GROUNDWATER FLOW MODELING AND ASSESSING THE IMPACT OF FERTILIZERS ON GROUNDWATER QUALITY: THE CASE OF HORMAT-GOLINA SUB-BASIN, AWASH BASIN, ETHIOPIA

M Sc. IN IRRIGATION AND DRAINAGE ENGINEERING

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ABBREVIATIONS AND ACRONYMS

BCM:	Billion Cubic Meter
DAP:	Diammoniam Phosphate
DD:	Draw down
EGS:	Ethiopia Geological Survey
GIS:	Geographic Information System
GWRA:	Groundwater Resource Assessment
GMS:	Groundwater Modelling System
GTP:	Growth and Transformation Plan
IWMI:	International Water Management Institute
KGVDP:	Kobo Girana Valley Development Project
MCE:	Metaferia Consulting Engineers
MOWIE:	Minister of Water Irrigation and Energy
MT3D:	Mass Transport in Three Dimensions
OKARD:	Office of Kobo Agricultural and Rural Development
PMWIN:	Processing Mod flow for Windows
SWL:	Static water level
USGS:	United States Geological Survey
VM:	Visual Modflow
WAPCOS:	Water and Power Construction Service
WHO:	World Health Organization

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ABSTRACT

Groundwater is the source of water supply for different purposes including domestic, irrigation and depending on its capacity, it is suitable for industrial activities. Groundwater in many parts of the world is under risk because of increasing demands, mismanagement and contamination. All previous studies had not been explored the predicted groundwater flow dynamics in relation to climate change and anthropogenic stress, but this study has developed on the groundwater fluctuation with respect to human pressure and climate change. ***Visual mod flow flex*** *5.1 was used for simulating the groundwater flow in response to different stress periods. Groundwater flow and transport modeling in this Sub-basin have provided information about groundwater quantity as well as the quality aspect for decision makers about the groundwater accessibility. The initial head measured values in before and after irrigation season has varied to a maximum of 0.8 m. The groundwater head level in before and after irrigation season was varied from 9.3 m to 8.26 m in the Southern boundary and from 41.5 m to 38.83 m in Northwestern boundary of the Sub-basin respectively. While the predicted groundwater head and drawdown of increased pumping rate with decreased recharge rate scenario was magnify the bad effects in the Sub-basin. The maximum depth of 0.27 m and 2.6 m drawdown was found in before and after irrigated season around the pumped wells respectively. The increased pumping rate with decreased recharge rate was replied to the groundwater head at the end of 2021has decreased by 2.81 min the Northwestern boundary of the Sub-basin as compared as using constant pumping rate with constant recharge rate. While decreased pumping rate with increased recharge rate was replied to the groundwater head at the end of 2021has increased by 2.23 m in the Northwestern boundary of the Sub-basin as compared as using constant pumping rate. The impacts of climate change and human pressure on groundwater have been the greatest threats in those supply wells. Decreased in pumping rate with increased recharge rate has accomplished to restore and protect the groundwater resources which is the best option for groundwater restoration and monitoring. Anthropogenic pressures including the application of fertilizers were a considerable cause of degraded groundwater quality in relation to Nitrate and Phosphate concentration with series of time. The groundwater quality has deteriorating with the applied Urea and DAP fertilizes in the selected wells of Hormat-Golina Sub-basin. Farmers have encouraged using practices that minimize the risk of groundwater pollution by carefully controlling and timing of the use of fertilizers to avoid over application.*

Key words: groundwater head, irrigation, climate change, human pressure, groundwater quality, Hormat-Golina, Ethiopia.

1 INTRODUCTION

1.1 Background

Groundwater in many parts of the world is under risk because of increasing demands, mismanagement and contamination with anthropogenic activities. The availability of groundwater can be determined by the nature of the geology including; the porosity, hydraulic conductivity, the characteristics of the rocks, the type of the aquifer and generally the hydro-geological nature of the aquifer. Many researchers stated that the capacity of groundwater has defined by water bearing stratum such as limestone, dolomite and marble and other rocks (Todd, 2005 and Hogeboom, *et al*., 2013).

Groundwater is the source of water supply for different purposes including; municipal, irrigation and depending on its capacity suitable for industrial activities. Groundwater does not need further treatment, it is better protected from pollution than surface water, it is less subject to seasonal or perennial fluctuations and more uniformly spread over larger regions than surface water (Delleur, 1999). In this regard, groundwater sources can be considered as better than surface water sources.

The deteriorating of groundwater quality may have natural causes (climate change), but there are mainly anthropogenic factors. The release and migration of pollutants from surface sources (in particular, cultivation and application of chemical fertilizers) and on-farm activities in rural areas can affect groundwater quality in the supply wells (Robert and Anna, 2017).

An irrigation system can extract water from the ground and distributes it over an area. Increases or decreases in irrigation activities are a key area of concern in precipitation studies that examine how significant modifications to the delivery of evaporation to the atmosphere which can alter the groundwater contribution from precipitation and affects the groundwater dynamics (Siebert, *et al*., 2010).

Climate change can influence the groundwater system, both directly (e.g., recharge due to precipitation) and indirectly (e.g., through changes in groundwater uses). Both processes can be affected by natural and human activities. Changes in climate could also affect groundwater primarily through changes in irrigation demands due to variations of precipitation (Crosbie *et al.*, 2010).

The climate change causes variations in rainfall patterns and affects the groundwater recharge, especially in arid and semi-arid areas. Climate change can alter the global hydrological cycle in terms of distribution and availability of regional water sources. Human pressure deals with over consumption of groundwater by pumping can distort the natural recharge-discharge equilibrium (Herrera and Hiscock, 2008).

Groundwater modeling is a way to represent a system in another form to explore the response of the system under a given condition, or to predict the performance of the system in the future. Groundwater modeling is a tool which is used for water resources planning and management, groundwater protection and giving recommended remedial action by considering the output of the model (Chiang, 2005).

Groundwater flow models are used to calculate the current hydraulic heads, drawdown and movement as well as the direction of groundwater through aquifers. Groundwater models play an important role in the development and management of groundwater sources in predicting the head, drawdown and concentration level of the groundwater. The outputs of the most groundwater model simulations are the hydraulic heads, drawdown level and concentration level which are in equilibrium with the specified hydro-geological conditions (i.e. boundary conditions, flow property and geological layer) defined for the modeled area.

Groundwater modeling has become a standard tool for professional hydro-geologists to effectively perform most tasks particularly groundwater head and transport of particle tracking in relation to the anthropogenic activities (Khadri and Chaitanya, 2016).

The degree of interaction between disposal of chemical fertilizers and groundwater quality depends on the application of fertilizers on the agricultural activities in relation to the water table. In the conceptual way, the disposal units of chemical fertilizers are above the water table surface (Mahvi *et al.*, 2005).

1.2 Statement of the problem

In Ethiopia there are a number of irrigation projects, among which Raya Kobo Irrigation Project is one that mainly depends on the groundwater source. Hormat-Golina Sub-basin are located under this project. The flow and transport of groundwater can be affected by global climate change, soil and rock characteristics, and anthropogenic pressure (Craig et al., 2010). But among those factors anthropogenic pressures; the application of fertilizers can cause a pollution of groundwater sources and the progressive deterioration of water quality in relation to Nitrate and Phosphate concentration. According to kobo Agricultural office yearly report's in Hormat-Golina sub-basin, farmers are extensively using fertilizers (Urea and DAP). During the time of irrigation, water can leach these chemicals and the groundwater chemistry could be changed.

In this Sub-basin since the establishment of the project, scientific studies had not conducted in related to the effect of chemical fertilizers on groundwater quality. Moreover, the ground water table fluctuations had not been explored through modeling in relation to climate change and anthropogenic activities. Initially the project was studied by Metaferia Consulting Engineers (2009). Later, based on the consultant's project design output, Getahun (2010) and Fesseha (2015) tried to explore the groundwater flow and non-fertilizer chemical concentration in those Sub-basins. Thus, there was no groundwater table prediction and groundwater quality on spatio-temporal scales subjected to both human and natural stresses in the sub-basin.

Predicting the resulting hydraulic head and concentration should be mandatory because continuously using groundwater can lead to the fluctuation of groundwater level and the groundwater quality deterioration (Brouyere. *et al*., 2004). Hence, the present study has initiated to quantify the groundwater head and its respected drawdown level in before and after irrigation season. Groundwater head prediction was developed by considering human interference and natural conditions as a scenario based analysis. Beside to the above initiation this study has also shown that the groundwater quality in related to applied Urea and DAP fertilizers.

1.3 Objectives of the Study

1.3.1 General objective

The general objective of this study is groundwater flow modeling and assessing the impacts of fertilizers on groundwater quality in the case of Hormat-Golina Sub- basin in Raya Kobo Irrigation Project.

1.3.2 Specific objectives

The specific objectives of this study were:

- To investigate the groundwater head and flow direction for irrigation and non-irrigation season
- To simulate the dynamics of groundwater level due to stresses (e.g. pumping and recharge as scenarios)
- To investigate the groundwater quality in relation to the applied Urea and DAP fertilizers

1.4 Research Questions

- Has the groundwater level is fluctuated in irrigated and non-irrigated season?
- How the groundwater level is varied due to different stress periods?
- Does the groundwater quality is changed with the applied fertilizers a series of time?

1.5 Significance of the Study

Decision makers can use groundwater models about the groundwater flow head as well as the drawdown level for groundwater planning and management for future consumption in relation to climate change and anthropogenic stresses.

Since all the previous studies were limited to understand the groundwater flow head prediction under natural and anthropogenic stresses, the current study has replied to those gaps. In addition to the above limitation, this study can also provide information about the effect of Urea and DAP fertilizers on groundwater quality in Hormat-Golina Sub-basin which comprises in Kobo Girana valley development project.

The result of this study can create awareness on farmers as to controlling the over application of chemical fertilizers in recharge zones for minimizing the effect of changing groundwater chemistry. The local farmers should have understanding about the groundwater system reaction to the external natural and manmade changes.

This study can also have devised the hydro-geological system characteristics and the interrelationship with groundwater flow and examine groundwater quality problems with related to excessive applied Urea and DAP fertilizers.

1.6 Scope and Limitation of the Study

The scopes of this study had groundwater modeling and assessing the effect of fertilizers on groundwater quality in relation to the applied Urea and DAP fertilizers in Hormat-Golina Sub-basin. Deep-meter was available to measure the water levels for each monitoring wells. The office and field worker's had willingness to provide information about the groundwater characteristics.

Conducting researches from whole pumping and monitoring wells in the Sub-basin can improve scientific evidences about groundwater quality but conducting the whole study has needed to long time and budget. Due to those limiting factors selecting representative samples were recommended.

There were a number of constraints to determine the groundwater flow head including problems related to recorded stream flow data since the rivers were ungagged. Measuring the hydro-geological characteristics of a given aquifer was difficult, since it had required using geophysical machines and its value was taken from Metaferia Consulting Engineers report (2009).

2 LITRATURE REVIEW

2.1 Groundwater Potential in Ethiopia

The groundwater potential in Ethiopia is directly related to the nature of the basement of aquifers in which the Western and South to central parts of the country are productive while in case of Northern Ethiopia and Borena lowlands (near the Southern border), the basement aquifers are categorized in to lowest productive. The basement rocks of Northern Ethiopia have low groundwater potential. In Southern Ethiopia, groundwater in the basement rocks has stored in and transmitted through layers and fractures. The crystalline basement aquifers of Western Ethiopia have better groundwater storage than in other areas. This higher groundwater potential is related to high rainfall that supports high recharge amount (Kebede, *et al*., 2018).

The estimated groundwater potential in Ethiopia was varied from WAPCOS report of 2.5 BCM to preliminary national estimated of Irrigation Water Management Institute (IWMI) had 4-5 BCM in 2010. In 2015, Minister of Water, Irrigation and Energy as a GTP II report had 28 BCM. Ground water potential in Ethiopia is controversial and there was no exact numerical estimation about exploitable potential since the groundwater potential is depending on the natural and manmade interactions with respect to time. High discrepancy in groundwater potential is a challenge to experts and decision makers about its sustainability.

2.2 Review of the Previous Groundwater Studies in the Study Area

Getahun (2010) tried to understand the groundwater head determination in Hormat-Golina basin based on the Metaferia Consultant Engineers report for quantification and abstraction of groundwater in different boreholes. Based on those reported data, the author stated that Hormat-Golina basin had a volcanic aquifer and unconsolidated alluvial deposits. The hydraulic gradient in the basin follows as surface topography and it has located towards to East for the highland volcanic and towards to Southeast for the valley floor.

According to Fesseha (2015), the groundwater quality was determined in Hormat-Golina Sub-basin. The groundwater quality result has shown that the vulnerability for non-fertilizers pollution was medium to high in the whole study area. Medium to high vulnerability was an indication of a good warning for the groundwater quality. But the study had not focused on how anthropogenic activities (particularly, the effect of fertilizers) was replied to the variation of the groundwater quality in the Sub-basin.

Based on the Metaferia Consulting Engineers (MCE, 2009) report, the main aquifer in the Kobo-Girana valley had unconsolidated sediment. Through the hydro-geological investigation for Hormat-Golina recharge area, the following recorded results were found. The average sediment thickness had 129 m and the average groundwater table in Hormat-Golina Sub-basin had 22 m. The groundwater depth was varied with different manmade and natural stress conditions.

2.3 The Effects of Irrigation on the Groundwater Reservoir

An irrigation system can extract water from the ground and distributes it over an area. Direct effects of doing this can reduction in groundwater storage in the aquifer and variation of groundwater quantity. The recharge rate is low as compared as pumping rate, the groundwater water level become decrease towards to the bottom of the aquifer during irrigation period. Increases or decreases in irrigation activity has a key area of concern in precipitation studies that examine how significant modifications to delivery of evaporation to the atmosphere can alter the groundwater contribution from precipitation and affects the groundwater dynamics (Siebert, *et al*., 2010).

Increased groundwater recharge systems occurred in the irrigation scheme. Although fairly high irrigation efficiencies can occur with best irrigation methods like sprinkler and drip irrigation, the groundwater recharge become lower from the irrigation canals. When the water table is raised, the groundwater storage can also have increased which can be suitable for irrigation, but water logging problems in agricultural lands can have negative consequences. The increased level of the water table can lead to reduced agricultural production. The indirect effects of water logging and soil Stalinization occur directly on irrigated land (Ojo, *et al*., 2011).

2.4 The Impact of Climate Change on Groundwater Resource

Climate change is likely to affect groundwater characteristics due to changes in precipitation, evapotranspiration and meteorological characteristics. Global warming can also affect the water supply by changing the evaporation and groundwater recharge. Climate change can alter the need and timing of water supply for both irrigation and domestic purpose. The effects of climate change on the interaction between unconfined aquifer and atmosphere should be modeled to determine the fluctuation of groundwater level (Scibek and Allen, 2006).

The rainfall events tend to be more intense, increasing the potential of the groundwater sources in relation to other environmental factors. The rainfall intensity is not only the limiting factor to control the groundwater level but also other interaction of hydro-geological features must take into considerations (Jyrkama and Sykes, 2007).

The evaporation rate from the groundwater has directly depended on the depth of water level. Increases in average temperature can cause the need for space cooling for crop production. The variability in precipitation can impact on irrigation needs and consequent demand for energy from groundwater pumping.

2.5 Groundwater Modeling Approach

Groundwater models have been extensively used to address the groundwater problems and to support the decision making about the groundwater characteristics. Hence, it has used to make predictions about the Sub-surface system's response to different stresses. Modeling can help to understand the hydrological system in response to natural and man-made stresses in a given area (Dogrul, *et al*., 2016).

Groundwater flow and transport of contaminant can be determined by different models including Processing Mod flow for Windows (PMWIN), Visual Mod Flow (VM) Flex, and Groundwater Modeling System (GMS) for simulating groundwater head.

Transport of chemical processes within modular three dimensional finite difference groundwater model can be used MT3D (Mass Transport in three dimensions) engine. Parameter estimation (PEST) Model extension cab be use to adjust the sensible model parameters. Groundwater modeling is a way to represent a system in another form to explore the response of the system under a given condition, or to predict the performance of the system in the future. Groundwater modeling is a tool which is used for water resources planning and management, groundwater protection and giving recommended remedial action by considering the output of the model (Linxian, *et al*., 2018).

Using Visual ModFlow Flex model first develop conceptual model which is a descriptive representation of a groundwater system that incorporates to the geological, boundary and hydrological conditions. Information about initial groundwater head is also included in the conceptual model. A good conceptual model should describe reality in a simple way that satisfies modeling objectives and management requirements (Sandow, *et al*., 2013)

Improve the credibility of the groundwater models with integrated model inputs and outputs that can be easily visualized with raw GIS field data in 3D. The determination of hydraulic heads, drawdown and transport of chemical concentration in a series of time also displayed together with conceptual model data to validate and demonstrate model credibility (Praveena and Aris, 2009).

The groundwater flow or contaminant transport in the case of Visual mod flow flex 5.1 modeling, the following key issues should be modeled under the conceptual model (Waterloo Hydrologic, 2015):

- Aquifer geometry,
- Boundary conditions and initial heads,
- Aquifer flow properties like hydraulic conductivity, porosity, storativity,
- Groundwater recharge and ground water discharge (pumping),
- Evapotranspiration,
- Initial concentration for transport model

This groundwater study has used visual Mod flow flex 5.1 model which was better handling for parameters and its simplicity for users. Visual Mod flow flex 5.1 has offered the following unique properties:

- Visual Mod flow flex has offered many new features that allow building more accurate and reliable groundwater outputs.
- Visual Mod flow flex has provided both GIS based 3D conceptual modeling and numerical modeling all in a single integrated software package. This reduces the need to maintain error prone process of transferring data back and forth between different software packages and data formats.

- Multiple model management for evaluating multiple hypotheses and hydro-geological interpretations all in a single project
- Flexible grid type selections for accommodating complex geology and eliminating model convergence problems
- The transport boundary condition is not separated from the flow boundary conditions

2.6 The Effect of Fertilizers on Groundwater Quality

Over application of Urea and DAP fertilizers can alter the normal concentration of Nitrate and Phosphate in the groundwater. Because of its solubility and negative charge, the Nitrate is very mobile and can easily leach from ground surface and joined to those sources of groundwater supply. High concentration of Nitrate in drinking water can potentially cause health problems such as methemoglobinemia (a decrease in the capacity of the blood to transport oxygen, also known as "blue baby syndrome") in stomach cancer, goiter and hypertension in adults (Fewtrell, 2004).

Because of many crop plants require large quantities of Nitrogen to produce high yields, additional Nitrogen in the form of fertilizer is applied to crops. Unfortunately, Nitrogen is extremely soluble and can be leached into groundwater from where it enters into watercourses. Land cover, Nitrogen content of fertilizers, rainfall, geological setting and water table are among most significant factors that contribute to occurrence of Nitrate in groundwater (Psarropoulou and Karatzas, 2013).

Moreover, uncertainties such as presence of multiple Nitrogen loading sources in a certain area, non-point Nitrate source overlapping and occurrence of bio-geochemical processes within the soil increase the complexity level of Nitrate to groundwater interconnectivity. In addition, high Nitrate concentrations in drinking water can have health implications for both humans and animals (Mary, *et al*., 2018).

In other case using DAP fertilizers can increase the concentration of the phosphate in the groundwater level. Naturally occurring levels of phosphates in surface and ground water bodies are not harmful to human health, animals and environments. While extremely high levels of phosphates can cause digestive problems. Phosphates originate from many sources including; sewage, manure and artificial fertilizers. Excess phosphate in watercourses causes a nutrient boost which often equates to excessive algae growth. The algae may then produce toxins that adversely affect the aquatic ecosystem, reducing oxygen levels and leading to loss of species and degradation of the waterway (Divya and Belagali, 2012).

