data obtained is not up to 12 months.

3.4 Boundary and Initial Condition

The first step in carrying out the modelling was to obtain the physical boundary of the study area. This was obtained by using Google Earth and GIS. Google Earth was used to map out the polygon for the study area which was saved as a .kml file and then imported into GIS. The .kml file was then converted into a layer and subsequently exported as a shape file to be used in GMS. The groundwater model was developed using GMS. The steps involved in the model development are stated below:

1. **Boundary coverage:**The model boundary is the first coverage that is created in GMS. It utilises the boundary shape file imported from ArcGIS.
2. **Source and sink coverage:** In this coverage, the wells and boundary conditions are specified. Two wells were used in this study. The data

requirements for the wells are the well locations, groundwater level data, and the pumping rate. The pumping rate used in this study was 400 L/day for both wells. The boundary condition used was the specified head boundary condition.

3.4.1 Determination of hydraulic head

The hydraulic head was calculated as shown in Figure 3.1. The impermeable datum was observed at an average depth of 18 meters The hydraulic conductivity was also obtained as 1.2×10^{-4}cm/s (Adeyeri et al., 2016).

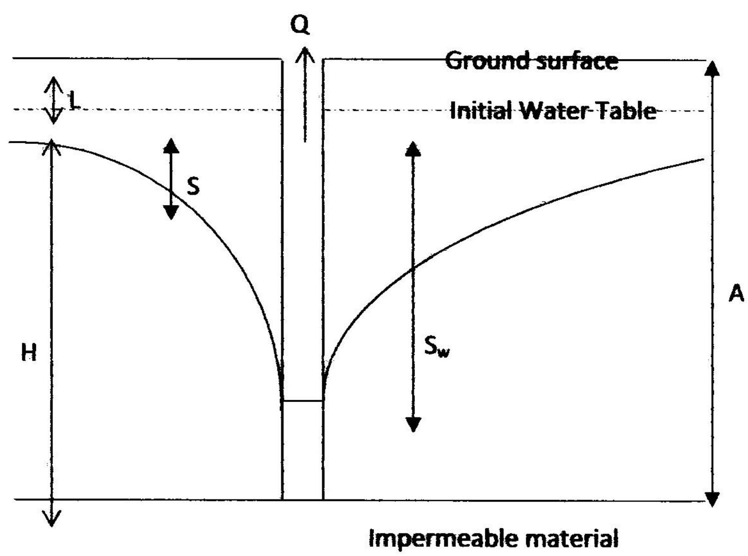

Figure 3.1: Basics of a pumping well

Figure 3.1 shows the description of a pumping well in an unconfined aquifer, where,Q = Pump rate (m^3/s),S = Drawdown (m),S_w = Drawdown in the well (m),L = Depth to initial water table (m),A = Altitude (Height above sea level), H = Hydraulic head (Thickness or depth of aquifer) (m),

3.4.2 The recharge rates

In the recharge coverage, the recharge rate is specified. The recharge was assumed to be uniform in the study area. The recharge rates were obtained from the time series modelling of trend results. The recharge rates used for the steady state run are shown in Table 3.2

Table 3.2: Recharge rate (Steady state run)

Date	Recharge rate
28/02/2017	0.000101786
31/03/2017	0.000235806
30/04/2017	0.0001745
31/05/2017	0.000125968
30/06/2017	0.000116667
31/07/2017	0.000220968
31/08/2017	3.70968E-05

3.4.3 MODFLOW grid

The MODFLOW grid was created to bound the study area. The grid was automatically generated based on refine points created around the wells to ensure each well falls between a cell in the grid. The next step was to interpolate top elevation, bottom elevation and starting heads data into the model. These data were imported as text files into GMS and interpolated to the MODFLOW layers. The top elevation data was gotten from Google Earth and subsoil investigation report carried out within the study area. The bottom elevation was gotten based on the depth of the boreholes. The starting head values was calculated from the groundwater level data obtained during the field work of this study.

3.4.4 Steady and transient state run

The model was set in a steady state (that is, when there was no pumping) run for 3rd of February, 2017. This was done to observe the head distribution for the study area and also to prepare the model for a steady state calibration. Groundwater heads observed in February were used as the observed head and a confidence interval of 1.5m was set. No calibration was needed as the model was seen to have met the conditions for a calibrated model, that is, the calculated heads were within the confidence interval, hence, the model can be said to be calibrated. The model was thereafter set under a transient run from 3rd of February, 2017 to 28th of July, 2017. This was done to see the model's response to stress (rainfall and pumping) during this period. As with the steady state, after the transient run, the model required no further calibration, hence, it was ready to be used for prediction.

3.4.5Predictive run

A prediction run was carried out after transient model calibration from August 2017 to October 2017. The forecast calibration was done by comparing predicted value to actual values obtained for the months of September and October.The pumping rate was still set at 400L/day for both wells, while the recharge rate used was calculated from rainfall data for the months.

3.5 Conceptual Model

Development of a valid conceptual model is the most important step in a computer modelling study. A conceptual model is a simplified representation of the essential features of the physical hydrogeological system, and its hydrological behaviour, to an adequate degree of detail. The conceptual model is usually presented graphically as a cross-section or block diagram, with supporting documentation outlining in descriptive and quantitative terms the essential system features. It forms the foundation upon which the interactive, site-specific model is built, and is itself based on an initial literature review, data collation and hydrogeological interpretation. While the conceptual model is an idealised summary of the current understanding of catchment conditions, and the key aspects of how the flow system works, it is subject to some simplifying assumptions. The assumptions are required partly because a complete reconstruction of the field system is not feasible, and partly because there is rarely sufficient data to completely describe the system in comprehensive detail. However, the conceptual model should be developed using the principle of simplicity (or parsimony), such that the model is as simple as possible, while retaining sufficient complexity to adequately represent the physical elements of the system, and to reproduce system behaviour. The principle of simplicity/parsimony is also known as Ockham's Razor - "Entia non sunt multiplicanda sine necessitate". This may be translated literally as "The number of entities should not be increased without good reason", or loosely as "It is vain to do with more what can be done with fewer" (Constable et al., 1987). This principle dates from the early 14th Century, and is fundamental to many aspects of life. In developing an adequate (parsimonious) conceptual model, however, sufficient degrees of freedom must be incorporated to the model features to allow simulation of a broad range of responses. It must be possible for the model to predict system responses ranging from desired to undesired outcomes. In other words, the model must not be configured or constrained such that it artificially produces a restricted range of prediction outcomes.

A good conceptual model should describe reality in a simple way that satisfies modelling objectives and management requirements (Bear and Verruijt 1987). It should summarise our understanding of water flow or contaminant transport in the case of groundwater quality modelling. The key issues that the conceptual model should include are:

i. Aquifer geometry and model domain
ii. Boundary conditions
iii. Aquifer parameters like hydraulic conductivity, porosity, storativity, etc
iv. Groundwater recharge • Sources and sinks identification
v. Water balance

3.6 Infilterometer Test

Infiltration is the process by which water arriving at the soil surface enters the soil. This process affects surface runoff, soil erosion, and groundwater recharge. Being able to measure the surface infiltration rate is necessary in many disciplines. The double ring infiltrometer is a simple instrument used for determining water infiltration of the soil (Measurements according to ASTM D3385-03 standard test method and DIN 19682 page 7). The rings are partially inserted into the soil and filled with water, after which the speed of infiltration is measured. The double ring limits the lateral spread of water after infiltration. The standard set consists of three pairs of inner and outer rings, allowing synchronic measuring. This saves time and produces reliable average data. Infiltration is the process of water penetrating the ground surface. The intensity of this process is called the infiltration rate. The infiltration rate is expressed in terms of the volume of water per ground surface and per unit of time [L/T, for instance mm/min]. The infiltration capacity of the soil indicates the maximum infiltration rate at a certain moment. Under certain circumstances, it may be necessary to determine the infiltration capacity of the soil, for instance in infiltration areas or infiltration basins. The double ring infiltrometer is suitable for almost any type of soil and is applied in irrigation and drainage projects, groundwater and infiltration basins, in optimising water availability for plants and to determine the effects of cultivation.