Furthermore, excessive amounts of phosphates in water bodies can lead to eutrophication, a condition of increasing algal production to extreme quantities until they die off. Additionally, excessive algae on the water surface accumulate can result in clogging of water supply pipelines and create bad odors when they are decade (Fadiran *et al.*, 2007). Beside to the above problems algal blooms have been linked to health problems such as skin irritation and death (of both human and animals) depending on the type and duration of exposure.

Fertilizers containing phosphates pollute surface water. Phosphates enter water systems naturally by dissolving out of rock, but phosphates are also mined and made into chemical fertilizers to grow crops. Applying chemical fertilizers to soil already saturated with phosphates and spreading excessive amounts of manure on land causes phosphates to run off during heavy rainfall and pollute nearby water sources. Excessive phosphate levels also affect the processes in drinking water treatment plants (Jenny G, 2018).

Chloride acts as an inert element in all natural water, rock and environments as it is not adsorbed to any marked degree on mineral surfaces and usually does not enter common rock forming minerals due to the large size of its ion. Chloride also has non-lithological origin and comes in groundwater from improper waste disposal, sewage and leachate pollution.

Chloride in the environment is conservative (non-reactive) and thus there is little loss when chloride in salts contained in food, beverages and household cleaning products is discharged to the environment through septic systems and wastewater treatment facilities. The remaining brine is then disposed of through the wastewater system where it may enter the underlying aquifer and ultimately discharge to a surface water body (John, *et al*, 2009).

3 MATERIAL AND METHODS

3.1 Description of the Study Area

3.1.1 Location

This study has carried out in the Hormat-Golina Sub-basin of Kobo Girana Irrigation Project. This Sub-basin is found in Kobo District under the Awash River Basin. Hormat-Golina Sub-basin has attitude ranging from 1400 m to 3100 m above sea level. The study area has situated between 39^{0}34'0" to 39^{0}45'0"E Longitudinal and 12^{0}2'0" to 12^{0}14'0" N Latitude geographical coordinate system (Fig. 3.1).

The groundwater divide line is the upper boundary of Hormat-Golina Sub-basin (MCE, 2009).The topographical location of Hormat-Golina Sub-basin is bounded by Zobel Mountain in the Eastern direction which is separated from lowlands of the Afar region by Zobel Mountain which has over 3100m high above sea level.

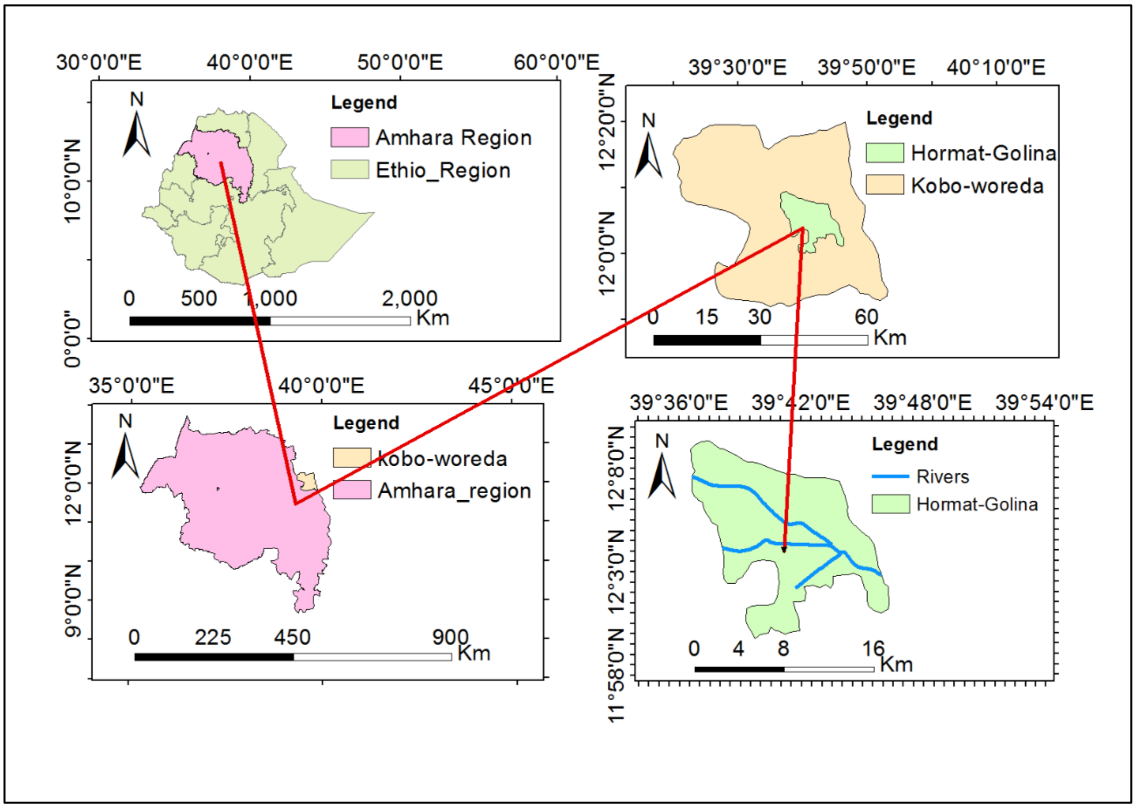


Figure 3. 1: Location map of the study area

3.1.2 Climate

According to Getahun (2014), the climate condition of Hormat-Golina Sub-basin has categorized as semi-arid in Kobo-Girana valley plain. The average monthly temperature in the Sub-basin has ranging from 12°C in December to 35°C in April.

The rainfall distribution is not evenly distributed since orographic effects modify the distribution of rainfall over the area. The main rainy season has often spread out from mid of June to the mid of October and the small rainy season has been occurred from mid of February to mid of April.

The principal feature of rainfall in the Sub-basin has characterized by seasonal, poor distribution and erratic. Compared to other districts of the zone, Kobo district has relatively hot climate and it has a mean annual temperature of 23.5^{o}c.

3.1.3 Land use/Land Cover

Based on field observation and Satellite image (USGS, Land sat image, 2019), the Sub-basin had Agricultural land, Forest Land, Urban area, water body and Bare land types of land use land cover units. Among those land use units' Agricultural land use units had the dominant land use land cover units while Water body land use land unit had small area coverage. The following table (Tab.3.1) has shown that the percentage area coverage of the land use land cover units.

Table 3. 1: Land use / land cover of the study Sub-basin in percentage

Land use land cover	Percentage of area coverage
Urban area	9.1
Forest land	16.5
Water body	3.7
Bare land	17.4
Agricultural land	53.3

In this Sub-basin, the main cereal crops being produced include: Teff, Sorghum and Maize. In addition to the above cereals, cultivation of commercial crops such as tomato, onion and pepper with legumes including chickpea is being commonly used by using different irrigation systems.

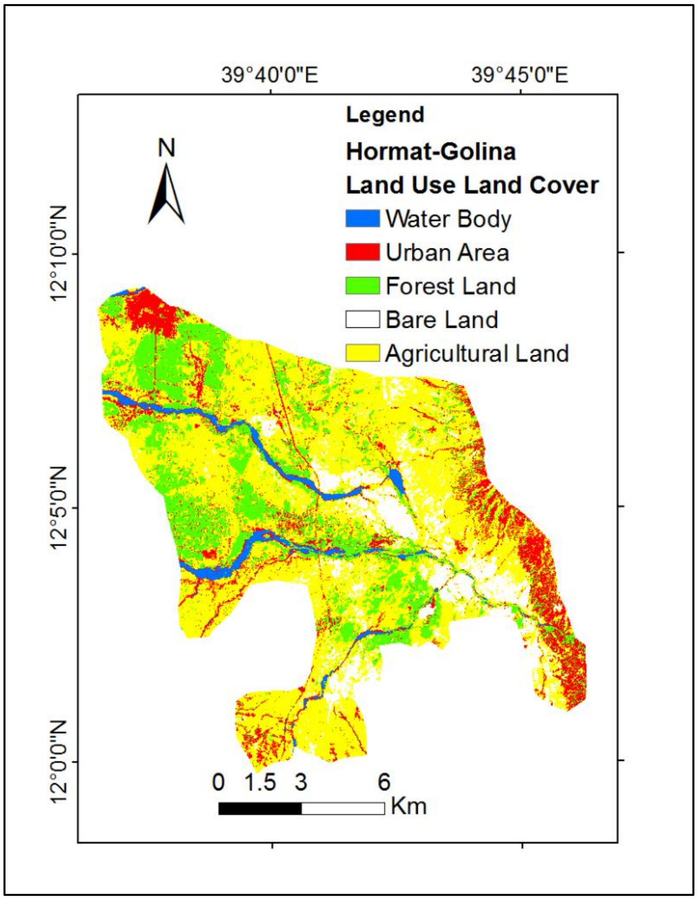


Figure 3. 2: Land use/land cover map of the study area

From the above land use land cover map about 53.3 % of the total area coverage has shown that the Agricultural land use and 3.7 % area coverage had water body land use land cover unit.

3.1.4 Geology

The study area has located near the highlands of Zobel Mountain from the Eastern direction and highlands in the North Western direction. From the previous Geological study which was carried out by Metaferia Consulting Engineers (MCE, 2009) and Geo-Engineering Service (GES, 2003) the main aquifer in the kobo-Girana valley had unconsolidated sediment.

The Northwestern highlands have originated from Basaltic rocks. The Eastern ridge (Zobel Mountain) originated from the Rhyolite and the valley floor originates from alluvial deposits. The well top data has provided information about how the thickness of the horizons was varied vertically. From the drilling well data, the soil horizons had not homogeneous across the layer even if it was varied with a meter of depth. Unconsolidated sediments rock was characterized under stratigraphic layer in the Sub-basin.

Well top data has shown that different types of horizons were located in the Sub-basin. The bed rock of the aquifer extends up to the fractured and massive basalt rock. The Rhyolite has often located near the highlands of Zobel Mountains. The basaltic rock in the Eastern highlands has shown slightly too moderately weathering and well fractured. The Rhyolite has often light pink, fine grained outcrop was seen with basalts at the outlet of Golina stream to Afar (Sileshi, 2007).

Local rivers had drained from Western highlands and surface runoff along the Sub-basin has occurred and flows towards to Afar depression. The sediment had unconsolidated and basaltic in composition. This unit had mapped as quaternary alluvial deposits with thickness ranging from 20 m to 150 m on the geological map of Ethiopia published in 1996.

The Drainage platform in the Sub-basin has designed to understand the effects of physical features. The agricultural drainage and topographical condition which remove water from the aquifer at a rate proportional to the difference between the head in the aquifer with some fixed head in the outlet. As the information gotten from Geo Engineering Service (GES, 2003) and Metaferia Consulting Engineers (MCE, 2009) the pumped wells had the following characteristics; wells had fully penetrating with very small diameter, geologic formations were horizontal, Darcy’s law has valid, discharged at the constant rate and has an infinite horizontal extent.

The hydro-geological characteristic of the Sub-basin has initially assessed from Geoengineering Services in 2003 and Metaferia Consulting Engineers in 2009, the groundwater flow outlet in Hormat-Golina Sub-basin has located towards to Afar depression.

3.2 Data Collection and Analysis

3.2.1 Groundwater head and flow direction during in stress periods

Investigating of this groundwater head and flow direction in irrigation and non-irrigation season was depending on the combination of primary and secondary data. Primary data was taken from reading of groundwater head in different pumping and monitoring wells. While the secondary data was taken from Meteorological station for climate data, geological characteristics and litho logical depth from Metaferia consulting Engineers and Geo Engineering Services reports.

3.2.1.1 Climate data

The climate data was taken from National Meteorological station to understand in detail climatic conditions in response to the groundwater contribution. In the study area, the climate data and its observation parameters has evaluated the groundwater potential with response to the surface nature of topography. Data of the following climate parameters were collected and analyzed: precipitation, evapotranspiration, temperature and recharge. That surface data collection from the area has reflected that the variability of the local conditions that affect the groundwater flow patterns.

The measured precipitation characteristics in the Sub-basin were considered with future variability of the Meteorological characteristics that had influence the groundwater flow regime. The groundwater flow conditions of an area were determined by its topographical and climatologically conditions. The following table (Tab.3.2) has shown that the Metrological parameters and their measurement techniques.

Table 3. 2: Metrological parameters and its measurement techniques

Parameters	Techniques
Precipitation and temperature	Rain-gage and Thermometer readings
Evapotranspiration	Crop-wat model/Penman-Monteith
Recharge	Using Roorkee’s empirical estimation

From the National Meteorological station to understand in detail climatic conditions in response to groundwater contribution, the following parameters were evaluated.

I. Estimation of areal rainfall

The rainfall data was taken from Kobo Meteorological station. Understanding the rainfall characteristics on the surface of the study area can reflect its contribution for groundwater recharge. To show the rainfall distribution Inverse distance weighting method of interpolation was selected since inadequacy rain gage station has observed in Hormat-Golina Sub-basin. Due to the mountainous barrier in those Sub-basin has assigned the meteorological station didn't cover the whole area. However, the selected station had average seasonal rainfall data which was used to determine the groundwater recharge.

II. Estimation of Evapotranspiration

Evapotranspiration is the process in which water is lost from plant leaves and surfaces to the atmosphere. The actual evapotranspiration information has provided how much amount of water that actually returned to the atmosphere depending on the availability of water. The evapotranspiration rate was estimated from the crop-wat 8.0 model (Penman-Monteith equation) and the average seasonal evapotranspiration rate was determined as 3.49 mm/day.

According to Waterloo Hydrologic (2015) the water table is located above the ground surface (top of layer 1), evapotranspiration loss from the water table occurred at the maximum rate and while the elevation of the water table is found below layer 1, evapotranspiration from the water table could negligible. Groundwater level measurement has made by deep-meter, the water table in the Sub-basin was found below the top of the grid cell elevation where the evapotranspiration rate was negligible.

Between the above limits, evapotranspiration from the water table varies linearly with water table elevation. The following table (Tab.3.3) has shown that the average monthly meteorological data which was collected from January 2019 to April 2019.

Table 3. 3: Average monthly meteorological data in those Sub-basins

Parameter	January	February	March	April
Min (°C)	5.3	9.1	13	14.3
Max (°C)	31.1	33.4	34.1	34.1
Relative-humidity (%)	44	54	54	55.0
Wind speed (m/s)	0.92	1.32	1.56	1.20
Rain fall (mm)	0	10.8	20.5	34.0
Sunshine hour	7.7	7.4	8.2	8.4

III. Recharge

Recharge rate was typically used to simulate the amount of water that contributed to the groundwater level. Most commonly, recharge occurred as a result of precipitation percolating into the groundwater system. However, recharge boundary can potentially be used to simulate recharge from sources other than precipitation such as; seepage from irrigation canal and local stream flows. However, the irrigation canals are furrow with unlined and the flow measurement had not been used in the farm inlet. While in a small farm area farmers had used sprinkler and drip irrigation method due to those cases the groundwater contribution from irrigation canal was negligible.

Now a day, there are different groundwater recharge estimation methods depending on different conditions. The Chloride Mass Balance method (CMB) has been widely used for estimating aquifer recharge in porous media (Scanlon *et al.,* 2002*).* However, groundwater recharge estimation by CMB is applicable when the flow condition has assumed to be steady state and it is valid only for a condition where there were no additions from the external sources like fertilizers which might be associated with a significant amount of chloride (Oluseyi *et al*., 2015). Based on those limitations empirical estimation of groundwater recharge was selected in this study.

In this study, the groundwater recharge estimation was computed by using the Roorkee's empirical estimation. Due to the lack of relevant information for computing recharge contribution by different methods Roorkee's empirical estimation was selected and only precipitation data has been required for its computation.

As it is mentioned above in the Meteorological data limitation together with the absence of Surface runoff data within the Sub-basin has made the estimation of groundwater recharge was very difficult. The recharge was estimated using empirical method by assuming the studied Sub-basin to have a uniform rainfall distribution. The prevailing climatic conditions, topographic features and the conceptualized groundwater system in the Sub-basin were limiting factors to classify the recharge rate in highland and lowland of the recharge zones.

The following empirical estimation of recharge was used to compute its contribution from the varied precipitation amount in the Sub-basin. The following equation (Eq. 3.1) has shown that the relationship between the amount of precipitation and its groundwater recharge. Roorkees has proposed a modified version of groundwater recharge estimation, the equation as follows,

$$R = 1.35(P - 14)^{0.5} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3.1$$

, where R is the net recharge due to precipitation in millimeter (mm), and P is the precipitation in millimeter (mm).

In this study the irrigation period had three months and the total amounts of precipitation within three months were measured with 65.3 mm. using the above empirical equation and substituting the value of precipitation the net recharge was given as;

$$R = 9.67\,mm$$

$$R = \frac{9.67mm}{90\ days} = \frac{0.107mm}{d} = 39.055\frac{mm}{yr}$$

Groundwater recharge was computed by Roorkee's empirical estimation of a recommended regions based on water level fluctuation and rainfall depth.

3.2.1.2 Hydrogeology/Geological data

The aquifers in the study area had mainly alluvial deposits, fractured and weathered basalts. The Sub-surface groundwater flow characterization in the study area has designed on the basis of results from both previous studies and pumping test data. The hydro-geological characteristics in the Sub-basin have provided information about the performance of groundwater flow that was pumped out for irrigation and Kobo town water supply for domestic purpose.

The sediment thickness has varied from 18 m to 212 m with average depth of 129 m (Semu, 2012) and the average sediment thickness was measured to129 m. The following table (Tab.3.4) has shown that the aquifer characteristics of the Sub-basin.

Table 3. 4: Geological characteristics of the sub-basins

Aquifer characteristics	Hormat-Golina	
	Range	Average
Sediment thickness (m)	18-212	129
Aquifer thickness (m)	20-150	90
Water Table depth (m)	9-41.5	25
Average Saturated thickness (m)		104

3.2.1.3 Existing wells characteristics

The Sub-basin has 34 functional pumping wells and 8 observation wells (KGVDPO). For this analysis, irrigation boreholes and Kobo town water supply wells that tap on the alluvial aquifer were used. Not all boreholes are being used for the irrigation at present. Currently no continuous recorded groundwater data was available concerning how the groundwater has been utilized during irrigation period within the existing wells.

The groundwater has been abstracted for both kobo town water supply and irrigation purpose. However, there was an electric power shortage for regulating the pump system and no regularly recorded groundwater flow data; it was difficult to determine the amount of water abstracted from the pumping wells. Based on the information gotten from Project Office, Kobo Town

Water Supply Office and pump operators who had work at well pumping stations; the pumping time in those irrigation season's has been varied from 8 hours to 16 hours.

The groundwater head in each pumping and monitoring wells has measured by deep-meter. Construction of wells and boreholes allows the measurement of fundamental hydro-geological parameters that describe the characteristics of flow in the groundwater system with respect to the depth of water table.

The following figure (Fig.3.3) has shown that the location of the existing pumping and observation wells within the Sub-basin.