The double-ring infiltrometer is often used for measuring infiltration rates, and has been described by Bouwer and by ASTM. These references contain standard guidelines for conducting double-ring infiltration tests; however, in practice a wide variety of testing methodologies are used. Ring infiltrometer consist of a single metal cylinder that is driven partially into the soil. The ring is filled with water, and the rate at which the water moves into the soil is measured. This rate becomes constant when the saturated infiltration rate for the particular soil has been reached. The size of the cylinder in these devices is one source of error. A 15-cm diameter ring produces measurement errors of approximately 30%, while a 50-cm diameter ring produces measurements errors of approximately 20% compared to the infiltration rate that would be measured with a ring of an infinite diameter. It has been suggested that a diameter of at least 100 cm should be used for accurate results. However, cylinders of this size become very difficult to use in practice on light soils, because large volumes of water are required to conduct tests on sandy soils with high infiltration rates. Applied Turfgrass Science 31 May 2005 Single-ring infiltrometer overestimate vertical infiltration rates. This has been attributed to the fact that the flow of water beneath the cylinder is not purely vertical, and diverges laterally. This lateral divergence is due to capillary forces within the soil, and layers of reduced hydraulic conductivity below the cylinder. A number of techniques for overcoming this error have been developed (such as a correction procedure that uses an empirical equation) for 15-cm diameter rings. Double-ring infiltrometers minimize the error associated with the single-ring method because the water level in the outer ring forces vertical infiltration of water in the inner ring. Another possible source of error occurs when driving the ring into the ground, as there can be a poor connection between the ring wall and the soil. This poor connection can cause a leakage of water along the ring wall and an overestimation of the infiltration rate. Placing a larger concentric ring around the inner ring and keeping this outer ring filled with water so that the water levels in both rings are approximately constant can reduce this leakage. The double-ring infiltrometer test is a well recognized and documented technique for directly measuring soil infiltration rates. Bouwer describes the double-ring infiltrometer as often being constructed from thin walled steel pipe with the inner and outer cylinder diameters being 20 and 30 cm, respectively; however, other diameters may be used. There are two operational techniques used with the double-ring infiltrometer for measuring the flow of water into the ground. In the constant head test, the water level in the inner ring is maintained at a fixed level and the volume of water used to maintain this level is measured. In the falling head test, the time that the water level takes to decrease in the inner ring is measured. In both constant and falling head tests, the water level in the outer ring is maintained at a constant level to prevent leakage between rings and to force vertical infiltration from the inner ring. Numerical modeling has shown that falling head and constant head methods give very similar results for fine textured soils, but the falling head test underestimates infiltration rates for coarse textured soils. The ASTM standard describes a procedure for measuring the soil infiltration rate with a double-ring infiltrometer for soil with a hydraulic conductivity between 1 × 10-2 and 1 × 10-6 cm/s (360 mm/h to 0.036 mm/h). The ASTM standard specifies inner and outer diameters of 30- and 60-cm, respectively. There are also some minor differences in the method that is suggested by the standard compared to that described by Bouwer.

3.6.1Soil water

3.6.1.1Soil water energy

Soil water is subjected to forces caused by gravity, capillarity, adsorption and osmosis. Capillary forces and osmosis in conjunction act as matrix force to the soil water (osmotic forces, in particular in areas low in salt, are negligible). The soil water energy is expressed in terms of potential energy or potential. The soil water potential is made up of the gravitational potential and the pressure potential (comprising a negative pressure or "suction" in the unsaturated zone and a positive pressure in the saturated zone). Under the influence of the potential differences, water flows in a certain direction at a certain speed. The rate of flow also depends on the hydraulic conductivity of the soil. The hydraulic conductivity [L/T] varies with moisture content of the soil: the dryer the soil, the lower the level of hydraulic conductivity; soil pores filled with air do not conduct water. Saturated soil has the highest level of hydraulic conductivity (saturated hydraulic conductivity). This hydraulic conductivity is mainly determined by the geometry and the distribution of pores.

3.6.1.2 Infiltration

Water infiltrates the soil during a shower or irrigation. If moistening exceeds the infiltration capacity, water ponds the ground surface. In that case, the infiltration rate equals the infiltration capacity. This will cause in homogeneous soils a saturated top layer, with below a near-saturated zone which will expand by wetting of the underlying soil.

The theory of Green & Ampt (1911) describes the process of infiltration. The theory is derived from Darcy's Law, formulated as: $f = K\,(Hw + D - Hf)\,/D$

where (see figure below): f refers to the infiltration capacity [L/T], K to the near-saturated hydraulic conductivity [L/T], Hw is the thickness of the water layer [L], D refers to the depth of the wetting front [L] and Hf refers to the pressure head at the wetting front [L].

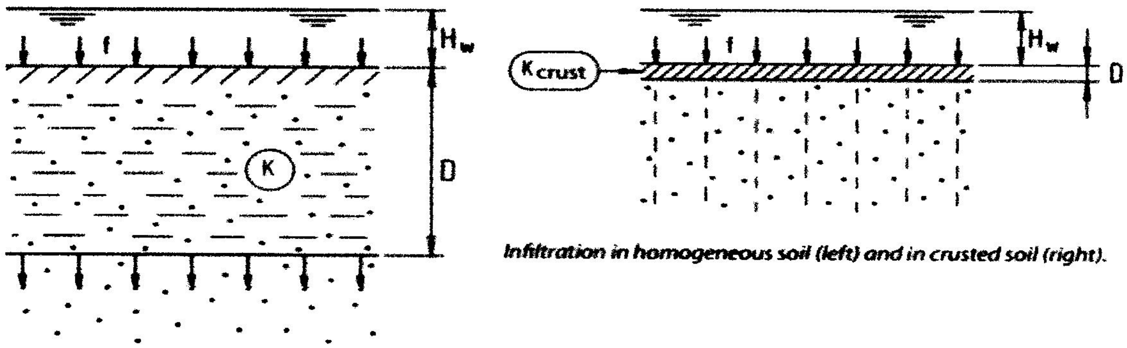

Fig.3.2: Infiltration in homogenous soil and in crusted soil

Some examples of constant infiltration rates (or near-saturated hydraulic conductivity) for different soil types are listed in table 3.1

Table 3.1: Example of Constant Infiltration Rate

Soil type	Constant infiltration rate (mm/h)
Sand	> 30
Sandy loam	20 - 30
Loam	10 - 20
Clayey loam	5 - 10
Clay	1 - 5

See Bouwer (1986), ILRI (1974), Ward & Robinson (1990) for further information concerning soil water, infiltration and the use of the double ring infiltrometer.

3.6.1.3Description

The standard double ring infiltrometer set consists of three pairs of inner and outer rings, a driving plate, an impact absorbing hammer, measuring bridges and measuring rods with floats. The pairs of stainless steel infiltration rings have the following diameters: 28/53 cm, 30/55 cm and 32/57 cm. The ring's height is 25 cm and it has one cutting edge (after DIN 19682-7). The purpose of the outer ring is to have the infiltrating water act as a buffer zone against infiltrating water straining away sideways from the inner ring (this applies in particular for heterogeneous soils). Steel pull-out hooks allow removal of the rings. The varying diameters make them easy to stow and transport. Each inner ring has a synthetic measuring bridge (3), the measuring rod (1) with float (4) moves freely up and down through a small tube (2) in the measuring bridge (see figure 3.4). The measuring rod indicates the water level. The float is positioned in the middle of the inner ring. As the measuring rod moves freely through the tube, the wind hardly affects measuring. The measuring rods have a millimeter calibration.

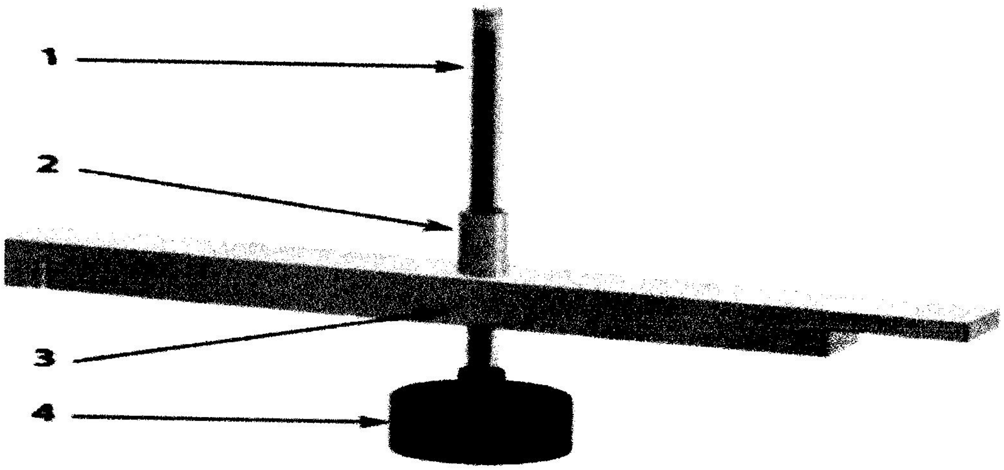

Fig.3.4: Inner Ring Synthetic Measuring Bridge

The galvanized steel driving plate is cross-shaped with a beating head in the middle. It is used for hammering in the 28 -57 cm infiltration rings. Pins located at the bottom of the ring ensure proper placement and allows the outer ring to be centrically positioned. The shape of the driving plate spreads the effect of the hammering and does not damage the rim. This also ensures undisturbed insertion into the soil. The steel hammer is impact-absorbing; its head contains lead bullets flowing in the direction of the stroke upon impact. Its nylon cups prevent damage to the driving plate.

3.6.2The Use of the Double Ring Infiltrometer

3.6.2.1 Installation

1.Place the inner ring with the cutting edge facing down on the ground. Remove small obstacles such as stones or twigs. When measuring below the ground surface, a profiled pit should be made.

2.Put the driving plate on top of the inner ring. Depending on its diameter the ring will fit over, between or within the pins located on the bottom side of the driving plate.

3. Use the impact-absorbing hammer to insert the infiltration ring about 5 cm vertically into the soil. Make sure to disturb the soil as little as possible. In stiff soils have someone stand on the driving plate while another person drives it in. Remove the driving plate from the inserted infiltration ring. Keep the depth of placement as limited as possible so as not to disturb the top layer. Insert the rings in any case to below a particular top layer, such as a disturbed or crusted top layer or layer with macro-pores. In the case you should encounter any play between the ring and the ground, push the ring back in its place. A disturbed crust can be healed using bentonite or other soil material.

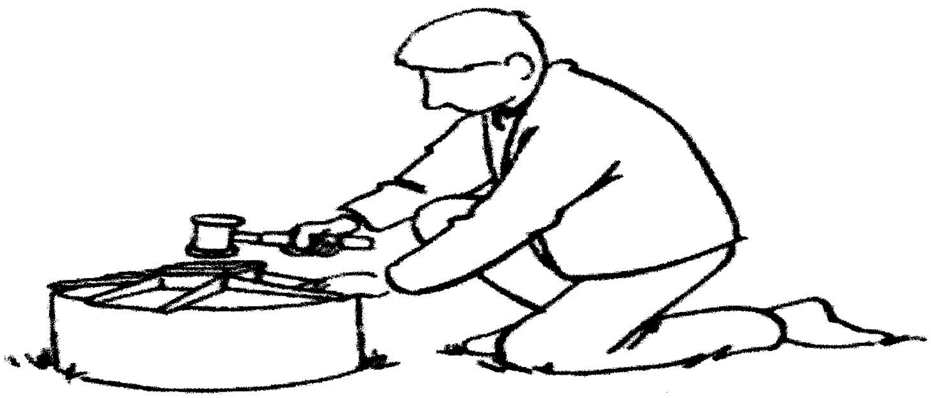

Fig. 3.5: Impact-Absorbing Hammer to Insert the Infiltration Ring

4.Place the outer ring with the cutting edge facing down around the inner ring and put the driving plate on top of it.

5. Repeat step 3. (see figure 3.4.1). The shape of the driving plate will ensure a depth identical to that of the inner ring.

6. The standard double ring infiltrometer set allows simultaneous measuring in threefold. Place the rings 2 - 10 m apart, depending on the field situation, and repeat

steps 1 to 5.Place all rings at a similar depth to allow comparison of the results. Differing ring diameters are not supposed to produce differing results.

7. Place the measuring bridge with measuring rod and float on the inner ring. Remove, without disturbing the soil structure, any vegetation that may hamper free movement of the float or affect the measuring.

8.Fill the outer ring with water, then the inner ring, to approximately 5 - 10 cm. Start measuring immediately to determine the infiltration curve. The water level within the infiltration rings should be as low as possible to ensure vertical infiltration. The rings should not go dry. It is recommended to fill to 5 - 10 cm. To protect the ground surface when pouring the water, use plastic foil, a jute cloth, sponge or a 1-2 cm layer of sand or gravel. It is also possible to pour the water via your hand on the ground. Make sure to have sufficient water at hand. Filling one set of rings requires approx. 25 litre.

Some remarks:

To measure only the infiltration capacity of saturated soil it will suffice to saturate the soil (by pouring water in thep rings) without measuring. To obtain optimal results in determining the infiltration capacity, use water of a similar quality and temperature top that of the real system you are examining.

3.6.3 Measuring

1. Start the measuring by noting the time and the water level in the inner ring (reference level) as indicated on the measuring rod. Use columns A and B on the field list. When carrying out synchronic measuring, use several field lists. Always use copies of the field list; use the original only for reproduction.

2.Determine the drop in the water level in the inner ring during a certain interval. Note the time and the water level in column A and B on the field list. Start with short intervals (for instance 1-2 min) and conclude measuring with a longer interval (20 - 30 min, depending on the type of soil). Make sure the infiltration rings do not go dry during measuring. Add water when only a few centimetres of water are left in the rings. Write the new levels in column B of the list. Keep the water in the inner and outer ring at a similar level. A higher water level in the outer ring will lead to a decreasing infiltration rate in the inner ring. A lower water level in the inner ring will cause the buffering against lateral spreading to decrease.

Fig. 3.5: Observation of water level in an infiltrometer apparatus

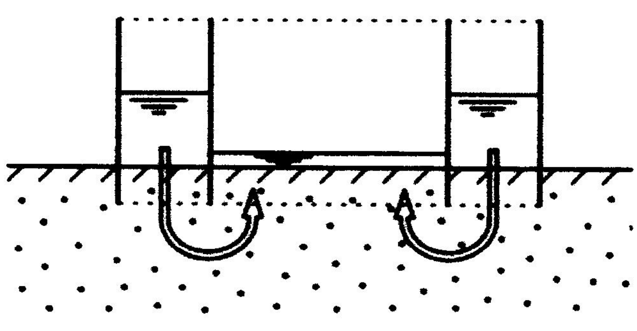

Fig. 3.6: Decreasing infiltration caused by different water levels in the inner and the outer rings.