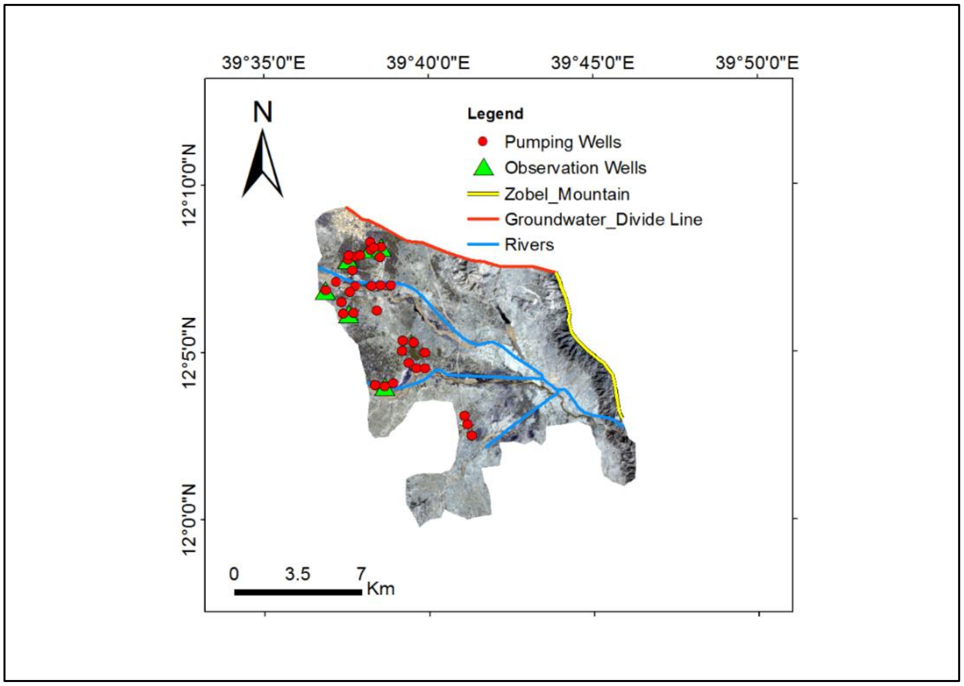


Figure 3. 3: The location of pumping and observation wells

From the above figure (Fig. 3.3), the pumping and observation wells has densely populated in Western boundary of Hormat-Golina Sub-basin. The lithological characteristics of each well were initially assessed from Metaferia Consulting Engineers (MCE, 2009). The majority of water level measurements have taken from pumping wells without monitoring wells.

3.2.1.4 Estimation of aquifer parameters

The groundwater flow model has required many different types of data to simulate the hydro-geological processes influencing the groundwater flow. The hydro-geological characteristics of the given aquifer have the following flow property parameter groups;

- Hydraulic Conductivity
- Storage
- Initial heads

The hydraulic conductivity values were computed from the Aquifer test model based on the pumping test data.

The pumping test data has used to determine the aquifer hydraulic parameters such as; hydraulic conductivity, storativity and specific yield which its value can used as the model input parameters. The hydraulic parameters provide information to better understanding of the water bearing stratum of the aquifer. The aquifer test model has carried out various pumping test to calculate the transmissivity and storativity of the geological formations underlying the area. The hydraulic conductivity values were determined by dividing transmissivity with the depth of each well.

Specific Storage (Ss) is defined as the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head due to aquifer compaction and water expansion.

In order to start solving the flow simulation, Visual Mod Flow Flex 5.1 has required initial heads. The Initial head values has also used to calculate the drawdown values which was measured by the difference between the starting head and the groundwater head after pumping with the prescribed irrigation time.

The value of the initial head measurement was taken as the static water level in before irrigation season. The initial head values of each well have used to determine how the groundwater head can be fluctuated after pumping. The initial heads in each well were measured in January 2019 and April 2019. The following table (Tab.3.5) has shown that the aquifer flow properties and its respected values.

Table 3. 5: The values of aquifer flow properties

Parameters	Value
Hydraulic conductivity (m/s)	0.0003(Unconsolidated material)
Specific storage	0.00001
Specific yield	0.2
Initial heads (m)	Measured depth

Hydraulic head data were collected from January 2019 and April 2019 from the irrigation wells and kobo town water supply wells. Simulating of groundwater head was done by Visual Mod flow flex 5.1 with a FORTRAN program developed by the United States Geological Survey (USGS).

3.2.1.5 Boundary conditions

Boundary conditions are the key components in conceptualizing the groundwater flow system. The conceptual model has required an appropriate set of boundary conditions to represent the system's relationship with the surrounding environment. In this study of groundwater flow model, specified flux (Neumann) boundary conditions has described through the exchange of flow between the model and the external system. In the Sub-basin the following boundary conditions were modeled.

- Pumping wells
- Recharge

However, due to the lack of recorded information and flow measurement of general head and river boundary conditions had not been modeled. The pumping wells and recharge boundary conditions were modeled for simulating this groundwater flow.

Hormat, Golina, Kelkelit and Weyilet rivers have found in the Sub-basin and taken as river boundary conditions. During dry season (December-mid of February) all those river potentials has totally lost in before reaching to their outlets.

Visual Mod Flow Flex 5.1 model has required incorporating streams and rivers into the groundwater model as river boundary condition. Interaction between surface water and groundwater has mainly simulated by assigning stage of water in the stream, stream bed thickness and conductivity values of stream bed. The recorded river bed conductivity across the river had not be available and river boundary condition was neglected.

The study area has bounded by highlands of Zobel Mountain from the Eastern boundary. The average leakage from the floor of the mountain was also difficult to measure and general head boundary conditions from the mountain area have been neglected.

Recharge boundary condition has used to incorporate recharge into groundwater model. The annual recharge amount was computed from using Roorkee's empirical estimation of 39.055 mm/yr. Well boundary condition has used to incorporate pumping wells into groundwater flow model.

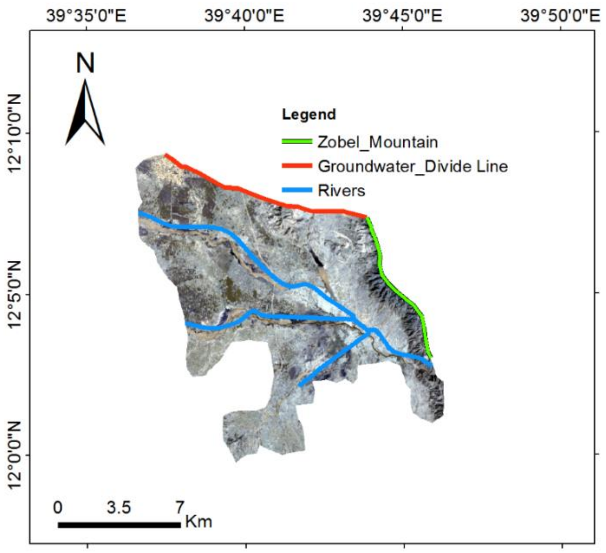


Figure 3. 4: The drainage characteristics of the Sub-basin

3.2.1.6 Measured groundwater data

In this study groundwater head was determined in two stress periods (before irrigation and after irrigation periods). The groundwater head under non-irrigation period has stated that there was no available pumping rate for irrigation activity. The groundwater table was nearly horizontal around the pumped wells before irrigation season.

Unlike the irrigated wells Kobo town water supply wells hadn’t been closed in non-irrigated season and the pumping boundary condition has taken into account. The following table (Tab.3.6) has shown that the measured static water level of each pumping wells in non-irrigated season (January, 2019).

Table 3. 6: The static water level before irrigation period

Well Id	Easting	Northing	Well depth (m)	Observed Head (m)
PK1	568066	1340931	134	25.9
PK2	568476	1341101	137	23.8
TK7	569334	1341467	167	13.9
PK6	569299	1341890	145	18.7
PK7	569892	1341651	187	20.8
PK8	569814	1341065	180	17.7
PHG1	567688	1338578	128	24.65
PHG2	567801	1337977	108	18.75
HG 18	574480	1332352	119	9.13
PHG4	566854	1339244	128	27.8
HG 14	571067	1336466	108.5	16.5
HG 7	568283	1340339	105.5	23.9
HG 8	568095	1341183	110	26.2
HG 11	571055	1335915	116.4	14.1
HG 10	570424	1339506	100	24.0
WS1	567405	1339719	74	46.1
WS2	568463	1339475	43	28.7

Water supply boreholes (Kobo town)					
Well Id	Easting	Northing	Well depth	discharge	Pumping rate
WS1	567405	1339719	74	-40	-1152
WS2	568463	1339475	43	-40	-1152

Where, WS1 and WS2 are Kobo town water supply wells.

In the second case the study had been conducted through the measured groundwater head after 90 days' irrigation period. The following table (Tab.3.7) has shown that the measured dynamic water level of each pumping wells after irrigation season (April, 2019).

Table 3.7: The dynamic water level after irrigation period

Well Id	Easting	Northing	Well depth (m)	Head (m)
PK1	568066	1340931	134	25.1
PK2	568476	1341101	137	23.2
TK7	569334	1341467	167	13.6
PK6	569299	1341890	145	18.4
PK7	569892	1341651	187	20.7
PK8	569814	1341065	180	17.7
PHG1	567688	1338578	128	24.1
PHG2	567801	1337977	108	18.5
HG 18	574480	1332352	119	8.4
PHG4	566854	1339244	128	27.1
HG 14	571067	1336466	108.5	16.2
HG 7	568283	1340339	105.5	23.6
HG 8	568095	1341183	110	25.9
HG 11	571055	1335915	116.4	13.8
HG 10	570424	1339506	100	23.5
WS1	567405	1339719	74	45.8
WS2	568463	1339475	43	28.6

The pumping time has been varied with different crop growth stage. The initial stage of growing season has required 8 hours pumping time. In the development and mid-season growing stages of 12 pumping hours and late season stage had10 hours' average pumping time was selected. From those fifteen irrigation wells and two Kobo town water supply wells had a total of $9.333*10^3$ m^3/day of groundwater was abstracted with in Ninety days' supply period. The following table (Tab.3.8) has shown that the measured daily groundwater was abstracted from the pumped wells in three months' irrigation periods.

Table 3.8: Daily water abstraction during crop season

Well			Q	January	February	March	April	daily
Id	East	North	L/sec	13d*8hrs	30*12hrs	30*12hrs	17d*10hr	Rate (m^3/d)
PK1	568066	1340931	-55	20592	71280	71280	33660	-539.21
PK2	568476	1341101	-80	29952	103680	103680	48960	-784.31
TK7	569334	1341467	-50	18720	64800	64800	30600	-490.19
PK6	569299	1341890	-40	14976	51840	51840	24480	-392.15
PK7	569892	1341651	-40	14976	51840	51840	24480	-392.15
PK8	569814	1341065	-50	18720	64800	64800	30600	-490.19
PHG1	567688	1338578	-50	18720	64800	64800	30600	-490.19
PHG2	567801	1337977	-45	16848	58320	58320	27540	-441.17
HG 18	574480	1332352	-50	18720	64800	64800	30600	-490.19
PHG4	566854	1339244	-45	16848	58320	58320	27540	-441.17
HG 14	571067	1336466	-50	18720	64800	64800	30600	-490.19
HG 7	568283	1340339	-50	18720	64800	64800	30600	-490.19
HG 8	568095	1341183	-28	10483.2	36288	36288	17136	-274.51
HG 11	571055	1335915	-50	18720	64800	64800	30600	-490.19
HG 10	570424	1339506	-34	12729.6	44064	44064	20808	-333.33
WS1	567405	1339719	-40		40*365d*8hrs*3600sec			-1152.0
WS2	568463	1339475	-40		40*365d*8hrs*3600sec			-1152.0

Where, d is day from the given month, Q is discharge and hrs. is the pumped time.

The model run under this flow conditions have selected from fifteen irrigation wells and two kobo town water supply wells. MODFLOW 2005 Numerical engine, Conjugated Gradient solver (PCG), and LFP (property package) was selected for simulating this groundwater flow.

3.2.1.7 Model assumptions

Model simulation has used to spatial and temporal data from various sources. Some assumptions were also made due to the lack of information:

- Due to the lack of detailed distribution of groundwater recharge, the previous groundwater recharge in the Sub-basins has taken from literature (53.5mm/yr).
- Specific yield was assumed to be ranges from 0.13 to 0.27 on average.
- The applied Urea and DAP fertilizers hadn't measured distance from the supply wells in that case the longitudinal disperssivity was taken as 10 m from the area to be applied towards to the supply wells.
- Decreased pumping rates by half in the sub-basins have met the community's minimum water requirement and during dry season all pumping wells should be functional.

3.2.2 Simulation of groundwater dynamics due to stresses

Investigation of this simulated groundwater dynamics due to different stress conditions (particularly, recharge and pumping rates) has been subject to primary and secondary data. The data collection and analysis method was similar to the above section (section 3.2.1).

Due to the lack of continuously recorded groundwater data in the Sub-basin, it had difficult to predict future groundwater head and its respected drawdown level. Based on the measured groundwater data, the groundwater dynamics was predicted within different stress conditions. The study area has located in Semi-arid condition; climate change had a role for controlling the groundwater dynamics.

The calibrated model had been run for different scenario based analyses with climate change and human induced impacts in relation to different simulation time. The following table (Tab.3.9) has clearly shown that the predicted groundwater dynamics with different simulation time representing vulnerable to climate change (recharge rate) and human pressures (pumping rates).

Table 3.9: Simulation of modeling for different scenarios

Simulation 1: Human pressure	Description
Scenario 1	Measured constant recharge rate of 39.055 mm/yr and pumping rate had23.2838*$10^3 m^3$/d using 17 wells
Scenario 2	The second pumping rate had(12.9048*$10^3 m^3$/d) due to stresses using 10 boreholes decreased by 55.4% of from scenario one
Scenario 3	The third pumping rate has increased from the pumping rate by 53.3% (43.6849*10^3 m^3/d) of the current rate in order to meet the daily water consumption from 34 boreholes
Simulation 2: climate change	
Scenario 4	The pumping rate has increased its rate (43.6849*10^3 m^3/d) using 34 wells influence by pressure of resources with a decreased recharge rate by 27% (28.51 mm/yr)
Scenario 5	The pumping rate has decreased its rate (12.9048*$10^3 m^3$/d) using 10 wells with increased recharge rate by 27% (53.5 mm/yr)

Pumping and recharge scenarios were used to evaluate the response of the groundwater system under variable groundwater abstraction and recharge rates. In this simulation of 17 pumping wells has taken as a base line data in order to run the predicted groundwater dynamics. Under transient state model two stress conditions (i.e. pumping and recharge) were selected with different scenarios. In this two years' groundwater level prediction, the boundary conditions and land use land cover conditions had been constant. The irrigation time within those two years' period had 330 days and 731 days for Kobo town domestic consumption was chosen as the time step. Pumping time was varied from a maximum of 16 hours to 8 hours.

3.2.2.1 Change in pumping rate

Pumping rate is the amount of groundwater that can be pumped out from the pumped wells. Predicting the groundwater dynamics has primarily depended on the pumped groundwater flow within the prescribed time.

Simulation 1: Constant recharge and change in human pressure

This Simulation of groundwater dynamics was refined by different scenarios which has been constant recharge rate with variable withdrawal groundwater rate. The recharge rate was kept constant during the simulation period starts from April, 2019.

3.2.2.2 Change in Recharge amount

Simulation 2: due to climate change the recharge rate has changed with different withdrawal rate. This Simulation of groundwater dynamics was refined by different scenarios which has been varied recharge rate and withdrawal groundwater rate.

The previous groundwater recharge was computed as 53.5 mm/yr. But currently using Roorkee's empirical estimation of 39.055 mm/yr recharge was computed. Due to the climate change, the recharge rate was varied with time. In this study the recharge rate has fluctuated by 27% with the current estimation as compared as the previous estimated result. Initial heads for model at active model cells (layer 1) was based on April 2019 data.

In Simulation 1 scenario 1, the groundwater head prediction was achieved through using the 15 irrigation and 2 kobo town water supply wells. The simulated Numerical model has chosen a transient state with total running time of two years.

The following table (Tab. 3.10) has shown from the daily water abstraction rate for the predicted growing crops and Kobo town water supply wells. From the designed constant hydrogeological stress time using 15 irrigation and 2 Kobo town water supply wells had a total of

$23.284*10^3 m^3/d$ was abstracted from the pumped wells within the predicted time for both Kobo town water supply and irrigation water demand.

Table 3.10: Predicted groundwater abstraction rate

Well Id	Easting	Northing	Q (L/sec)	Annual Groundwater consumption	daily Rate (m^3/d)
PK1	568066	1340931	-55	55*330*3600/1000	-1432.11
PK2	568476	1341101	-80	80*330*3600/1000	-2083.07
TK7	569334	1341467	-50	50*330*3600/1000	-1301.92
PK6	569299	1341890	-40	40*330*3600/1000	-1041.53
PK7	569892	1341651	-40	40*330*3600/1000	-1041.53
PK8	569814	1341065	-50	50*330*3600/1000	-1301.92
PHG1	567688	1338578	-50	50*330*3600/1000	-1301.92
PHG2	567801	1337977	-45	45*330*3600/1000	-1171.73
HG 18	574480	1332352	-50	50*330*3600/1000	-1301.92
PHG4	566854	1339244	-45	45*330*3600/1000	-1171.73
HG 14	571067	1336466	-50	50*330*3600/1000	-1301.92
HG 7	568283	1340339	-50	50*330*3600/1000	-1301.92
HG 8	568095	1341183	-28	28*330*3600/1000	-729.074
HG 11	571055	1335915	-50	50*330*3600/1000	-1301.92
HG 10	570424	1339506	-34	34*330*3600/1000	-885.304
Water supply boreholes (Kobo town)					
WS1	567405	1339719	-40	40*731d*8hrs*3600sec	-2307.16
WS2	568463	1339475	-40	40*731d*8hrs*3600sec	-2307.16

Q is constant rate of discharge, WS1 and WS2 is water supply borehole for kobo town (average 8-16 hrs pumping time per day) within two years' period.

In Simulation 1 scenario 2, the decreased pumping wells from 17 boreholes to 10 boreholes has shown that the variation of groundwater dynamics in a response of decreased pumping rate.

Initial heads for model at active model cells (layer 1) was based on April 2019 data. The predicted model can be helps to understand how the changed pumping rate had the response to groundwater dynamics.

The following table (Tab.3.11) has shown from the constant hydrogeological stress using 9 irrigations and 1 Kobo town water supply wells of a total 12.9048*10^3 m^3/d was abstracted from the pumped wells within the predicted time. In this scenario the pumping rate was decreased by 55.4% from the first scenario.

Table 3.11: The decreased pumping rate by half

Well Id	Easting	Northing	Q L/sec	Annual Groundwater consumption	daily Rate (m^3/d)
PK1	568066	1340931	-55	55*330*3600/1000	-1432.11
TK7	569334	1341467	-50	50*330*3600/1000	-1301.92
PK8	569814	1341065	-50	50*330*3600/1000	-1301.92
PHG2	567801	1337977	-45	45*330*3600/1000	-1171.73
HG 18	574480	1332352	-50	50*330*3600/1000	-1301.92
PHG4	566854	1339244	-45	45*330*3600/1000	-1171.73
HG 14	571067	1336466	-50	50*330*3600/1000	-1301.92
HG 8	568095	1341183	-28	28*330*3600/1000	-729.074
HG 10	570424	1339506	-34	34*330*3600/1000	-885.304
		Water supply boreholes (Kobo town)			
WS1	567405	1339719	-40	40*731d*8hrs*3600sec	-2307.16

In Simulation 1 scenario 3, the increased pumping wells from 17 wells to 34 boreholes has shown that the variation of groundwater dynamics in a response of increased pumping rates.