3. Stop measuring only if the infiltration rate has reached a constant value. A change of < 10% in a certain phase is often considered as constant. Depending on the type of soil this may occur within 1 or 2 hours, in exceptional cases only after a day.

4. Remove the rings using the pull-out hooks.

5. Rinse the rings; make sure no earth sticks and sets to the rings. Proper maintenance will prevent unnecessary disturbance of the soil upon installation.

3.6.3.1 Computation of the measuring data

1. Calculate the cumulative time and time steps in columns C and D using the data in columns A and B. Determine the infiltration in column E by calculating the water level differences between intervals in column B.

2. Calculate the infiltration capacity (mm/min) in column F by dividing for each interval the infiltration (column E) by the time step (column D). If necessary, convert the infiltration capacity to e.g. [m/hour] in column G.

3. The tabulated data can be used to determine the infiltration curve. Plot out the calculated infiltration capacity (column F or G) on the y-axis of a graph and the cumulative time (column C) on the x-axis.

4. The near-saturated hydraulic conductivity equals the more or less constant infiltration capacity established toward conclusion of the measuring. Use multiple measurements to calculate a reliable mean value for a certain type of soil or landscape unit.

5. Determine, if necessary, the cumulative infiltration for a certain period. The cumulative infiltration is the total amount of water infiltrating over a certain period of time (L, for instance mm). Fill in column H of the field list by adding the total infiltration (column E) for each interval from the starting of measuring on.

3.6.3.2 Applications

The double ring infiltrometer is suitable for almost any type of soil with the exception of clogging soils, stony soils or the soil of steep slopes. The outer ring causes almost vertical infiltration of water from the inner ring. A number of soil hydrological features can be determined (per soil layer):

1. Infiltration capacity.
2. Near-saturated hydraulic conductivity.
3. Infiltration curve.

4. Cumulative infiltration over a certain period.

The double ring infiltrometer is applied, among other things, in determining the infiltration capacity of flooded soils for:

1. Surface irrigation and drainage projects.Infiltration or water purification basins.
2. Seepage from watercourses, canals, basins or wastewater lagoons.
3. Soil leaching at waste storage sites.
4. Research into the effects of cultivation.
5. Research into drainage effects.
6. Research into badly permeable layers of sports fields.

3.6.3.3 Troubleshooting

1. If horizontal insertion of the infiltration ring and the driving plate is not successful, a stone or a root might impedep the process. Choose another spot for measuring.

i. If the infiltration rate proves not to be constant, continue measuring. A variance of less than 10% per interval is considered as constant.

ii. Increased infiltration is established. This may result from:

a. Macro pores. They tend to occur in soils susceptible to shrinkage (cracks and fissures resulting from drought), as a result of vegetation (rooting), soil fauna, or in strongly disturbed topsoil (ploughing). Insert the ring well into the soil, to below the disturbed top layer. Carry out measuring at several representative spots to obtain a reliable mean infiltration curve of the soil or landscape unit.

b. Disturbance of the soil caused by installation of the ring. Bentonite or other types of clay may be used to healp crusted or disturbed soils. Play between the infiltration ring and the ground can be fixed by applying soil.

c. If the water level in the inner ring exceeds the level in the outer ring, buffering against lateral spreading is insufficient. Make sure the water in both rings has the same level.

d. In well-layered soils, water will tend to strain off sideways, despite the use of the double ring. If necessary, determine the infiltration curve of the underlying layers separately in a pit.

e. Too high a water level in the infiltration rings will cause the water to spread laterally. The maximum water level should be 5 -10 cm.

f. Sustained measuring will increase lateral spreading.

2. Infiltration is below expectation. Several factors may be the cause:

a. The soil is crusted. First, establish the infiltration curve of the undisturbed (crusted) soil, then remove the crust andρ measure again. A large difference in infiltration indicates the occurrence of a crust. Usually the crust will measure less than 1 centimetre (Bouwer, 1986).

b. If the water level in the outer ring exceeds the level in the inner ring, water from the inner ring will hardly infiltrateρ and may become negative. Make sure the water has the same level in both rings.

c. The water poured into the rings has disturbed the soil structure. Protect the soil and use plastic foil, a jute cloth,ρ sponge, or a 1-2 cm layer of sand or gravel. It is also possible to pour the water on the ground via your hand.

d. Water used for measuring, containing sediments or other suspending agents may cause a low-permeable layer. Useρ water of a similar quality and temperature to that of the soil of which you are measuring the infiltration capacity.

3.7 Modelling Softwares

3.7.1 Groundwater Modelling System (Gms) 10.1

GMS (Groundwater Modelling System) is a comprehensive software package for developing computer simulations of groundwater problems (flow and contaminant transport). The Environmental Modelling Research Laboratory at Brigham Young University in Utah oversees the continued development of GMS, but GMS is distributed commercially through a variety of vendors. GMS provides tools for site characterization, model development, post-processing, calibration, and visualization (Kumar, 2012).

3.7.2 MODFLOW

GMS makes use of MODFLOW which is a computer code that solves the groundwater flow equation. MODFLOW is a modular finite-difference flow model computer code and is considered as the standard code for groundwater simulation (Strikker, 2014).

3.7.3 Google earth

Google Earth is a virtual globe, map and geographical information programme. It maps the Earth by the superimposition of images obtained from satellite imagery, aerial photography and a three dimensional geographic information system (GIS) globe.

3.7.4 ArcGIS 10.3

ArcGIS is a geographic information system (GIS) for working with maps and geographic information. It is used for: creating and using maps; compiling geographic data; analysing mapped information; sharing and discovering geographic information; using maps and geographic information in a range of applications; and managing geographic information in a database (Wikipedia, 2016).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Infiltration Test

The infiltration capacity of a soil decreases rapidly over time during infiltration. The course of infiltration capacity in time is expressed in terms of the infiltration curve (see figure 4.1 and 4.2).

Table 4.1 Infiltration table for test A

A	B		C	D	E	F	G	H
Time Reading Hour min sec	Water level		Cumulative Time Determine From A min	Time interval Determine from A min	Infiltration Determine from B mm	Infiltration capacity Cal. From D&E Mm/min	Infiltration capacity cal. From F .../...	Cummulative infiltration Determine from E Mm/min
	Before Reading mm	After Reading Mm						
0	20	20	0	0	0	0	0	0
5	20	18.9	5	5	1.1	0.22	0.22	0.22
10	18.9	18	15	10	2.0	0.2	0.2	0.42
15	18	17.5	30	15	2.5	0.166	0.166	0.586
20	17.5	16.8	50	20	3.2	0.16	0.16	0.746
25	16.8	16.1	75	25	3.9	0.195	0.195	0.941
30	16.1	15.6	105	30	4.4	0.147	0.147	1.088
35	15.6	15	140	35	5	0.143	0.143	1.231
40	15	14.5	180	40	5.5	0.137	0.137	1.368
45	14.5	14	225	45	6	0.13	0.13	1.498
50	14	13.6	275	50	6.4	0.13	0.13	1.628
55	13.6	13	330	55	7	0.13	0.13	1.758
60	13	12.5	390	60	7.5	0.13	0.13	1.888