The following table (Tab.3.12) has shown that the constant hydrogeological stress in using the whole functional irrigation and town water supply wells in response to pumping rates. When using the whole irrigation boreholes and water supply had a total 43.684*10^3 m^3/d groundwater was abstracted from 34 boreholes per crop season in the predicted time. The amount of water abstracted in this scenario was increased by 53.3% from the amount used in scenario one. In this scenario the increased amount of discharge from the boreholes has needed from additional pumping boreholes.

Table 3.12: The pumping wells increased by double

Well Id	X	Y	Q L/sec	Annual Groundwater consumption	daily Rate (m^3/d)
HG1	568171	1339140	-51	51*330*3600/1000	-1327.96
HG3	569659	1338130	-20	20*330*3600/1000	-520.767
HG4	569354	1339493	-51	51*330*3600/1000	-1327.96
HG 6	568723	1341185	-50	50*330*3600/1000	-1301.92
HG 9	569858	1339504	-10	10*330*3600/1000	-260.384
HG12	572295	1335804	-50	50*330*3600/1000	-1301.92
HG13	571683	1336365	-50	50*330*3600/1000	-1301.92
HG 16	574874	1331241	-25	25*330*3600/1000	-650.959
HG 17	574664	1331880	-50	50*330*3600/1000	-1301.92
PK9	569485	1341610	-50	50*330*3600/1000	-1301.92
PHG3	568356	1337982	-50	50*330*3600/1000	-1301.92
PHG5	571398	1335248	-57	57*330*3600/1000	-1484.19
PHG6	571821	1334963	-58.5	58.5*330*3600/1000	-1523.24
PHG7	572289	1334951	-51.6	51.6*330*3600/1000	-1343.58
PHG8	570553	1334124	-46.4	46.4*330*3600/1000	-1208.18
PHG9	570089	1333952	-53.5	53.5*330*3600/1000	-1393.05
PHG10	569560	1334010	-59.5	59.5*330*3600/1000	-1549.28
Water supply boreholes (Kobo town)					
WS1	567405	1339719		40*731d*8hrs*3600sec	-2307.16
WS2	568463	1339475		40*731d*8hrs*3600sec	-2307.16

In simulation 2 scenario 4, the groundwater dynamics has determined in relation to climate change since the Sub-basin has categorized to semi-arid climatic condition. In simulation 2 scenario 4 the current withdrawal rate has increased to 34 wells and decreased recharge rate by 27% (28.51 mm/yr) in order to satisfy the daily water requirement of the communities.

In simulation 2 scenario 5the current withdrawal rate has decreased to 10 pumping wells and increased recharge rate by 27% (53.5 mm/yr) for the sake of groundwater reservoir.

3.2.3 The impacts of Urea and DAP fertilizers on groundwater quality

The groundwater quality data in Hormat-Golina Sub-basin has primarily concerned the effect of fertilizers on it. Simulating the groundwater quality related to the applied Urea and DAP fertilizers could understand the groundwater flow in relation to sorption and its chemical reaction with the rock materials. The data collection and analysis method for Solute transport model under boundary conditions were similar to the simulation of groundwater flow model.

The Mass Transport Model has been used to run for determining the concentration of Nitrate and Phosphate from Urea and DAP fertilizers with three-month prescribed time. Predefined grid size and layer type used in the flow model were used by transport model. The boundary conditions used in the groundwater flow model has converted to Mass Transport in Three Dimensions (MT3Ds), since the active cells has assigned to active concentration cells while inactive cells had not considered for transport simulation.

The concentration of Nitrate and Phosphate from Urea and DAP fertilizers were applied to the concentration observation wells. Mass Transport Models has required incorporating pore space of the rock materials. The initial concentration of Nitrate and Phosphate from Urea and DAP fertilizers were taken as the laboratory result in January 2019.

The chemical concentration of the groundwater in Hormat-Golina Sub-basin has stimulated by using mass transport modeling for a period 90 days of irrigation period. In this study the transient model has simulated for transport process of each chemical concentration which was left from the Urea and DAP fertilizers in the period between January 2019 to April 2019.

The concentration observation date was started from 1/17/2019 for those three wells have taken as initial concentration for each groundwater quality parameters. Simulating Mass transport model for running the groundwater quality the following data were collected.

Table 3. 13: Groundwater data for Solute transport model

Parameters	Value
Total porosity	0.3
Effective porosity	0.2
longitudinal dispersvitiy (m)	10
Initial concentration (mg/l)	Measured concentration

3.2.3.1 Groundwater sampling

In order to understand the effect of fertilizers on groundwater quality, groundwater sampling was taken from the water supply pumping wells. Testing the whole pumping wells has provided best information about the physico-chemical characteristics of the groundwater but laboratory expenses was difficult to test all supply wells. Based on the above limitation this study has clearly shown the pattern of each groundwater quality parameters from three supply wells.

Necessary to obtain a representation of groundwater sample had been mandatory, but in this study the selected samples were based on frequently applied of fertilizers around the supply wells. One sample well was selected in the Eastern boundary of Hormat-Golina and the other two sample wells were from the Western boundary. Normally 100 ML plastics bottles were used and stored in the store house for chemical analysis since the storage media can helps to avoid the alteration of chemical composition before reaching to the laboratory.

Sample was taken to follow procedures for proper storage and transportation of groundwater. Laboratory sample bottles were cleaned by distilled water in order to avoid sample contamination. The supply well PK7 had its own observation wells (OW1), the supply well PHG2 had observation well (OW2) and the supply well PHG4 had observation well (OW3). The water samples were selected from those supply wells and water quality laboratories has conducted in three consecutive months from January 17 to April 17 with four times for 30 days' interval. The observation wells were varied by 22 m to 320 m from the pumping wells.

The following table (Tab.3.14) has shown from the selected characteristics of pumping and observation wells in Hormat-Golina Sub-basin.

Table 3. 14: The selected groundwater sample well characteristics

Well Name	x	Y	Well depth (m)	discharge (l/s)	Head(m)	Start time	End time
PK7	569892	1341651	183	-40	19.6	1/17/2019	4/17/2019
PHG2	567801	1337977	108	-45	18.5	1/17/2019	4/17/2019
PHG4	566854	1339244	116	-45	27.4	1/17/2019	4/17/2019
OW1	569928	1341651	203	-40	20.4	1/17/2019	4/17/2019
OW2	568121	1337977	150	-45	19.1	1/17/2019	4/17/2019
OW3	566854	1339266	128	-45	28.0	1/17/2019	4/17/2019

The negative sign in the above table has shown that the discharge rate pumped from the wells.

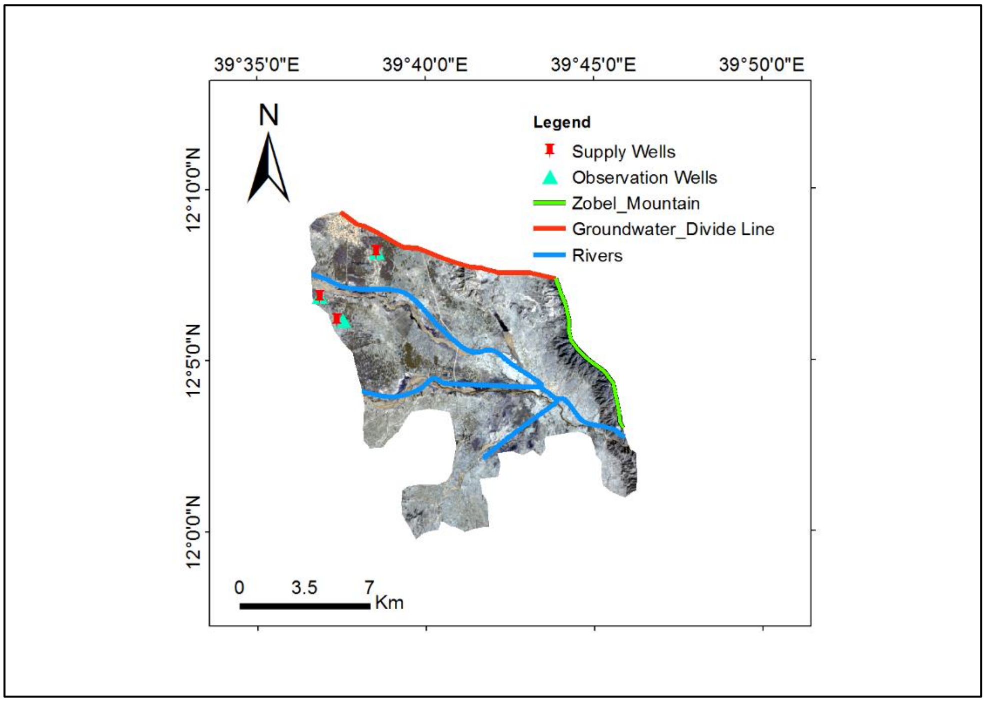


Figure 3. 5: The location map of the selected groundwater samples

According to Kobo District Agricultural office report (2015) in Hormat-Golina Sub-basin, irrigated agriculture was being the dominant farming activity. However, in the last two decades' farmers have been using extensive chemical fertilizers for crop production.

3.3.2 Laboratory Analysis

In the laboratory analysis Nitrate concentration from Urea was determined by phenoldisulphonic acid method and for phosphate concentration residues were calculated by using Spectrophotometer. Chloride concentrations from the released wastes were determined by titration method. The groundwater chemistry parameters and its testing method has listed in the following table (Tab.3.15).

Table 3. 15: The physico- chemical parameter testing methods

Concentration	Test method
Nitrate	phenoldisulphonic acid
Phosphate	Spectrophotometer
Chloride	Argentometric (Titration method)

The groundwater samples were taken from three observation wells on the basis of the site investigation where the farmers have been using excessive fertilizers and then tested in Soil and water laboratory analysis of Sirinka Agricultural Research Center.

I. Phenoldisulphonic method

A calibration curve was prepared by using standard nitrate ($KNO3$) solution. Standard Potassium Nitrate ($KNO3$) solutions has taken in different separate beakers and evaporated dryness on a hot plate. Phenoldisulphonic acid has added and residue was dissolved. To develop color Ammonium ($NH4$) was added and diluted to 100 ML standard volumetric flasks. Contents were mixed well and the solutions from each of the standard flasks are transferred to a cuvette. The absorbance was measured at 410 nm wavelength filter using colorimeter.

Water sample has taken into another beaker and evaporated to dryness on a hot plate. phenoldisulphonic acid has added into the beaker and the residue was dissolved. To develop color Ammonium ($NH4$) was added and diluted to 100 ML standard volumetric flasks. Contents were mixed well and the solution from the standard flask was transferred to a cuvette. The absorbance was measured at 410 nm wavelength filter using colorimeter. Blank solution was prepared by excluding the water sample. Calibration curve was drawn by plotting absorbance against the concentration of Nitrate ($NO3^-$). Finally, the concentration of Nitrate ($NO3^-$) in the water sample was recorded from the colorimeter.

II. spectrophotometer method

Spectrophotometer measures the intensity of light that passes through a solution. This was accomplished by shining light at a specific wavelength through a solution and comparing the intensity with a reference blank.

Rinse of graduated cylinders, cuvettes with distilled water and phosphomolybdic acid reagent were added to calibration sample. For the blank solution distilled water, phosphomolybdic acid reagent was added to a cuvette. The solutions were allowed to sit for 30 minutes to develop color. Record absorptivity from spectrophotometer for the blank and calibration samples was done. The concentration of Phosphate in the water sample was read from the spectrophotometer.

III. Argentometric Method

Based on the principle that in a natural or slightly alkaline sample, Potassium chromate can indicate the endpoint of the silver Nitrate titration of chloride. Silver chloride had quantitatively precipitated before red silver chromate was formed. Water sample was measured and potassium dichromate (K2CrO4) was added as an indicator. The solution was then titrated against 0.01N Silver Nitrate (AgNO3) solution until yellow color changed to brown at the end point and the result was expressed in mg/l.

3.2.3.2 Groundwater quality parameters analysis

In the study area, most commonly used fertilizers being Urea and DAP. During irrigation, these chemical fertilizers has leached into the ground and joined to groundwater. As the information obtained from Kobo District Agricultural Office, the consumption of chemical fertilizers (Urea and DAP) application rate per hectare per cropping season had increased with time.

The groundwater quality parameter in this study had including: Nitrate from Urea fertilizers, Phosphate from DAP fertilizers and Chloride from waste disposal as well as Chloride content rocks.

Nitrate: Urea is one of the Nitrogenous fertilizers that have received wider attention in agriculture, because of its potential role for seedling damage, ammonia volatilization and water pollution problems. Urea enters surface and groundwater through leaching and surface run off from agricultural lands. Its entry into ground water depends on physical properties of soil like texture.

Phosphate: Phosphates originate from many sources; including sewage, manure and also found in DAP fertilizers from agricultural lands to near-by the supply wells.

Chloride: Chloride occurs naturally in all types of water samples. Chloride in natural water results from agricultural activities it had to dissolution of chloride from chloride containing rocks.

Agricultural practices such as releases of residues and chemical fertilizers which had degrade the quality of the groundwater. The extent and magnitude of the degradation was difficult to assess because of its non-point source in nature. World health organization (WHO) has established the standard guidelines of groundwater quality parameters. According to Divya and Belagali (2012) report the following table (Tab.3.16) has shown that the standard guideline for chemical characteristics of groundwater.

Table 3. 16: WHO standard values for physio-chemical parameters

Parameters	WHO standards (mg/l)
Nitrate	50
Phosphate	0.1
Chloride	250-1000

3.3 Groundwater Flow Model Setup

In this case, modeling has been carried out layered based unconfined model data which was obtained from Metaferia Consulting Engineers report, physical investigation, current recorded groundwater data and laboratory result for physic-chemical analysis. To carry out this study, unconfined aquifers have conceptualized with appropriate boundary conditions. The study area has located with the coordinate system of UTM Zone 37 N (WGS84). Model structures have provided the geological surfaces that were represent the tops and bottoms of the geological model.

The lithological characteristics of the pumping wells can provide information about the depth of the layer of the geology. In Visual Mod Flow Flex 5.1, horizons were created by clipping or extending interpolated surface data objects to the boundary of the conceptual model. During model setup conceptual model has established throughout considering model inputs including flow property within an existing boundary conditions to develop numerical model.

3.4 **Groundwater Governing Equations**

Groundwater models has simplified and conceptualized representations of hydrologic cycle. The equation has primarily used for hydrologic prediction and for understanding the effect of hydrologic processes on groundwater storage.

A general form of governing groundwater equation in the three dimensional non-equilibrium movement of groundwater with constant density through porous, three dimensional and heterogeneous flow of groundwater has described by the partial differential equation (Freeze and Cherry, 1979)

The governing equation for groundwater flow through saturated porous media in three dimensions has derived from Darcy's law and the continuity equation and is given as in equation (Eq. 3.2).

$$\frac{\partial}{\partial x}(Kx\frac{\partial h}{\partial x}) + \frac{\partial}{\partial y}(Ky\frac{\partial h}{\partial y}) + \frac{\partial}{\partial z}(Kz\frac{\partial h}{\partial z}) \pm W = (Ss\frac{\partial h}{\partial t})\text{---------------------}3.2$$

Where

Kx, Ky and Kz are the hydraulic conductivity along the x, y and z directions(LT^{-1})

h is potentiometric head (L)

W is the volumetric flux per unit volume and represents the sources and/or sinks of water per unit time (T^{-1})

Ss is specific storage of the porous material (L^{-1} and T is the time (T)

The governing equation for solute transport model through saturated porous media in three dimensions to simulate the migration of contaminant towards to groundwater storage. The partial differential equation for three dimensional transports of contaminants in groundwater has given as in equation (Eq. 3.3).

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial xi}[Dij\frac{\partial}{\partial xi}] - \frac{\partial}{\partial xi}(Vic) + \frac{qs}{\theta}cs + \sum_{k=1}^{n} Rk)\text{---------------------}3.3$$

Where, C is the concentration of contaminant dissolved in groundwater, t is the time (t),

xi is the distance along the respective Cartesian coordinate axis,

Dij is the hydrodynamic dispersion coefficient,

Vi is the seepage or linear pore velocity,

qs is the volumetric flux of water per unit volume of aquifer representing sources (positive) and sinks (negative),

Cs is the concentration of sources or sinks, θ is the porosity of the porous medium and,

Rk is the chemical reaction term

3.5 Model Discretization

The conceptual model has used central finite difference method, which involves fitting the conceptual model to finite difference grids. This allows confirming the grid to each wells and boundary conditions. Developing and predicting groundwater flow and solute transport model needs to understand the relationship between the conceptual and the numerical models. Conceptual Model refers to a basic, high level representation of the hydro-geological system being modeled.

In this conceptual model for groundwater flow determination had polygon, point and polyline data performed by Geographical Information System (GIS). The numerical models have modeled through the developed conceptual models.

In Hormat-Golina Sub-basin, the numerical model has mapped with 40 rows and 40 columns with the corresponding cell height of 636.324 and 442.588 m along the X and Y direction respectively. Deformed grid type was selected for (the tops and bottoms of the model layers follow the horizons elevations).

Visual Mod flow flex 5.1has allowed to translating the conceptual model to finite difference models for running and analyzing of the groundwater flow and concentration of chemical content. Automatically populates the specified grid with the defined geological formations, boundary conditions and property zone attributes. USGS Mod flow 2005 was chosen as an engine to run a numerical model.

3.6 Sensitivity Analysis

In a sensitivity analysis, parameter values have individually changed to determine the effect on model calibration and prediction in using visual modflow flex 5.1 model. The indication of which parameter changes can have significant impact on the model results and which parameter changes have little or no impact on the model results. This analysis helps to properly select parameters to include in a PEST run which focus more on the sensitive parameters and less on the non-sensitive parameters.

Model calibration is the process of adjusting the model input parameters so as to match them with the existing field conditions to obtain a model representation of the processes within some acceptable criteria. Doherty and Johnston in 2003 developed the PEST run which is a non-linear parameter estimation and optimization package.

Model calibration was achieved through Parameter Estimation (PEST) approach until the hydraulic heads and the transport values calculated by Visual ModFlow Flex 5.1 matches with its observed values to a satisfactory degree at the end of simulation.

In this study Parameter Estimation (PEST 12.3.1) version of Watermark Numerical Modeling was used to run in order to understand the sensitivity analysis of the model.

The calibration of this model has accomplished through Parameter Estimation (PEST) adjustment of the model's hydraulic conductivity over an iteration of using Jacobean Matrix

3.7 Model performance measures

The accuracy of model has judged by root mean square value of square root of the sum of the square of the differences between calculated and observed heads and concentrations, divided by the number of observation wells (Anderson and Woessner, 1992). The model performance in using this Visual Mod Flow Flex 5.1 the following model performance has measured.

The Standard Error of the Estimate (SEE) is a measure of the variability of the residual head and concentration around the expected value, and is expressed by the following equation (Eq. 3.4).

$$SEE = \frac{\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(Ri-\mu)^2}}{n} \text{----------------------------3.4}$$

$Ri = X\ cal - Xobs$and $\mu\ (mean) = \frac{1}{n}\sum_{i=1}^{n} Ri$

$$X\ cal\ and\ Xobs\ is\ the\ calculated\ and\ observed\ points$$

The root mean square error (RMSE) is defined by the following equation (Eq. 3.5).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Ri)^2} - - - - - - - - - - - - - 3.5$$

The objective of $RMSE\ in$ groundwater model calibration is to minimize the sum of squared residuals. Residual are differences between calculated and observed groundwater heads.