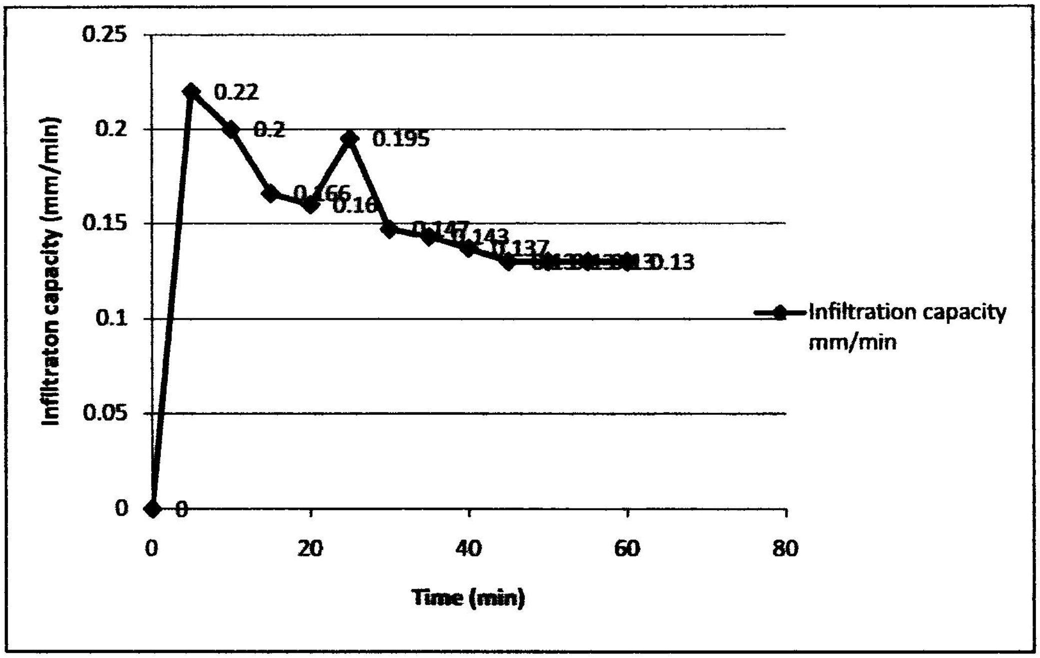

Fig.4.1: Infiltration Capacity Against Time For Test A

Table 4.2 Infiltration table for test B

A	B		C	D	E	F	G	H
Time Reading Hour min sec	Water level Before Reading Mm	After Reading mm	Cumulative Time Determine From A min	Time interval Determine from A min	Infiltration Determine from B mm	Infiltration capacity Cal. From D&E Mm/min	Infiltration capacity cal. From F .../...	Cummulative infiltration Determine from E Mm/min
0	20	20	0	0	0	0	0	0
5	20	18.5	5	5	1.5	0.3	0.3	0.3
10	18.5	17.6	15	10	2.4	0.24	0.24	0.54
15	17.6	17	30	15	3	0.2	0.2	0.74
20	17	16.2	50	20	3.8	0.19	0.19	0.93
25	16.2	16	75	25	4	0.16	0.16	1.09
30	16	15.3	105	30	4.7	0.156	0.156	1.
35	15.3	15	140	35	5	0.143	0.143	1.246
40	15	14.8	180	40	5.2	0.142	0.142	1.388
45	14.8	14.5	225	45	5.5	0.12	0.12	1.508
50	14.5	14	275	50	6	0.12	0.12	1.628
55	14	13.4	330	55	6.6	0.12	0.12	1.748
60	13.4	12.8	390	60	7.2	0.12	0.12	1.868

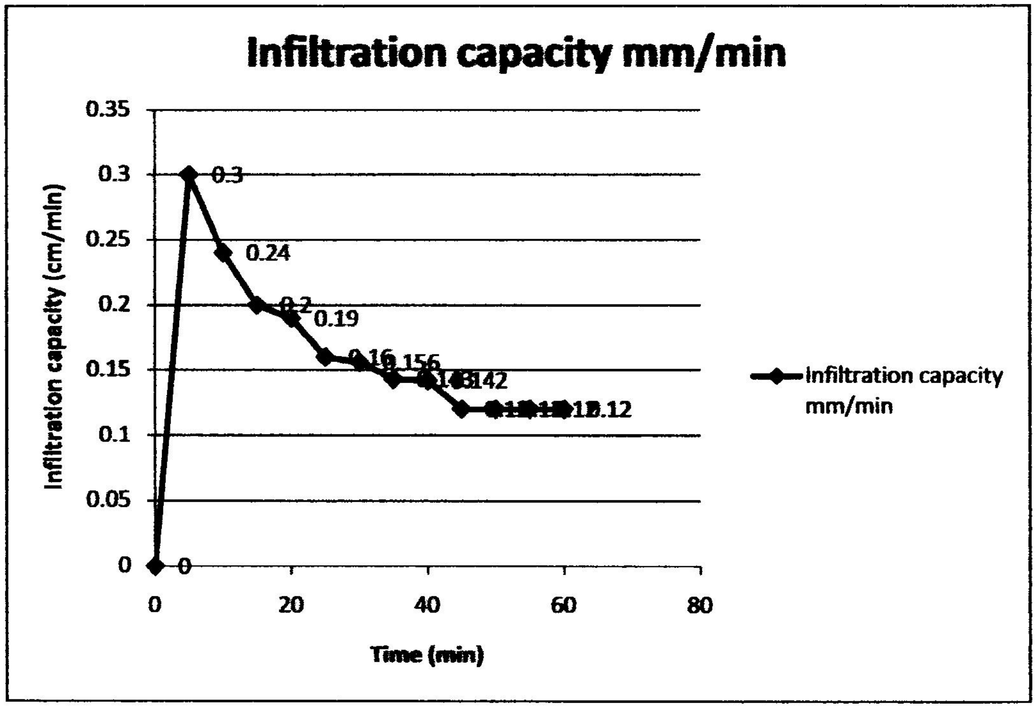

Fig.4.2: Infiltration Capacity Against Time For Test B

From test A, the constant infiltration started 0 at time of 0min and constant infiltration of 0.13mm/min begins at a time 45min of the test. This implies that the soil have an infiltration capacity of 0.13 as observed from test A.

From the result of the test obtain from test A, constant infiltration of 0.12mm/min begins at a time of 45min of the test. This is an indication that the soil infiltration capacity is 0.12mm/min as observed from test B.

The initial infiltration capacity in dry grounds is high, which is caused by a large matrix suction of the soil. In the near-saturated zone, potential differences are less; the water content hardly causes any variance in matrix suction. Consequently, the infiltration capacity decreases usually within a couple of hours until it reaches a constant value almost equalling the saturated hydraulic conductivity (the enclosure of air bubbles during infiltration prevents maximum saturation). Some factors affecting the infiltration capacity at the soil surface are: soil compaction caused by ruts and treading, washing of fine particles into surface pores, and cracks and fissures (macro pores). These factors may lead to crusted soils. In addition, the vegetation and soil cultivation may affect infiltration capacity. The thickness of the ponded water layer will only affect the onset of infiltration. The downward speed of infiltrating water depends on the texture, the structure and stratification (heterogeneity) of the soil, the soil moisture content and the groundwater level. A high groundwater level will cause stagnation of infiltrating water and the infiltration capacity will decrease, approaching zero. A heterogeneous soil is often perceived as a succession of single, homogeneous soil layers. In a heterogeneous soil with downward decreasing permeability, the infiltration capacity equals the weighted average infiltration rate of the separate layers. A heterogeneous soil with downward increasing permeability, for example a crusted soil, will at a certain stage no longer be saturated (see figure above). The infiltration capacity will be affected if this occurs in a near-surface soil layer.

4.2 Trend Analysis

Time series analysis includes the determination of the trend and seasonal component of the series. The table 4.0 summarises the trend and seasonal model results for the various months of the year.

Table 4.3: Summary sheet of trend results for Well 1

Sample	Month	Trend model	Recharge/Discharge Rate	Monthly	Rise/Fall
WELL 1	Feb	-4.7651 - 0.014308*t	-0.014308m/day	400mm	Fall
	Mar	Yt = -5.1193 - 0.004104*t	-0.004104m/day	123mm	Fall
	Apr	Yt = -5.1547 + 0.0282*t	+0.0282m/day	834mm	Rise
	May	Yt = -4.6936 + 0.0460*t	+0.0460m/day	1426mm	Rise
	Jun	Yt = -4.017 + 0.0472*t	+0.0472m/day	1416mm	Rise
	Jul	Yt = -3.938 + 0.0126*t	+0.0126m/day	390mm	Rise
	Aug	Yt = -3.718 + 0.120*t	+0.120m/day	600mm	Rise

The results for trend analysis indicates the month of May as the month with the highest monthly of groundwater recharge with an average monthly rise in Groundwater of 1426mm. this is the month with expected large volume of groundwater recharge which is ideal for farming and domestic used. From Table 4.0 and 4.1, between the months of March and April, there is an expected seasonal shift (considering the change in slope pattern). This requires seasonal analysis to determine the expected date in which the seasonal change occurs, but cannot be accomplished since obtained data is not up to 12 months.

Table 4.4: Summary sheet of trend results for Well 2

Sample	Month	Trend model	Recharge/Discharge Rate	Monthly	Rise/Fall
WELL 2	Feb	Yt = -4.79829 - 0.013971*t	-0.013971m/day	380mm	Fall
	Mar	Yt = -5.1617 - 0.003389*t	-0.003389m/day	101mm	Fall
	Apr	Yt = -5.1895 + 0.0278*t	+0.0278m/day	846mm	Rise
	May	Yt = -4.7253 + 0.0435*t	+0.0435m/day	1348mm	Rise
	Jun	Yt = -3.855 + 0.0442*t	+0.0442m/day	1326mm	Rise
	Jul	Yt = -3.992 + 0.0123*t	+0.0123m/day	381mm	Rise
	Aug	Yt = -3.764 + 0.128*t	+0.0128m/day	640mm	Rise

4.3 Model boundary and location of Wells

The model boundary for the study area as developed using the GMS software is shown in Figure 4.1. The boundary area for this study is 3600 meters square and is located with Holy Apostolic Nursery School Ikole Ekiti.

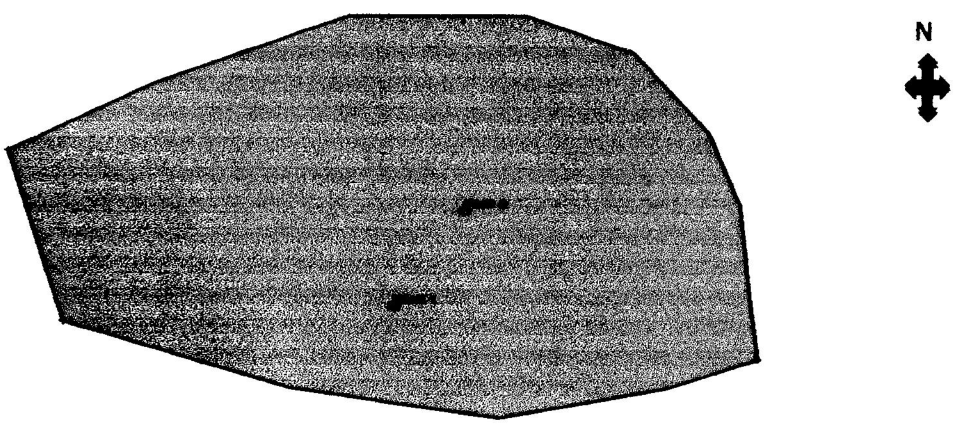

Figure 4.3: Model Boundary and well location

Legend

Model Boundary

4.4 MODFLOW Grid

The MODFLOW grid which was created had 18 rows and 21 columns (Figure 4.2). The grids was selected to indicates points in which the model results will be predicted. This is a spatial grid alignment for model predictions and calibration. Modelling using finite difference approach requires closely packed grid point since the prediction is based on closely related data points. The finner the grid the more accurate the model prediction not neglecting the effect of boundary and initial conditions.

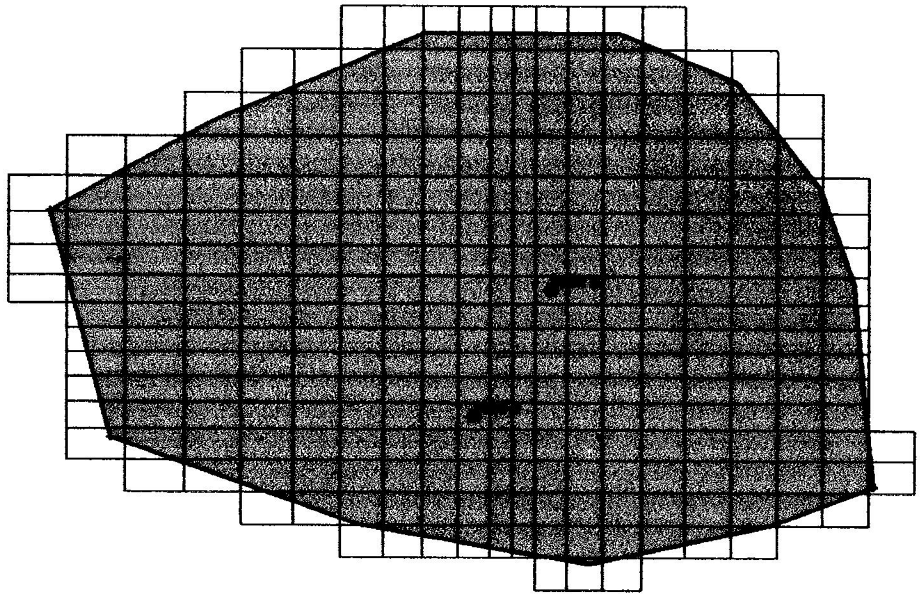

Figure 4.4: Model Grid

4.5 Layer elevation

A vertical cross-section for the single-layer model for the study area showing the layer elevations and water level at row 8 is shown in Figure 4.3. This indicates the layers within the external boundary. The variation at the top layer indicates variability within the ground slope in the boundary area. From Figure 4.3 the shaded portion indicates the well no 2. The slopes gradient in the water table level is very low (considering the blue middle line). The fluctuations at this level indicate variability in groundwater table.

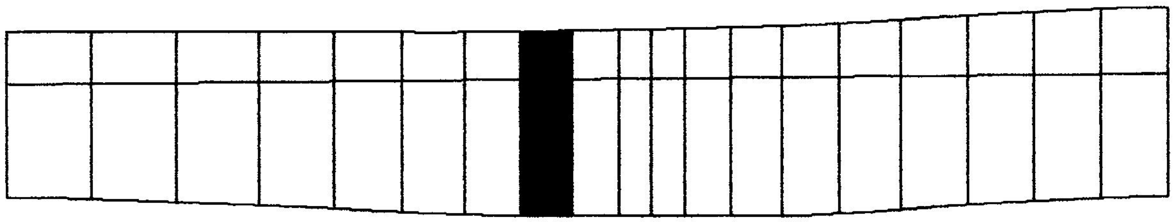

Fig. 4.5: Layer Elevation

4.6 Steady state run

The results of the steady state run are shown in Figure 4.4. The head distribution would suggest that the groundwater flow in the area is towards the southwest direction (area with red color) of the study area. The higher heads are around the northeast (blue color points) while the lower heads are around the south-western parts of the model. The direction of flow of groundwater is from north east towards south west with a slope of 0.003m/run. The steady state run indicate normal groundwater flow condition without much transient effect.