The Normalized Root Mean Squared is the RMSE divided by the maximum difference in the observed

head values, and is expressed by the following equation (Eq. 3.6).

$$Normalized\ RMS = \frac{RMS}{(\boldsymbol{Xobs})max-(\boldsymbol{Xobs})min} \text{------------------3.6}$$

The Correlation Coefficient (*Cor*) is calculated as the covariance between the calculated results ($Xcal$) and the observed results ($Xobs$) at selected data points divided by the product of their standard deviations. The correlation coefficient is calculated using the following equation (Eq.3.7). $$Cor = \frac{\frac{1}{n}\sum(Xi - \mu cal)(Xi - \mu obs)}{\sqrt{\frac{1}{n}\sum(Xcal - \mu cal)^2} * \sqrt{\frac{1}{n}\sum(Xobs - \mu obs)^2}} --- 3.7$$

μcal *and* μobs is the mean value of calculated and observed heads respectively

Model calibration was stopped at the end of the simulation when reasonable matches between the observed and calculated hydraulic heads and transports model has achieved. After each run, differences between simulated and observed heads has calculated with every difference should be minimal. The model calibrations have indicated a reasonably good match between observed and calculated hydraulic heads and transport concentrations. The model performance was achieved through different scenarios representing insights about the future changes in groundwater due to pumping and recharges rates.

4 RESULT AND DISCUSSIONS

4.1 Groundwater head and flow direction for irrigation and non-irrigation season

The groundwater head and flow direction in Hormat-Golina Sub-basin was analyzed by different stress periods (before and after irrigation season). Before irrigation, the groundwater flow head and its flow direction has only determined from kobo town water supply. After the irrigation period, the groundwater flow head and its direction has already determined through the combination of both kobo town water supply and pumped irrigation boreholes. When irrigation period was started the drawdown level has changed with time since the static water level has already varied.

Hydraulic conductivity was more sensible for groundwater flow model while specific yield was less sensible during running this flow model. The calibrated model has run for determining the groundwater head as well as the drawdown level in irrigated and non-irrigated season.

After calibration the model has been completed in before and after irrigation season, the standard error of the calculated and observed head was 0.46m and 0.49 m respectively. Table 4.1 has shown the transient state calibration of the model performance between observed and calculated heads.

Table 4. 1: Groundwater flow model performance characteristics

Model status	before irrigation	After irrigation
Standard error of the estimate (m)	0.46	0.49
Root mean square(m)	1.83	2.01
Normalized root mean square (%)	4.95	5.37
Correlation coefficient	0.98	0.98

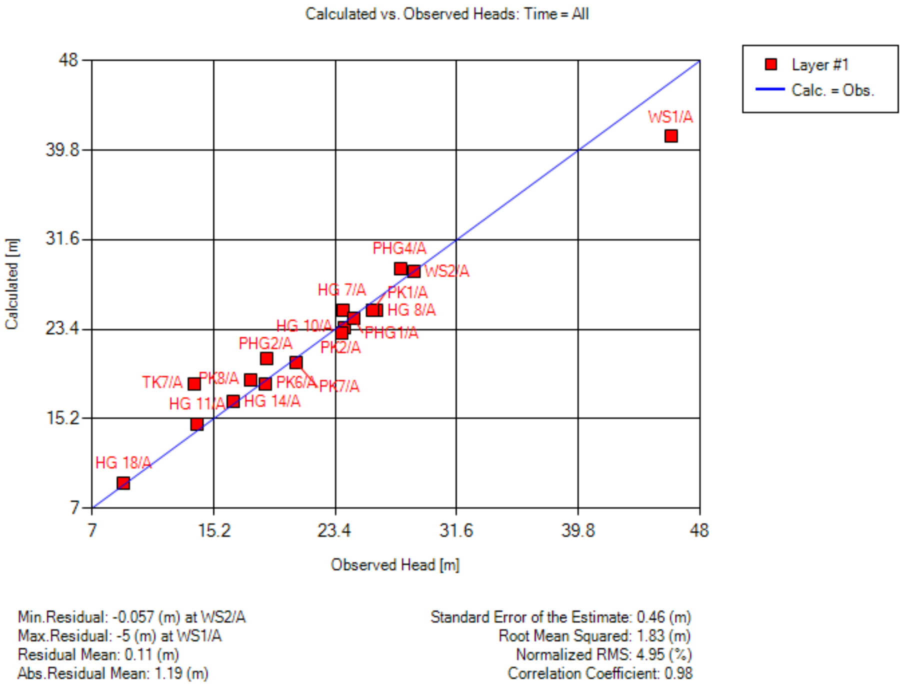


Figure 4. 1: The calibrated model result in non-irrigation season

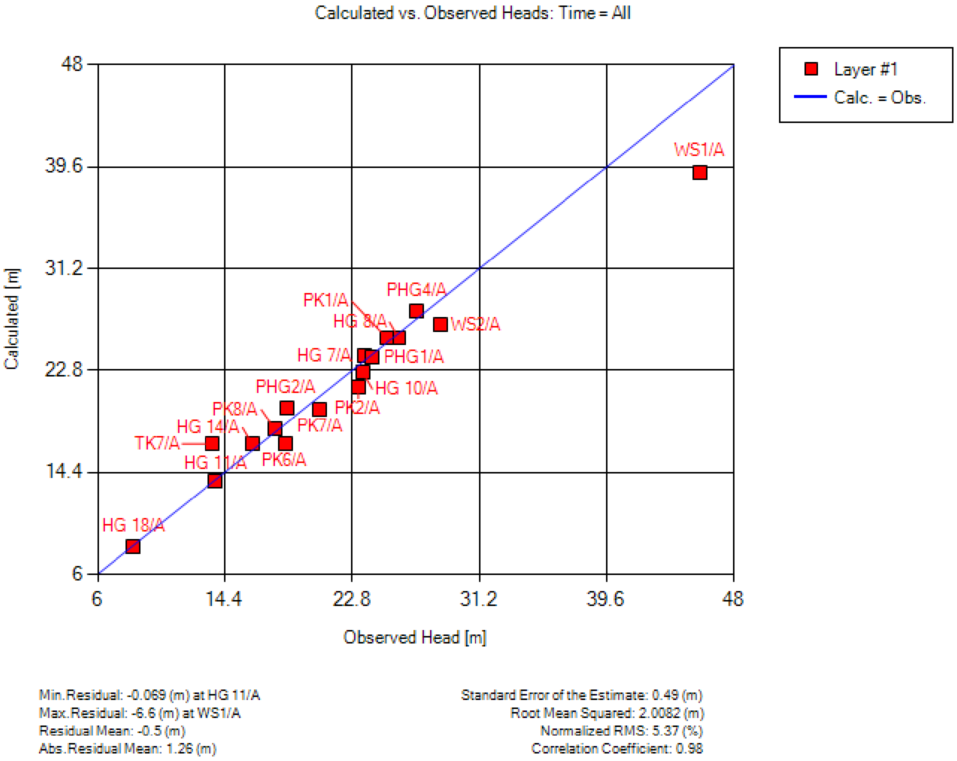
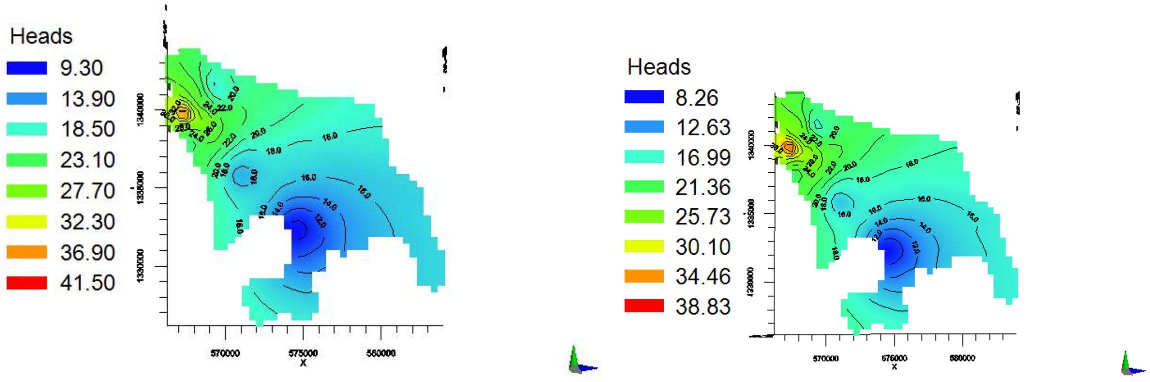


Figure 4. 2: The calibrated model result in after irrigation season

The groundwater head result in non-irrigation period has shown that its level was changed with respect to Kobo town water supply wells. The simulation of 15 irrigation wells with 2 water supply well data points were taken, the hydraulic head as well as the flow direction has shown in the following model result.



(a) (b)

Figure 4. 3: The model result for before and after irrigation season

The above figure (Fig. 4.3) had shown that the groundwater head before irrigation season (a) and after irrigation season (b). Under this simulation result, the graphical representation can help to understand the effect of pumping rates had on groundwater head during stresses periods. Unlike in non-irrigation season the irrigation boreholes were opened in non-irrigation season.

Different color has shown from the above figure can express the groundwater head in the Sub-basin with respect to time by using inverse distance interpolation methods. The model result has shown in the Northwestern boundary of the Sub-basin; the groundwater head was found on greater depth while in the Southern part of the Sub-basin has located on shallow groundwater head.

The model result has already shown from the above figure (Fig. 4.3 a), the groundwater head level in before irrigation season was varied from 9.3 m in the Southern boundary to 41.5 m in Northwestern boundary of the Sub-basin.

In the time before growing season, the curved streams around the pumped wells has nearly stable since irrigated wells were stopped but town water supply wells were responsible to control the groundwater head.

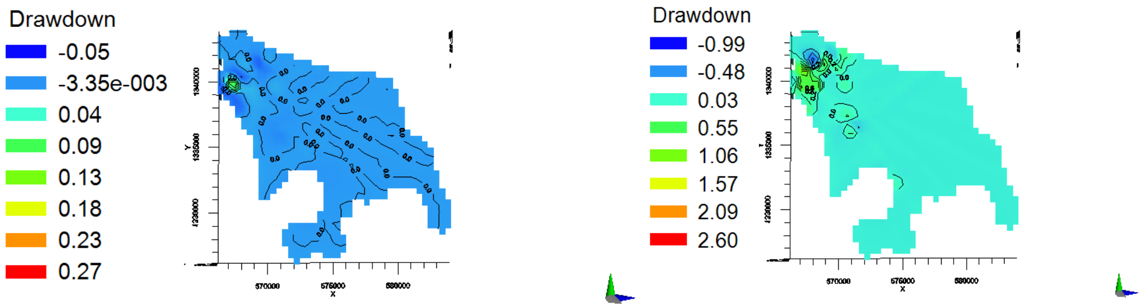
The initial head values before irrigation season was recorded during January 2019 and its result was varied to a maximum of 0.8 m as compared as the measured depth of the initial heads from after irrigation season.

In the above figure (Fig.4.3 b) the groundwater head has shown after irrigation season; which can help to understand the effects of irrigation boreholes on groundwater head and changed to a maximum of 2.67 m within three months' irrigation period.

The model result has shown from the above figure (Fig. 4.3 b) the groundwater head level in irrigation season was varied from 8.26 m in the Southern boundary to 38.83 m in Northwestern boundary of the Sub-basin.

Comparing both seasons (before and after irrigation), groundwater declination can't be fully compensated by groundwater recharge especially in areas where the Western boundary which has dense irrigation boreholes. Furthermore, the groundwater table for irrigation season was emphasized on more water table variation had greater on the Northwestern boundary than Eastern boundary of the Sub-basin.

After the growing season, the groundwater tables have a tendency to decrease its level due to water pumping for irrigation as well as the town water supply for domestic purpose. There was a substantial increase of the groundwater table in non-irrigation seasons and a decline in irrigation seasons. The declination of the water table in irrigation seasons has directly related to the pumping rates. The pumping rate was higher than the aquifer replenishment rate in irrigation season.



(a (b)

Figure 4. 4: The drawdown level in before and after irrigation season

From the above figure (Fig.4.4 a) the drawdown level has shown that the maximum depth of 0.27 m found in the non-irrigated season around the pumped wells.

In the above figure (Fig.4.4 b) the drawdown level has shown that the maximum depth of 2.6 m found in the irrigated season around the pumped wells. The drawdown level was depending on the amount of water abstracted from the groundwater reservoir.

The drawdown level at the end of the irrigation season was varied by 2.33 m in the Northwestern boundary of the Sub-basin as compared as the non-irrigated season. The drawdown level at the end of the irrigation season was varied by 0.94 m in the Southwestern boundary of the Sub-basin.

4.2 Simulation of groundwater dynamics due to stresses

4 2.1 Groundwater head

The scenario based groundwater flow prediction result has been applied with different stress conditions (i.e. pumping and recharge rates).

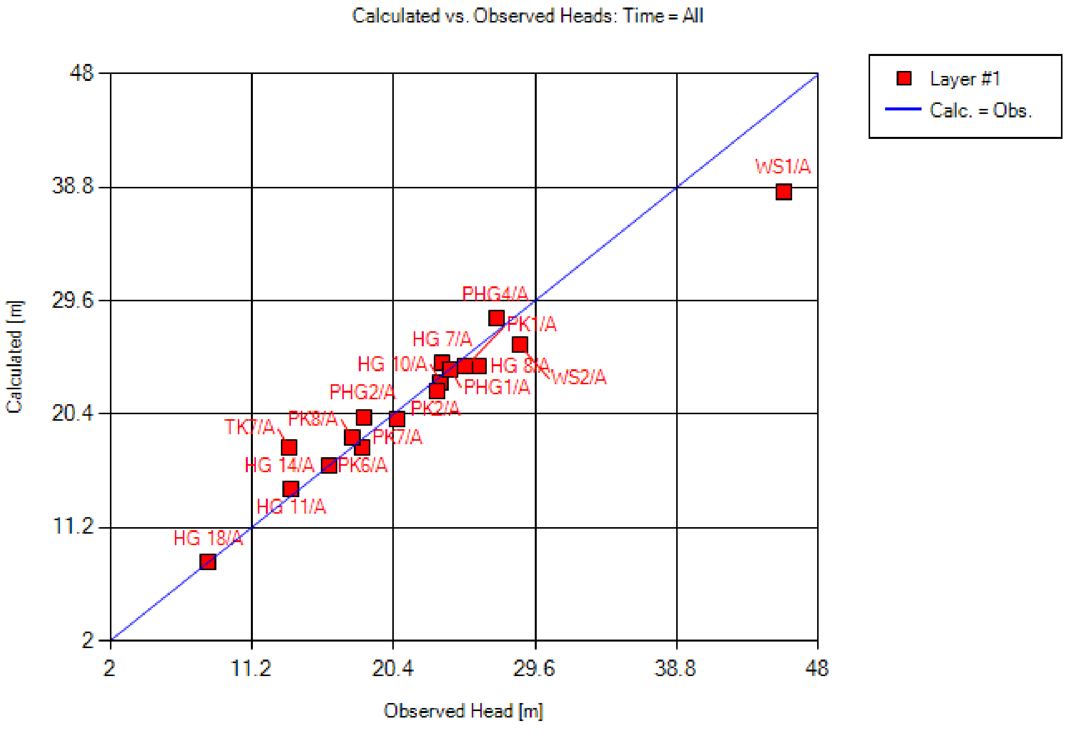
Using 15 irrigation and 2 Kobo town water supply wells have been a total of 23.284*10^3 m^3/d groundwater abstracted from the pumped wells within the predicted two years for both water supply and irrigation demand. In this scenario result, the hydro geological stress conditions have been constant with time from 39.055 mm/yr of groundwater recharge.

In this transient state calibration of groundwater model, the model has subjected to various stress periods. A scenario based analysis had further into 5 scenarios with simulation of the pumping and climate change. In all cases the hydraulic conductivity values were more sensible parameter while the specific yield was less sensible parameters from the PEST run model result see on appendix (appendix1).

After calibration the model has been completed in different stress periods, the standard error of the calculated and observed head for simulation 1 scenario 1, scenario 2 and scenario 3 was found 0.56 m, 0.72 m and 0.42 m respectively. Table 4.2 has shown the transient state calibration of the model performance between observed and calculated heads for different scenarios.

Table 4. 2: Groundwater flow model performance result for scenario analysis

Model status	Scenario 1	Scenario 2	Scenario 3
Standard error of the estimate (m)	0.56	0.72	0.42
Root mean square (m)	2.28	2.18	2.47
Normalized root mean square (%)	6.11	5.84	6.55
Correlation coefficient	0.98	0.99	0.94



Min.Residual: -0.017 (m) at HG 18/A
Max.Residual: -7.3 (m) at WS1/A
Residual Mean: -0.38 (m)
Abs.Residual Mean: 1.44 (m)

Standard Error of the Estimate: 0.56 (m)
Root Mean Squared: 2.28 (m)
Normalized RMS: 6.11 (%)
Correlation Coefficient: 0.98

Figure 4. 5: The calculated vs modeled result for constant pumping rate

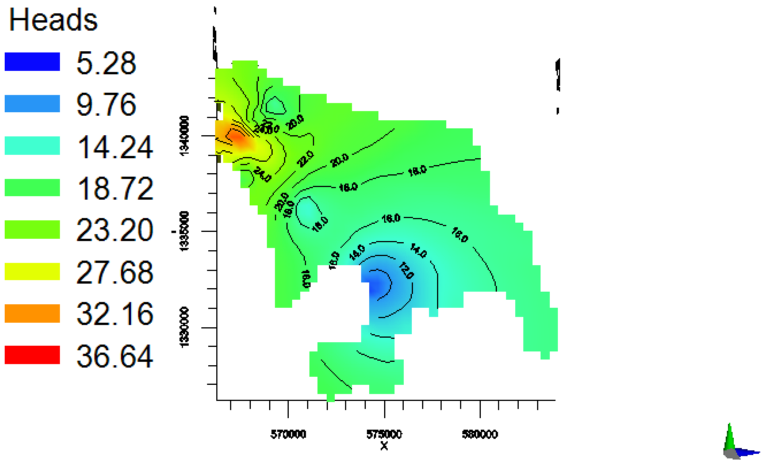
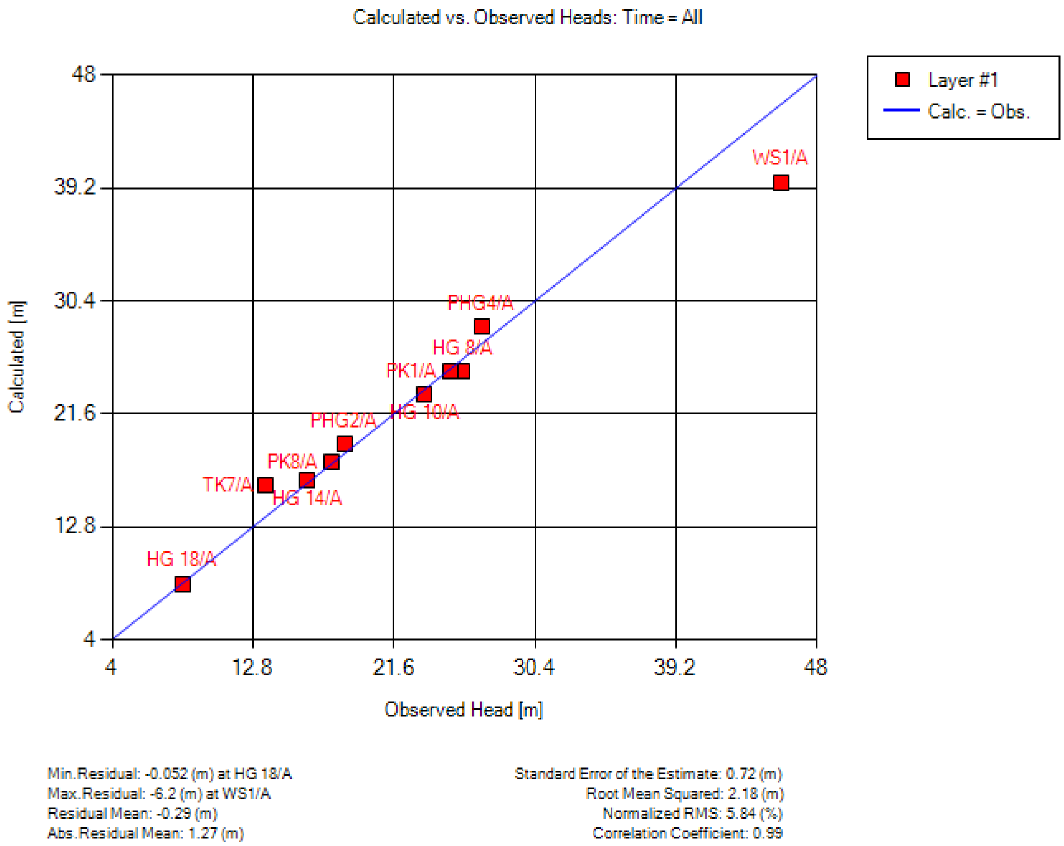


Figure 4. 6: The predicted groundwater head with constant rate

In the above figure (Fig. 4.6) the predicted groundwater head values have shown that constant pumping rates with constant recharge rate. In the Northwestern boundary of the Sub-basin has been changing its level due to pumping wells in the predicted growing time.