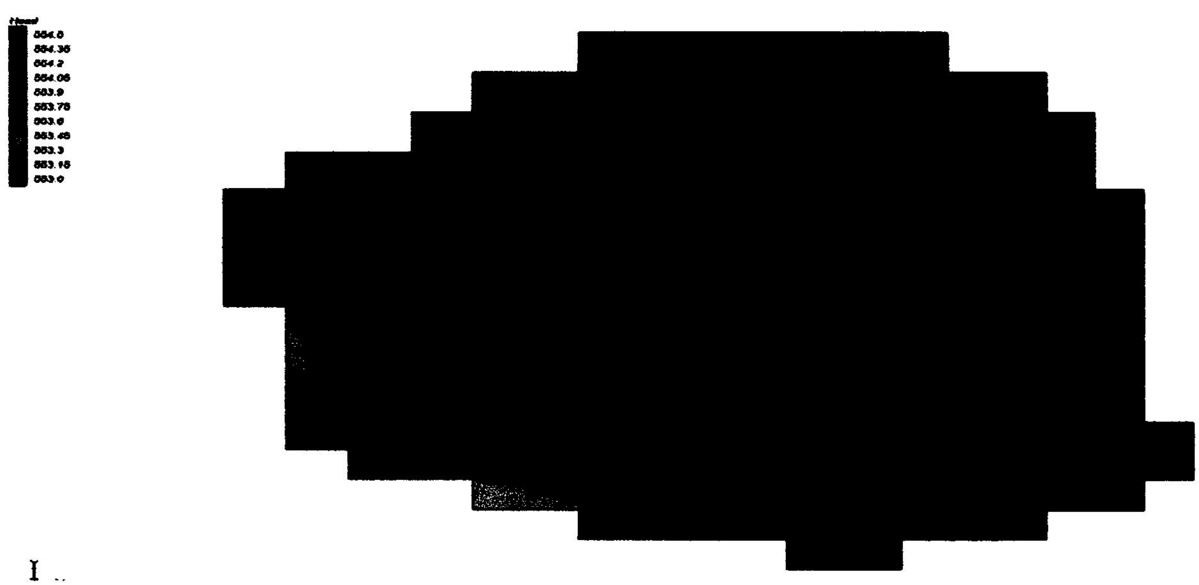

Fig.4.6: Result of a Steady State Run

4.6.1 Steady state calibration

As stated in section three, after the steady state run, the model was already in a calibrated state. This is evident by the green coloration shown in the calibrated target beside each well (Figure 4.6). A yellow colouration would have meant the model was fairly or almost calibrated, while a red colouration would mean the model was not yet calibrated.

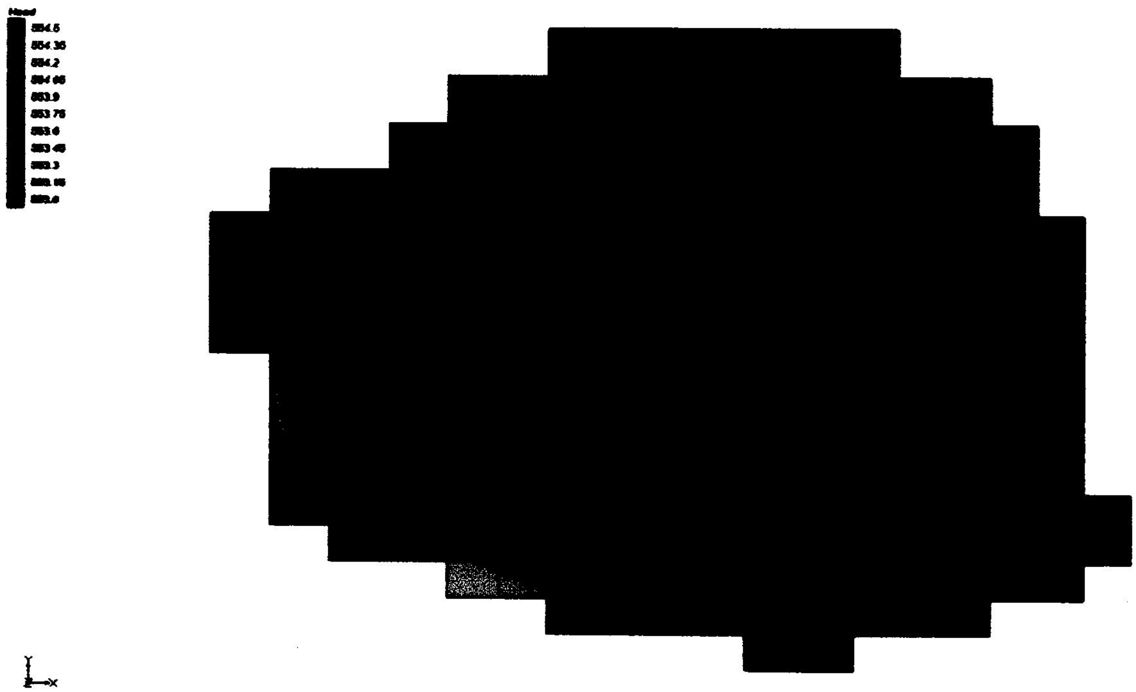

Fig.4.7 Steady State Calibration

4.7 Transient Run And Calibration

The model was put under transient run from February to July to test its suitability for prediction. The heads after the transient run is shown in Figure 4.6 and Figure 4.7. As with the steady state run, after the transient run, no further model calibration was needed as calibration conditions were already met (Figure 4.6 and Figure 4.7).

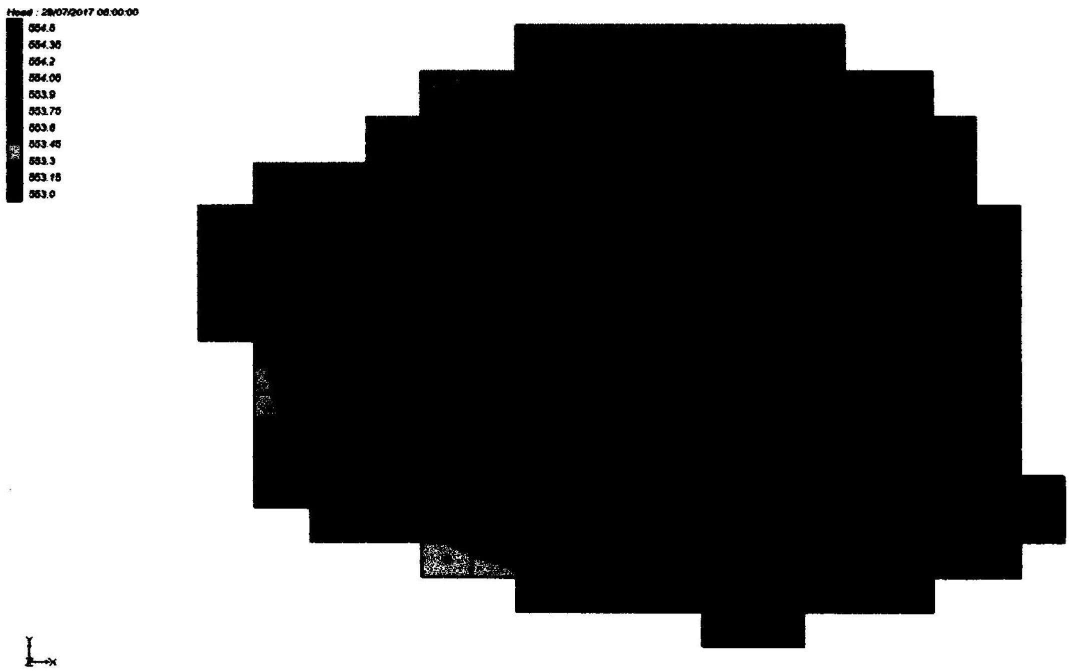

Fig.4.8: Transient run and Calibration for well 1

Fig. 4.9: Transient run and Calibration for well 2

4.8 Model prediction

With the transient model in a calibrated state, the model was used to predict groundwater heads for the months of August, September and October 2017. The results of the simulation are shown in Figures 4.8, 4.9 and 4.10. The results show that there was no much difference in terms of increase or decrease in the values of hydraulic head across the model.