The result of this groundwater of movement has shown from the Northern boundary towards to the Southern direction due to the drainage effect. In simulation 1 scenario 1, the predicted estimation of human pressure (pumping rate) and climate change (recharge rate) has been constant, its level was varied from 5.28 m in the Southern boundary to 36.64 m in the Northwestern boundary.

In Simulation 1scenario 2 and scenario 3 when the pumping wells has decreased from a total of 17 wells to 10 wells and increased to 34 wells respectively, the following calibrated result has been shown.



Min.Residual: -0.052 (m) at HG 18/A
Max.Residual: -6.2 (m) at WS1/A
Residual Mean: -0.29 (m)
Abs.Residual Mean: 1.27 (m)

Standard Error of the Estimate: 0.72 (m)
Root Mean Squared: 2.18 (m)
Normalized RMS: 5.84 (%)
Correlation Coefficient: 0.99

Figure 4. 7: The calculated vs modeled result for decreased pumping rate

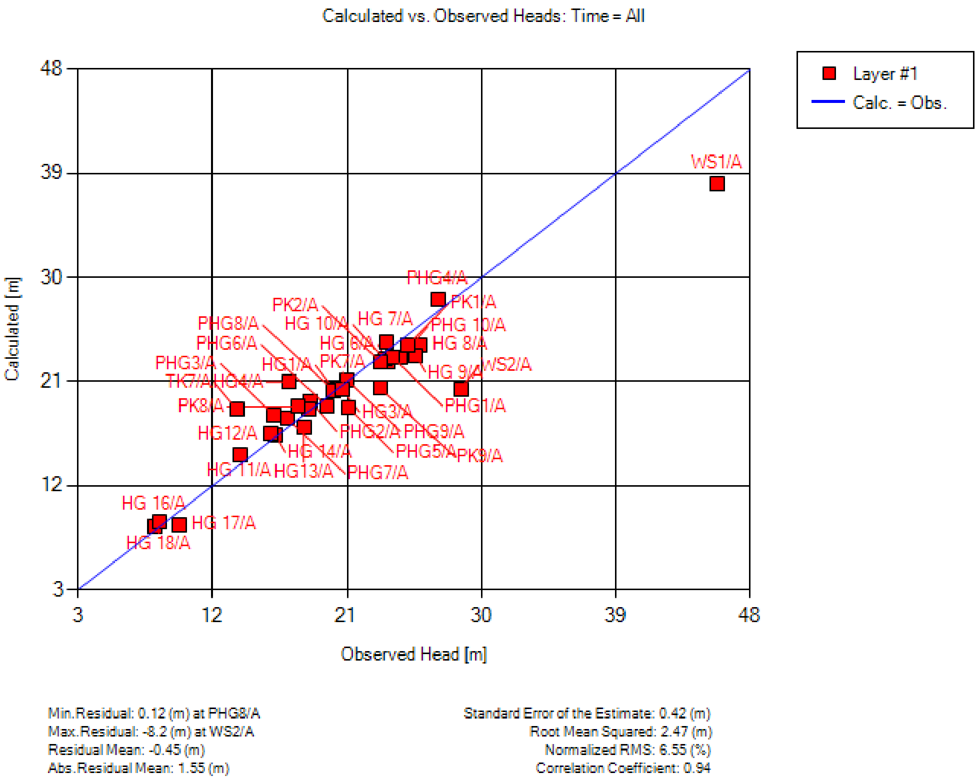
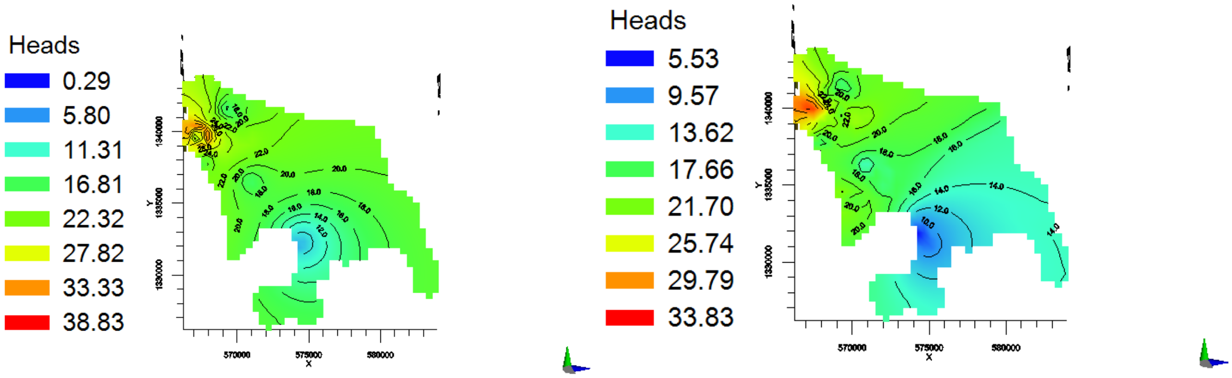


Figure 4. 8: The calculated vs modeled result for increased pumping rate

For Simulation 1scenario 2 and scenario 3, the following groundwater head result has been shown.



(a).

(b).

Figure 4. 9: The predicted groundwater head result due to change of pumping well

The above figure (Fig.4.9 a) has shown that the groundwater head due to the decreased pumping wells by half with constant measured recharge rate. In Simulation 1 scenario 2, the groundwater head had been highly varied in a response of decreased pumping rate. The groundwater head level due to the decreased pumping wells by half with constant recharge was varied from 5.8m in the Southern boundary to 38.83 m in Northwestern boundary of the Sub-basin.

The predicted groundwater head at the end of 2021 has increased by 0.52 m in the floor of the Sub-basin and increased by 2.19 m in the Northwestern boundary of the Sub-basin as compared as the previous groundwater head determination scenario (Scenario 1).

In figure 4.9 b, the groundwater head has been changed with time due to the increased pumping wells by two with constant recharge rates. The model result from the above figure (Fig. 4.9 b) has shown that the groundwater head level due to the increased pumping wells by two with constant recharge rate was varied from 5.53 m in the Southern boundary to 33.83 m in Northwestern boundary of the Sub-basin.

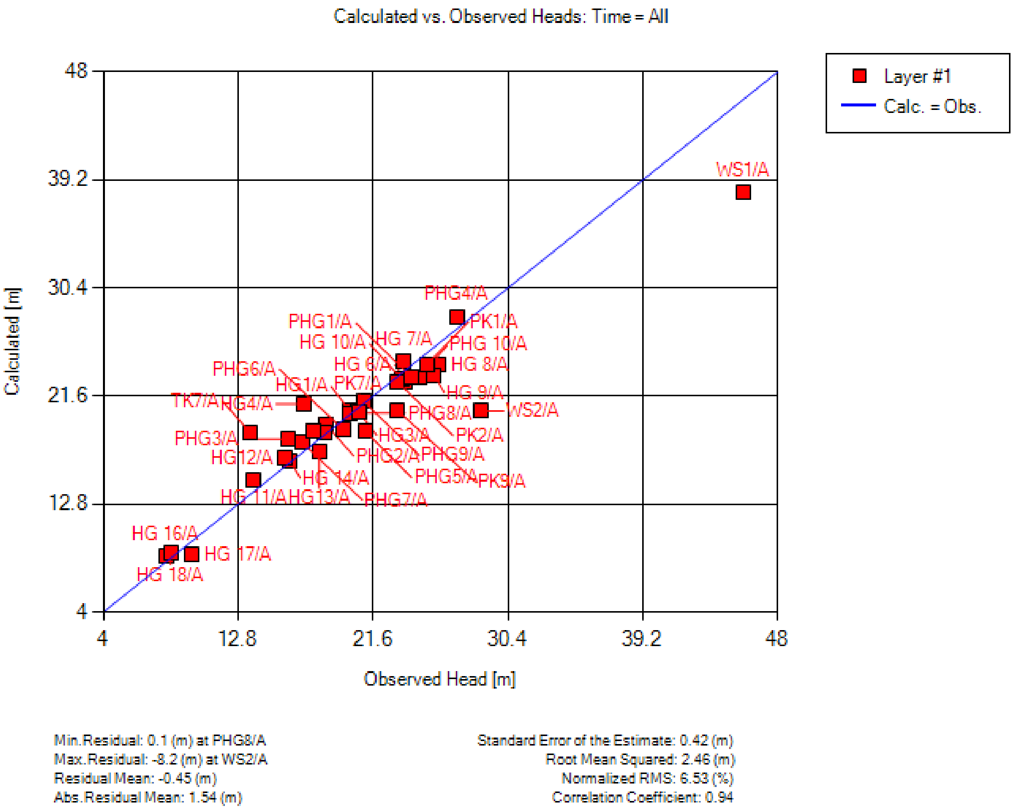
The increased pumping rate has replied to the groundwater head at the end of 2021was increased by 0.27 m in the floor of the Sub-basin due to the drain effect of the flow and decreased by 2.81 m in the Northwestern boundary of the Sub-basin as compared as the previous groundwater head determination scenario (Scenario 1).

Using transient state calibration for climate change to match the initial heads with the simulated hydraulic heads by sequential adjustment of model parameters. In all cases the hydraulic conductivity value was more sensible parameter while specific yield was less sensible parameters from the PEST run model result.

Climate change can control groundwater table fluctuation. Groundwater recharge has primarily depended on climate change. After calibration the model has been completed in different stress periods. The standard error of the calculated and observed head values in Simulation 2scenario 4 and scenario 5has found 0.42m and 0.72 m respectively. Table 4.3 has shown that the transient state calibration of the model performance between observed and calculated heads for two scenarios.

Table 4. 3: Groundwater model performance result for scenario analysis

Model status	Scenario 4	Scenario 5
Standard error of the estimate (m)	0.42	0.72
Root mean square (m)	2.46	2.19
Normalized root mean square (%)	6.53	5.84
Correlation coefficient	0.94	0.99



Min.Residual: 0.1 (m) at PHG8/A
Max.Residual: -8.2 (m) at WS2/A
Residual Mean: -0.45 (m)
Abs.Residual Mean: 1.54 (m)

Standard Error of the Estimate: 0.42 (m)
Root Mean Squared: 2.46 (m)
Normalized RMS: 6.53 (%)
Correlation Coefficient: 0.94

Figure 4. 10: The calibration of increased pumping rate with climate change

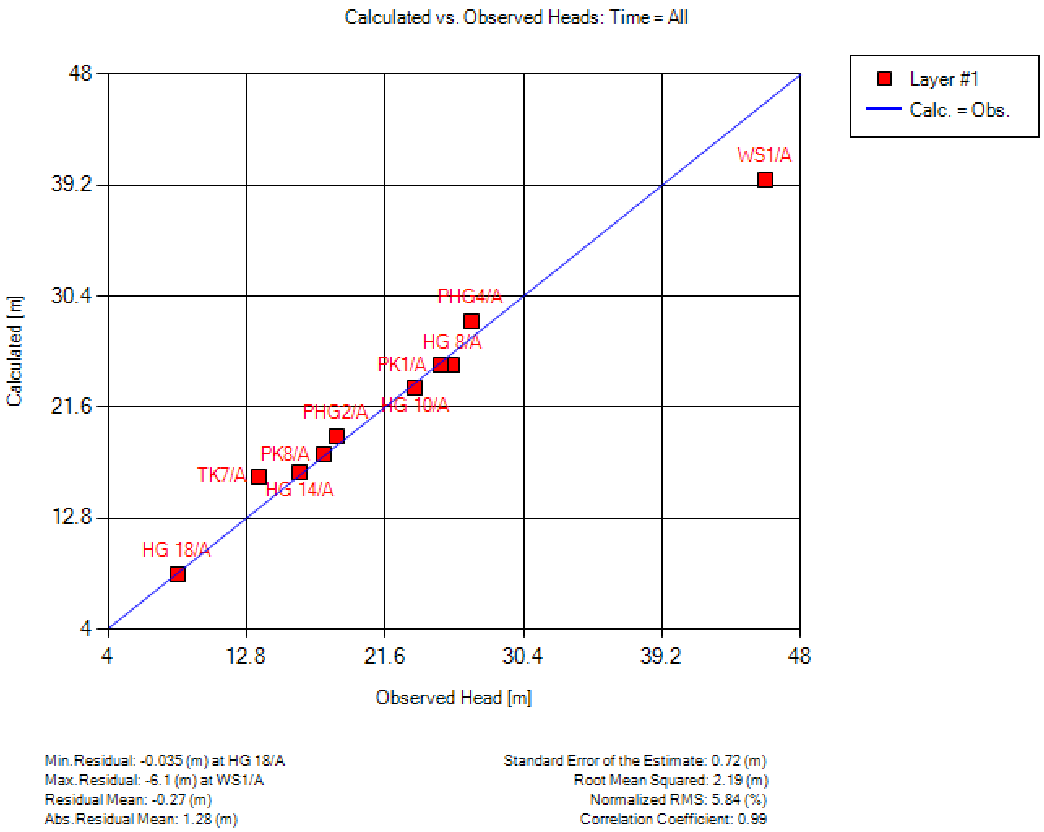
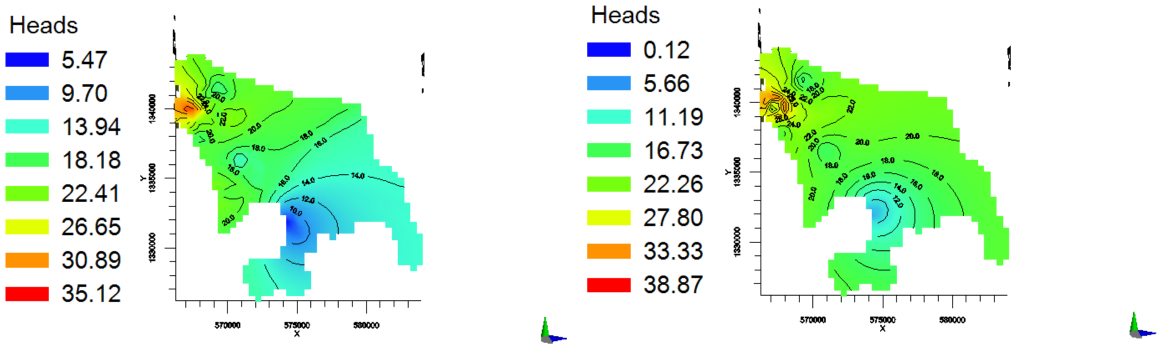


Figure 4. 11: The calibration of decreased pumping rate with increased recharge rate



(a)

(b)

Figure 4. 12: The predicted groundwater head with variation of recharge rate

In the above figure (Fig.4.12 a) the model result has shown that the groundwater head due to the increased pumping rates with decrease recharge rate. The model result has varied; the groundwater head in using the whole irrigation and water supply boreholes of a total 43.68*10^3 m^3/d groundwater was abstracted from 34 boreholes per crop season within the predicted time.

The groundwater head due to climate change with human pressure was varied from 5.47 m in the Southern boundary to 35.12 m in Northwestern boundary of the Sub-basin.

The increased pumping rate was replied to the groundwater head at the end of 2021 has increased by 0.19 m in the floor of the Sub-basin due to the drain effect of the flow and decreased by 1.52 m in the Northwestern boundary of the Sub-basin as compared as the previous groundwater head determination scenario (Scenario 1).

In figure 4.6 b, the predicted groundwater head has shown due to the decreased of pumping rates with increased recharge rate. Simulation 2 Scenario 5 (Fig. 4.12 b), the result has varied in using a total $12.9048*10^3 m^3/d$ of groundwater from 10 boreholes per crop season within the predicted time. The groundwater head due to climate change with human pressure was varied from 5.66 m in the Southern boundary to 38.87 m in Northwestern boundary of the Sub-basin.

The decreased pumping rate was replied to the groundwater head at the end of 2021 has increased by 0.38 m in the floor of the Sub-basin due to the drainage effect of the flow and increased by 2.23m in the Northwestern boundary of the Sub-basin as compared as the previous groundwater head determination scenario (Scenario 1).

4.2.2 Drawdown

The groundwater has been abstracted for different purposes; the drawdown level was changed from the normal conditions. The predicted drawdown level in those scenario analyses has been little variation with time.

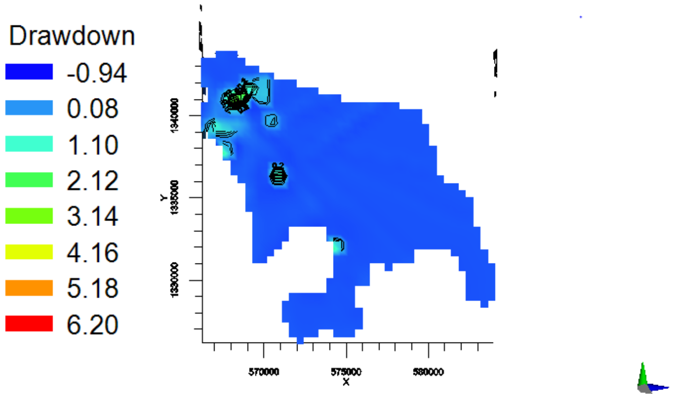
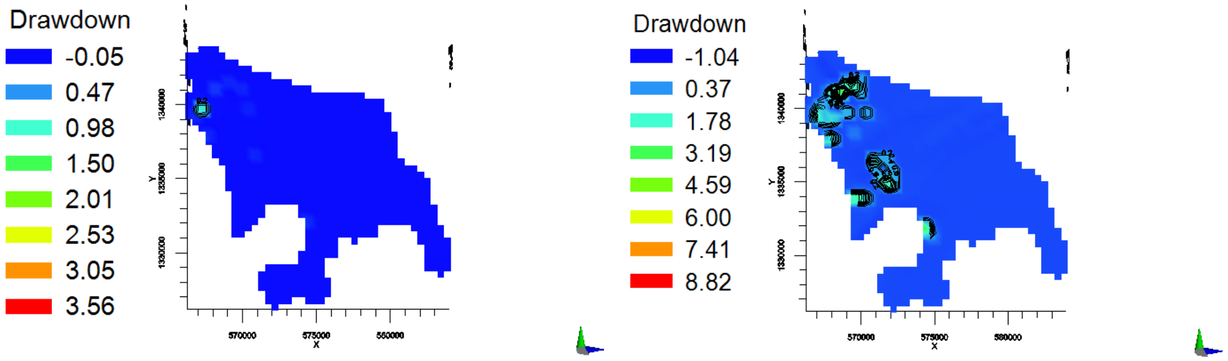


Figure 4. 13: The predicted drawdown level of using constant pumping wells

The above figure (Fig. 4.13) the predicted drawdown levels have shown in constant pumping with recharge rates. The drawdown level in Northwestern boundary of Hormat-Golina Sub-basin has been changing due to the effect of pumping wells in the predicted growing time.

The predicted drawdown level after two years has been determined due to constant pumping and recharges effects for irrigation period, the maximum depth of 6.2 m around the pumped wells.



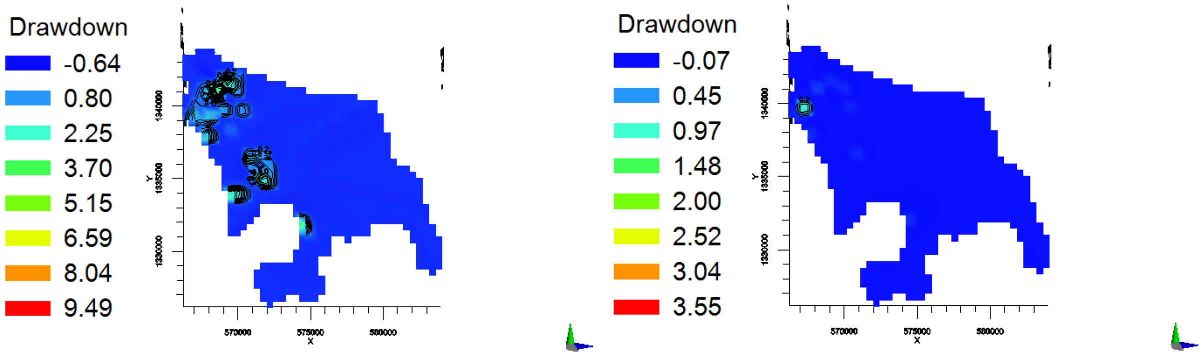
(a) (b)

Figure 4. 14: The predicted drawdown level of variation of pumping wells

In the above figure (Fig.4.14 a), the model result has shown that the drawdown level due to the decreased pumping rates with constant recharge rate. The predicted drawdown level for using 10 water supply boreholes has modeled from a maximum depth of 3.56 m in Northwestern boundary due to the effect of increased pumping wells.

Figure 4.14 b, has shown that the drawdown level due to the increased pumping rates with constant recharge rate. The predicted drawdown level for using 34 water supply boreholes has modeled from a maximum depth of 8.8 m due to the effect of increased pumping wells with constant recharge rates.

The decreased and increased pumping rate with constant recharge rate was replied to the drawdown level at the end of 2021 has decreased by 2.64 m and increased by 2.6 m respectively in the Northwestern boundary of the Sub-basin as compared as the previous drawdown determination scenario (Scenario 1).



(a) (b)

Figure 4. 15: The predicted drawdown level of due to climate change

In the above figure (Fig.4.15 a) the model result has shown that the drawdown level due to the increased pumping rates with decrease recharge rate. The predicted drawdown level for using 34 water supply boreholes supply boreholes had a maximum depth of 9.49 m due to the effect of increased pumping wells with decreased recharge rates.

Figure 4.15 b, has shown that the drawdown level due to the decreased of pumping rates with increased recharge rate. The predicted drawdown level for using 10 water supply boreholes had a maximum depth of 3.55 m due to the effect of decreased pumping wells with increased recharge rates.

The increased and decreased pumping rate with variable recharge rate was replied to the drawdown level at the end of 2021 has increased by 3.29 m and decreased by 2.65 m respectively in the Northwestern boundary of the Sub-basin as compared as the previous drawdown determination scenario (Scenario 1).

4.3 Groundwater quality Assessment

4.3.1 Laboratory result

The effects of fertilizers on groundwater quality in case of from the selected supply wells had the following results were found:

From the selected observation wells in Hormat-Golina Sub-basin, the concentration of Nitrate, Phosphate and Chloride was increased from January to April month. The following table (Tab. 4.4) has shown that the concentration of Nitrate result in groundwater sample within three observation wells. Farmers are applying Urea and DAP fertilizers by broadcast method due to this case the varied concentration of groundwater had non-point source and it was difficult to decided where is highly susceptible to change its concentration.

Table 4. 4: The concentration of Nitrate from leaching of Urea

Well ID	Easting	Northing	Depth (m)	Conc (mg/l)
OW1	569928	1341651	21.2	0.56
OW1	569928	1341651	20.7	0.70
OW1	569928	1341651	20.5	0.72
OW1	569928	1341651	20.4	0.84
OW2	568121	1337977	19.1	0.84
OW2	568121	1337977	18.7	0.98
OW2	568121	1337977	18.4	1.13
OW2	568121	1337977	18.3	1.40
OW3	566854	1339266	28.3	0.28
OW3	566854	1339266	28.0	0.42
OW3	566854	1339266	27.8	0.42
OW3	566854	1339266	27.6	0.47

The monthly laboratory results have shown in observation wells; the Nitrate concentration of the groundwater was varied relatively higher in deep groundwater depth. When the groundwater depth is relatively shallow the leached fertilizers has easily joined to the water table. Farmers are excessively using Urea fertilizers for crop production; that applied fertilizers has changed to increase the Nitrate content groundwater concentration with time.

The concentration of Phosphate from those three observation wells have increased with time. The monthly laboratory result has shown that the Phosphate content of the groundwater concentration was varied from 0.31 mg/l to 0.42 mg/l in relatively higher groundwater depth. The following table (Tab. 4.5) has shown that the concentration of Phosphate concentration result in groundwater sample within three observation wells.

Table 4. 5: The concentration of Phosphate from the leached DAP

Well ID	Easting	Northing	Depth (m)	Conc (mg/l)
OW1	569928	1341651	21.2	0.42
OW1	569928	1341651	20.7	0.44
OW1	569928	1341651	20.5	0.49
OW1	569928	1341651	20.4	0.52
OW2	568121	1337977	19.1	0.53
OW2	568121	1337977	18.7	0.54
OW2	568121	1337977	18.4	0.69
OW2	568121	1337977	18.3	0.72
OW3	566854	1339266	28.3	0.31
OW3	566854	1339266	28.0	0.37
OW3	566854	1339266	27.8	0.41
OW3	566854	1339266	27.6	0.42

The concentration of Chloride from those three observation wells have increased with time.
The monthly laboratory result has shown that the Chloride content of the groundwater concentration was varied from 1.12 mg/l to 1.29 mg/l in relatively higher groundwater depth.

The groundwater quality analysis results among the three observation wells have revealed higher concentration of chloride was located in observation well two (OW2). The areas with higher chloride concentration have marked as the populous part of the Sub-basin contributing chloride in the groundwater through various anthropogenic activities.

The following table (Tab. 4.6) has shown that the concentration of chloride result in groundwater sample within three observation wells.

Table 4. 6: The concentration of Chloride from the observation wells

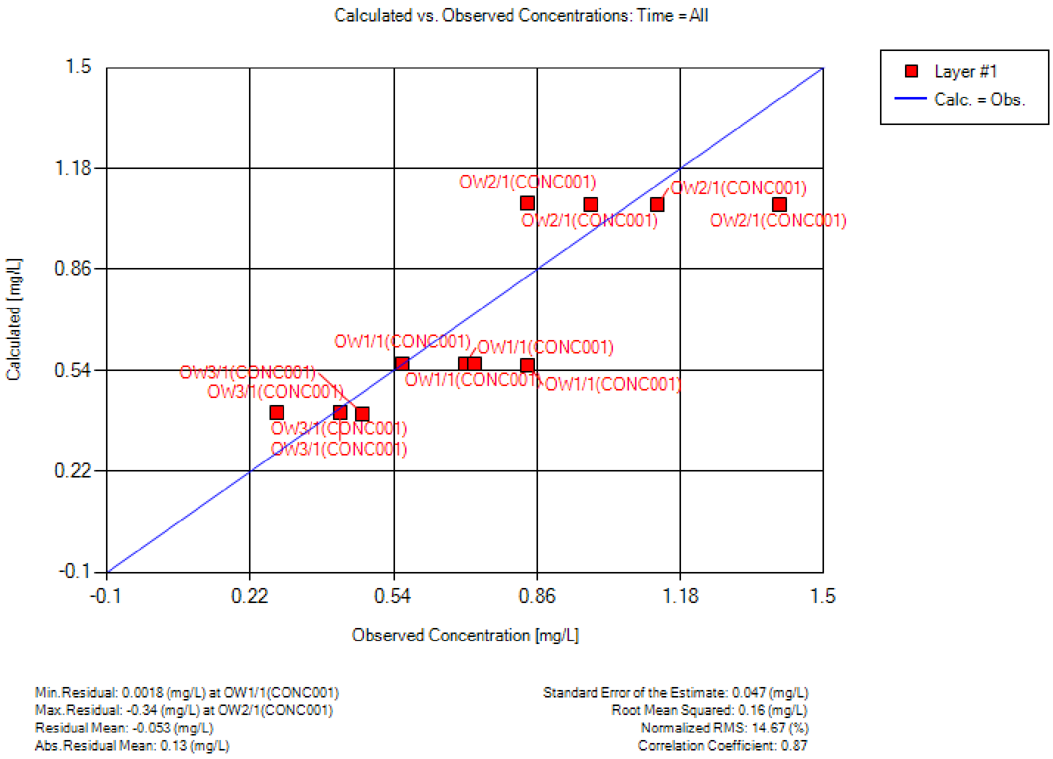
Well ID	Easting	Northing	Depth (m)	Conc (mg/l)
OW1	569928	1341651	21.2	0.84
OW1	569928	1341651	20.7	0.88
OW1	569928	1341651	20.5	0.98
OW1	569928	1341651	20.4	1.10
OW2	568121	1337977	19.1	1.12
OW2	568121	1337977	18.7	1.18
OW2	568121	1337977	18.4	1.23
OW2	568121	1337977	18.3	1.29
OW3	566854	1339266	28.3	0.66
OW3	566854	1339266	28.0	0.68
OW3	566854	1339266	27.8	0.79
OW3	566854	1339266	27.6	0.83

4.3.2 Model result

The sensitivity analysis for each chemical species has shown in the appendix (appendix A). Using mass transport model for the concentration of each groundwater parameters in a time series has shown in the following graphical form.

Table 4. 7: Solute transport model performance characteristics

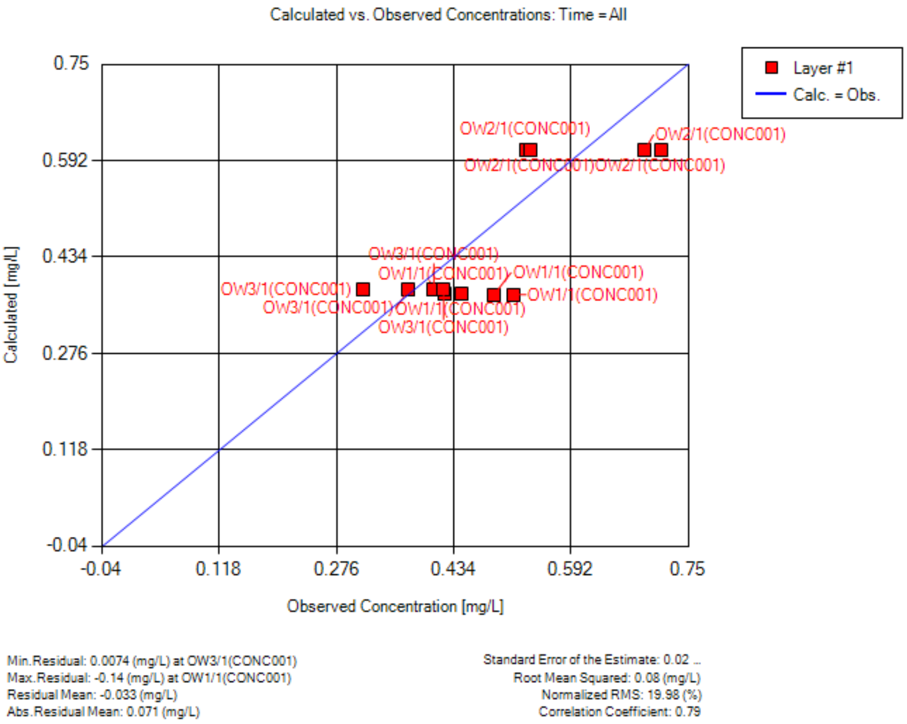
Model status	Nitrate	Phosphate	chloride
Standard error of the estimate (mg/l)	0.46	0.022	0.51
Root mean square (mg/l)	1.63	0.081	1.82
Normalized root mean square (%)	14.53	20.51	17.78
Correlation coefficient	0.87	0.79	0.81



Min.Residual: 0.0018 (mg/L) at OW1/1(CONC001)
Max.Residual: -0.34 (mg/L) at OW2/1(CONC001)
Residual Mean: -0.053 (mg/L)
Abs.Residual Mean: 0.13 (mg/L)

Standard Error of the Estimate: 0.047 (mg/L)
Root Mean Squared: 0.16 (mg/L)
Normalized RMS: 14.67 (%)
Correlation Coefficient: 0.87

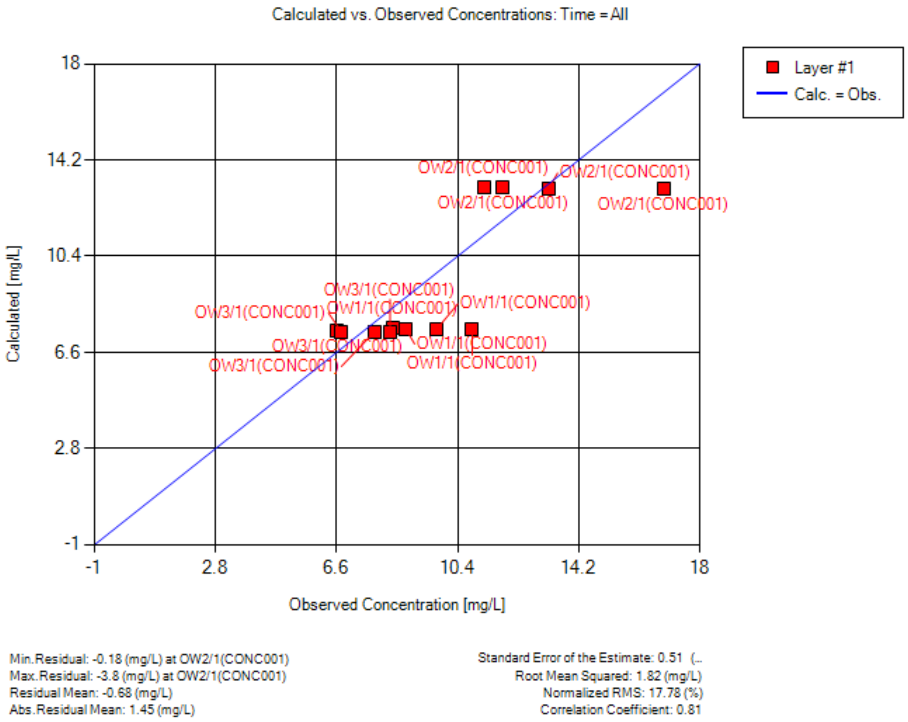
Figure 4. 16: The Calculated vs observed concentration of Nitrate



Min.Residual: 0.0074 (mg/L) at OW3/1(CONC001)
Max.Residual: -0.14 (mg/L) at OW1/1(CONC001)
Residual Mean: -0.033 (mg/L)
Abs.Residual Mean: 0.071 (mg/L)

Standard Error of the Estimate: 0.02 ...
Root Mean Squared: 0.08 (mg/L)
Normalized RMS: 19.98 (%)
Correlation Coefficient: 0.79

Figure 4. 17: The Calculated vs observed concentration of Phosphate



Min.Residual: -0.18 (mg/L) at OW2/1(CONC001)
Max.Residual: -3.8 (mg/L) at OW2/1(CONC001)
Residual Mean: -0.68 (mg/L)
Abs.Residual Mean: 1.45 (mg/L)

Standard Error of the Estimate: 0.51 (...
Root Mean Squared: 1.82 (mg/L)
Normalized RMS: 17.78 (%)
Correlation Coefficient: 0.81