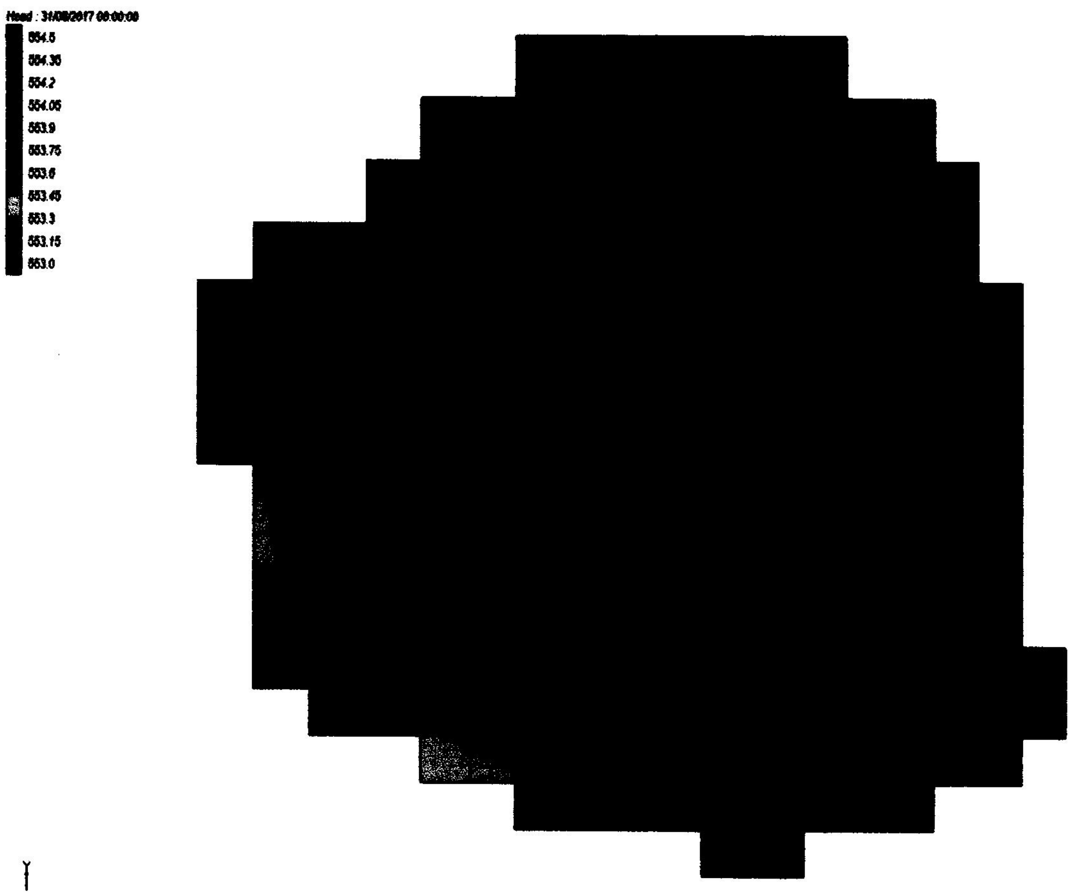

Fig.4.10: Model Prediction for August

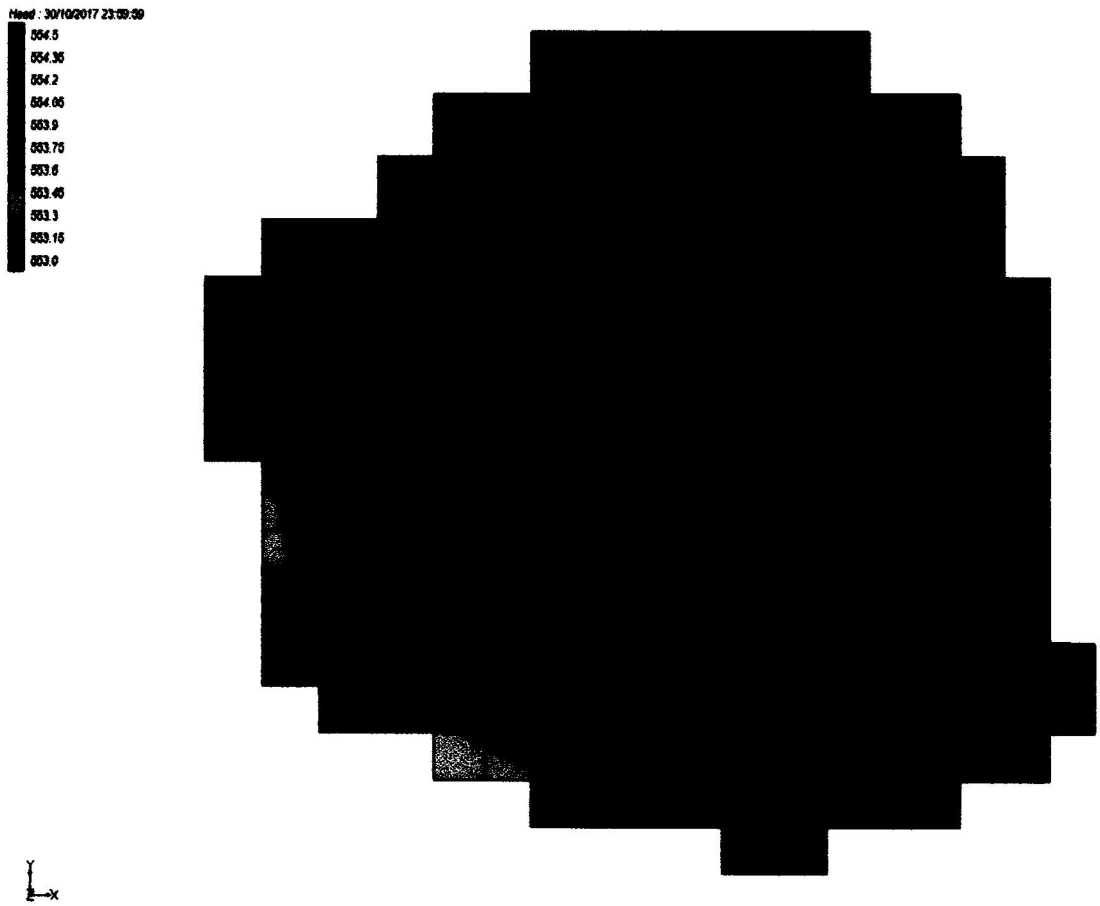

Fig.4.12: Model Prediction for October

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