Figure 4. 18: The Calculated vs observed concentration of Chloride

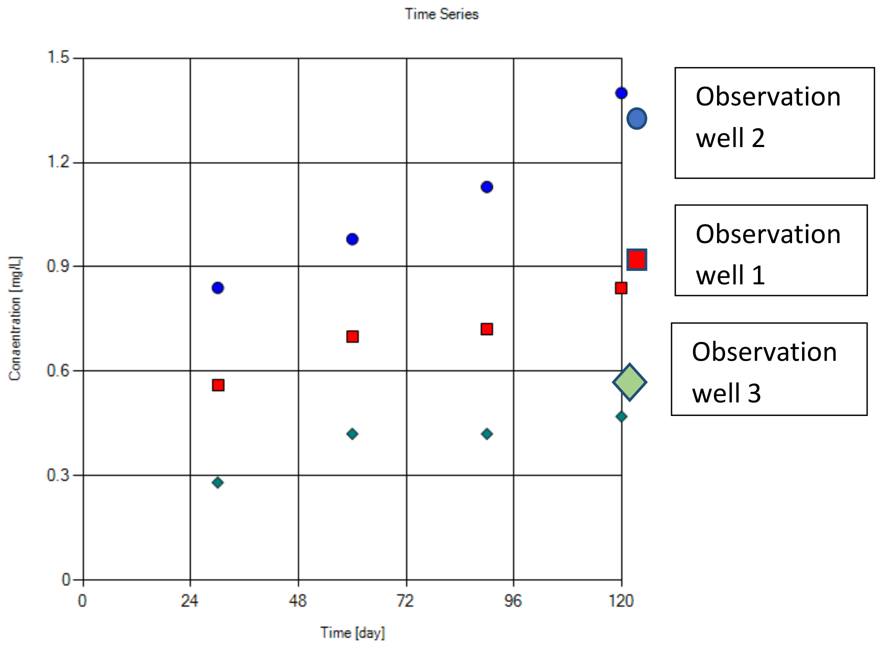


Figure 4. 19: The concentration Nitrate in a time series

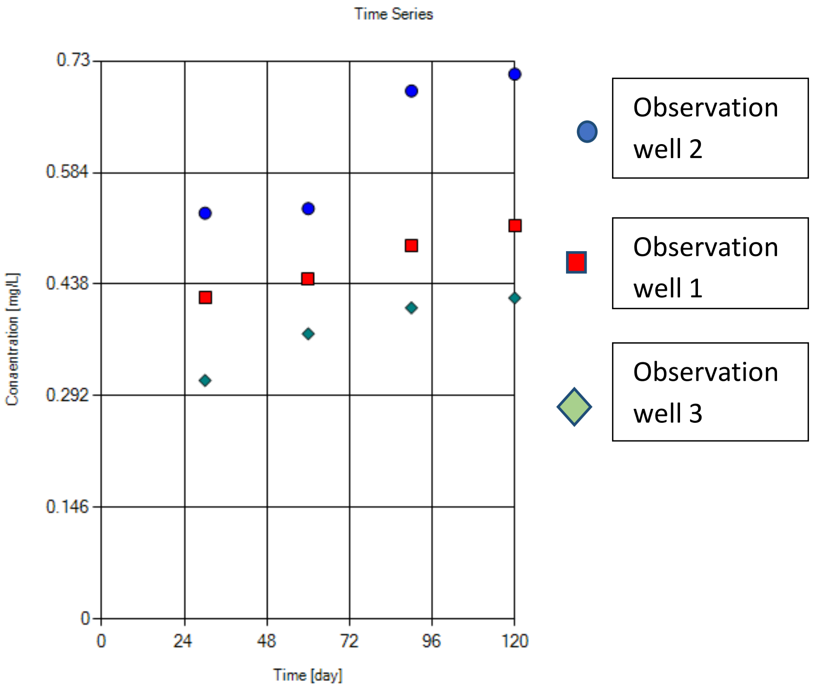


Figure 4. 20: The concentration of Phosphate in a time series

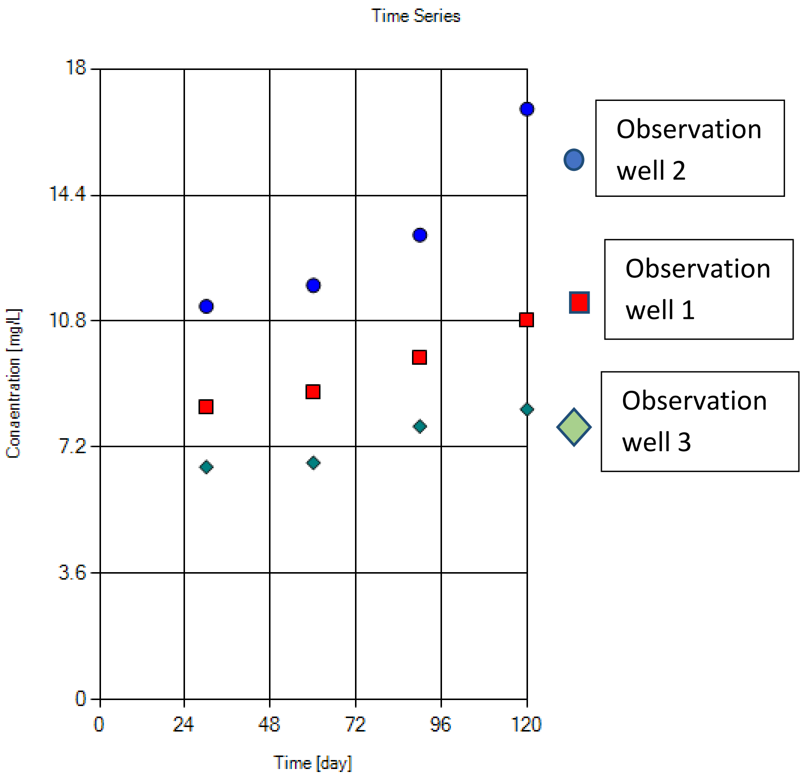


Figure 4. 21: The concentration Chloride in a time series

5. SUMMARY AND CONCLUSIONS

5.1 Summary

This study was intended to obtain a better understanding of the groundwater flow systems in Hormat-Golina Sub-basin by applying visual mod flow flex 5.1 numerical groundwater flow model.

The simulated groundwater head and its respected drawdown model results have highly varied in before and after irrigation season. This response can have shown that the groundwater reservoir was declining with time when farmers are using the same rate of groundwater abstraction rate.

The groundwater head level in before and after irrigation season was varied from 9.3 m to 8.26 m in the Southern boundary and from 41.5 m to 38.83 m in Northwestern boundary of the Sub-basin respectively.

In the time before growing season, the curved streams around the pumped wells had nearly stable since irrigated wells were stopped but town water supply wells had responsible to control the respected groundwater head.

The initial head values before irrigation season was recorded during January 2019 and its result was varied to a maximum of 0.8 m as compared as the measured depth of the initial heads from after irrigation season.

The field observation together with the model result was used to realize the characteristics of the groundwater system under transient state condition for groundwater head determination despite of the uncertainties of the results.

The groundwater elevation has varied within a given 3 month's irrigation period with 39.055 mm per year recharge rate with the assumed uniform recharge rate in both Sub-basins due to the lack of metrological data.

The predicted simulation of this visual Mod flow flex 5.1 model had different pumping scenarios response that groundwater head from using 23.28x 10^3 m^3/d in 17 supply wells to 43.68*10^3

m^3/d in 34 supply wells. During irrigation season using the whole supply wells, the predicted groundwater head results can have shown a maximum recorded level in the pumped wells near to the Northwestern boundary of the Sub-basin at the end of 2021.

In the scenario based groundwater level prediction: the flow properties, geological conditions and pumping time were constant throughout the year.

A reasonable decreased pumping well from the current 17 wells to 10 boreholes, the groundwater head was varied in a response of decreased pumping rate with increased recharge rate. The decreased pumping rate with constant recharge rate has likely to reply the groundwater head at the end of 2021 was increased by 2.23 m in the Northwestern boundary of the Sub-basin.

The increased pumping rate with decreased recharge rate has likely to respond the groundwater head at the end of 2021was decreased by 2.81 m in the Northwestern boundary of the Sub-basin. Due to the pumping characteristics of the groundwater system the groundwater flow direction has located from the Eastern boundary towards to the Western boundary.

The calibrated model of this study has been run for different scenarios based climate change and human induced impacts with different simulation time since climate change is a global issue that affects the availability of groundwater.

Due to the drain characteristics of the groundwater system, the hydraulic heads in the Southern boundary of the Sub-basin have easily found below the ground level. The drawdown level in the Sub-basin was higher around the pumped wells during irrigation period.

Due to the massive usage of chemical fertilizers, the groundwater contamination was increasing with time and the mass transport simulation was running forward towards to the supply wells.

Farmers are using excessive fertilizers (commonly Urea and DAP) which was the root cause of deteriorating groundwater quality in relation to Nitrate and phosphate concentration with time.

Transport simulation was stated by transient conditions and makes a thorough validation prior to use for predictions and management of the contamination of the groundwater flow with respect to the applied chemical fertilizers.

5.2 Conclusions

The following conclusions have drawn from the results obtained from this study.

The groundwater head before irrigation season in the Sub-basin was found to be higher than groundwater head in after irrigation season since pumping rates can have control its level.

In addition, the model simulated head contour map has shown that the general hydraulic gradient in the Sub-basin pursues the hydraulic gradient was located from Eastern boundary (i.e. the highlands of Zobel Mountain) towards to Western direction since the irrigation boreholes were dense in the Western part of the boundary.

Transient model for the pumping and climate scenarios has made for better predictions of groundwater flow since the predicted result was shown that the pumping effect and the climate change for groundwater flow are strongly time dependent.

Reduced pumping rate with increased recharge rate scenario was acceptable range in terms of groundwater management and future sustainability has been suffering from an over exploration of the groundwater from the unconfined aquifer.

In using this visual mod flow flex 5.1 Model River and general head boundary conditions were not being incorporated due to lack of recorded bed hydraulic conductivity. The hydraulic conductivity value of the model was highly sensible parameter as compared as the storage properties of the groundwater flow.

Using increased pumping rate with decreased recharge rate scenarios of groundwater pumping rate was not recommended for groundwater restoration. The model result for the drawdown level was not seen clearly with a series of color map.

The Volumetric budget was higher for the entire model at end of the time step due to the decreased pumping rates with increased recharge rates (appendix B).

Farmers are using massive Urea and DAP fertilizers which were the root cause of deteriorating groundwater quality in relation to Nitrate and Phosphate concentration with series of time. The water quality laboratory results were shown that the concentration of Nitrate, Phosphate and Chloride from the selected observation wells has increased with time.

Assessing groundwater quality related to applied fertilizer was depending on the applied chemical fertilizers around the pumped wells. When the groundwater depth had relatively shallow, the leached fertilizers was easily joined to the water table. In Hormat-Golina Sub-basin, the selected observation well two (OW2) has located at lower groundwater depth with its respected groundwater concentration was highly varied.

The physico-chemical data obtained from three months' water quality laboratory result were not being sufficient to predict the groundwater quality for longer period. This study has shown simply how the effect of fertilizers on groundwater quality within the prescribed transient time.

Recommendations

Based on the result from above groundwater modeling and assessing the impact of fertilizers on groundwater quality the following recommendations were listed.

- In this study, some boundary conditions were not modeled through the lack of measured data. However, for a better determination of groundwater flow and transport of particle tracking, further investigation of boundary conditions should be applying on the model simulation.
- In order to get the accurate information of groundwater recharge from the precipitation rain gage stations should be added.
- River discharge measuring stations should be installed at three places: where the two main streams (Golina and Hormat) that drain the highland join the valley floor and at the outlet of the Sub-basin in order to determine the groundwater contribution from the rivers. For better estimation of recharge determination from the river, river bed conductivity should be computed across the river sides of both Hormat and Golina rivers.
- There was no substantial groundwater recharge from recharge contribution; the local farmers should have used a decreased pump rate for the sake of groundwater storage and its future sustainability.
- Continuous recorded groundwater data should be applied in the Sub-basins which can have an important role to decide the groundwater characteristics in a time of stresses.
- For the sake of stable geological structures and future groundwater accessibility additional pumping wells shouldn’t be installed.
- Reducing groundwater pollution from the use of Urea and DAP fertilizers can be achieved through simple good agricultural management practices. Farmers are encouraged to use practices that minimize the risk of Nitrate pollution by carefully controlling the timing of the use of fertilizers to avoid over application, and considering all possible sources of Nitrogen available to the crop in the control way application rates.
- Extension workers should create awareness about the impacts of over application of Urea and DAP fertilizers on groundwater pollution.

REFERENCES

Alaael, S., Mona R. 2018. Modeling of Water Flow and Nitrate Transport to Subsurface Drains. Arabian Gulf University, Manama, Regional Water, Energy and Food Center, Zewail City, Nile Research Institute, National Water Research Center, Egypt.

Anju, A., Rajkumar, V. R. and Purandara, B. 2015. Simulation of Groundwater Levels in Malaprabha Command Area using Visual MODFLOW FLEX. Department of Civil Engineering, Sheshgiri College of Engineering and Technology, Belgaum, Karnataka, India.

Anderson, M and Wossener, W.W. 1992. Applied groundwater modelling simulation of flow and advective transport, Florida.

Asfaw, B. 2003. Regional hydrogeological investigation of Northern Ethiopia. EFDR minister of mines, Geological Survey of Ethiopia, Hydrogeology, Engineering Geology, Geothermal, department Addis Ababa, Ethiopia.

Brouyere, S., Carabin, G. and Dassargues, A. 2004. Climate change impacts on groundwater resources: modelled deficits in a chalky aquifer, Geer basin, Belgium, Hydrogeology Journal, Volume. 12, P. 123-134.

Cesar, A. 2017. Simulation and Prediction of the Groundwater Level in the Surrounding Area of the Nebraska Management System Evaluation Area site in Central Nebraska. Civil Engineering thesis, Dissertations, and Student Research. http://digitalcommons.unl.edu/civilengdiss/112 Accessed on 03 March 2019.

Chiang, W.H.2005. 3D groundwater modelling with PMWIN: A Simulation system for modelling groundwater flow and transport processes. Second edition, ISBN-13978-3-540-27590-9, Springer Berlin Heidelberg New York.

Cirpka, O. 1999. Numerical methods of groundwater flow and transport. Technical report in Stanford University, Department of Civil and Environmental Engineering.

Craig, C., Rick, E., Susan, H., Rafik, H., Gabrielle, P. and Carolina, P. 2010. Water and Climate Change: Impacts on groundwater resources and adaptation options. Water Working Notes are published by the Water Sector Board of the Sustainable Development Network of the World Bank Group. Note number,25.

Crosbie, R., McCallum, J., Walker, G. and Chiew, F. 2010. Modeling climate change impacts on groundwater recharge in the Murray-Darling Basin, Australia. Hydrogeology Journal, Vol 18 No7, P. 1639-1656.

Delleur, J. 1999. The handbook of Groundwater Engineering. ISBN 0-8493-2698-2 (CRC Press), U.S.A and Canada ISBN 3-540-64745-7 (Springer-Verlag), Germeny.

Divya, J. and Belagali, S.L. 2012. Impact of chemical fertilizers on water quality in selected agricultural areas of Mysore district, Karnataka, India. Department of Studies in Environmental Science, University of Mysore, India. International journal of environmental sciences volume 2, no 3, p.1449-1457.

Dogrul, C., Charles, F. and Tariq N. 2016. Groundwater Modeling in Support of Water Resources Management and Planning under Complex Climate, Regulatory, and Economic Stresses. California Department of Water Resources, DOI:10.3390/w8120592.

Fadiran, A.O, Dlamini, S.C. and Mavuso, A. 2007. A comparative study of the phosphate levelsin some surface and ground water bodies of Swaziland. Chemical Society of Ethiopia Vol 22, No 2, P. 197-206.Printed in Ethiopia.

Fesseha Fentahun. 2015. Groundwater quality, vulnerability and potential assessment in kobo valley development project, Ethiopia.

Fewtrell, L. 2004.Drinking-Water Nitrate, Methemoglobinemia, and Global Burden of Disease. Environmental Health Perspective. P. 1371–1374, DOI: 10.1289/ehp.7216.

Getahun Kinfu. 2010. Numerical groundwater flow modeling of the kobo valley: Northern Ethiopia.

Herrera, P.M. and Hiscock, K. 2008. The effects of climate change on potential groundwater recharge in Great Britain.

Hogeboom, H.J. Pieter, R., Maarten, S. and Martijn, J. 2013. Modelling the Influence of Groundwater Abstractions on the Water Level of Lake Naivasha, Kenya Under Data-Scarce Conditions, University of Twente, Netherland. Department of Water Engineering & Management (WEM). Volume 29 issue 12, P. 4447–4463.

John R. M., David L. L. and Alan D. A. 2009. Chloride in Groundwater and Surface Water in Areas Underlain by the Glacial Aquifer System, Northern United States. National Water-Quality Assessment Program.

Jyrkama, M. and Sykes, J. 2007. The impact of climate change on spatially varying groundwater recharge in the grand river watershed (Ontario). Journal of Hydrology, 338(3), P. 237-250.

Kebede, S., Hailu, A., Crane, E. and Dochartaigh, B.E. 2018. Africa Groundwater and Hydrogeology of Ethiopia. British Geological Survey. *http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Ethiopia* /Accessed on 06 December 2018/.

Khadri, S.F. and Chaitanya, P. 2016. Ground water flow modeling for calibrating steady state using MODFLOW software: a case study of Mahesh River basin, India. Model of Earth System and environment: Volume 2, number 1.Springer International Publishing Switzerland, 2016. DOI: 10.1007/s40808-015-0049-7.

Linxian, H., Lichun, W., Jingli, S., Xingwei, L., Qichen, H., Liting, X., Lizhi, Z. and Yong, X. 2018. Parallel Processing Transport Model MT3DMS by Using Open specifications for Multi-Processing. international journal of environmental research and public health. DOI: doi.org/10.3390%2Fijerph15061063.

Mahvi, A., Nouri, J., Babaei, A. and Nabizadeh, R. 2013. Agricultural activities impact on groundwater nitrate pollution, International Journal of Environment Science and Technology. Volume 2, issue 1 P. 41-47. DOI: org/10.1007/BF03325856.

Mohammedsultan Abdella. 2010. Ground water flow modeling assisted by GIS and remote sensing techniques in Raya Valley, Ethiopia.

Nata Tadesse, Dessie Nedaw, Kifle Woldearegay,Tesfamichael Gebreyohannes and Frank, V.S. 2015. Groundwater Management for Irrigation in the Raya and Kobo Valleys, Northern Ethiopia.International journal of earth science and engineering, June 2015, Vol 08, No 3 P. 36-46.

Ojo, O., Ochieng, G., and Otieno, F. 2011. Assessment of water logging and salinity problems in South Africa: An overview of Vaal hart's irrigation scheme Department of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa and Technology, Innovation and Partnerships Unit, Durban University of Technology, South Africa. WIT Transactions on Ecology and Environment, Volume 153. P. 477-484. DOI:10.2495/WS110421

Oluseyi, O., Adeleke, V., Makinde, A., Eruola, O. and Oluwaseun, F. 2015**.** Estimation of Groundwater Recharges Using Empirical Formulae in Odeda Local Government Area, Ogun State, Nigeria. Open access journal, Challenges 2015, P. 271-281; doi:10.3390/challe6020271.

Praveena, S.M. and Aris, A. Z. 2009. Groundwater resources assessment using numerical model: A case study in low-lying coastal area. School of Science and Technology, University Sabah, Malaysia, Department of Environmental Sciences, Faculty of Environmental Studies, University Putra Malaysia. International Journal of Environmental science and technology, Vol 7, No1, P. 135-146.

Psarropoulou, E.T. and Karatzas, G.P. 2013. Pollution of Nitrates - contaminant transport in heterogeneous porous media: a case study of the coastal aquifer of Corinth, GreeceSchool of Environmental Engineering. Global NEST Journal, Vol 16, No 1, p. 9-23.

Robert, N. and Anna, I. 2017. Factors Affecting Groundwater Quality in The Context of the Exploitation of Small Drinking Water Intakes. Department of Environmental Technologies and Bioanalitycs, Faculty of Civil Engineering, Environmental and Geodetic

Sciences, Technical University of Koszalin, Sniadeckich, Koszalin, Poland, Architecture and civil engineering environment, no 1 p. 153-161.

Sandow, M. Y., Obed, F. F., Larry, P. C., Prosper, M. N. and Daniel, K. A. 2013. Hydrogeological Conditions of a Crystalline Aquifer: Simulation of Optimal Abstraction Rates under Scenarios of Reduced Recharge.Department of Earth Science, University of Ghana, Legon, Accra, Ghana. The Scientific World Journal, DOI: 10.1155/2013/606375.

Scibek, J. and Allen, D. M. 2006. Modeled impacts of predicted climate change on recharge and groundwater levels. Water Resources Research.

Semu Moges. 2012.Agricultural Use of Groundwater in Ethiopia: Assessment of Potential and Analysis of Economics, Policies, Constraints and Opportunities.Addis Ababa University, Ethiopia.

Siebert, S., Burke, J., Faures, M., Frenken, K., Hoogeveen, J., Doll, P. and Portmann, F.2010. Groundwater use for irrigation as a global inventory. Institute of Crop Science and Resource Conservation, University of Bonn, Bonn, Germany. Food and Agriculture Organization of the United Nations, Rome, Italy. Institute of Physical Geography, Goethe University Frankfurt, Frankfurt am Main, Germany. Hydrology and earth System Sciences. Volume 14, P. 1863–1880. DOI:10.5194/hess-14-1863-2010.

Sileshi Mamo. 2007. Raya Hydrogeology and isotope hydrological investigation project, final report. Ministry of Mines and Energy Geological Survey of Ethiopia.

Todd, D.K. 2005. Groundwater Hydrology. Third edition ISBN 0-471-05937-4(cloth) and ISBN 0-471-45254-8(WIE).

Waterloo Hydrologic. 2018. Integrated Conceptual and Numerical Groundwater Modeling. Visual MODFLOW Flex 5.1 user manual, June 2018 in Waterloo, Canada.

World health organization (WHO). 1983. Environmental health impact assessment of irrigated Agriculture. Geneva, Switzerland.www.open.ac.uk/openlearn Accessed on 13 June 2019.

APPENDICES

Appendix A: The measured and modeled values of the model

Table A. 1: After calibration for non-irrigated season

Well name	Measured	Modeled	Residual	Sensitivity
PK1	25.9	25.64422	0.25578	0.000101
PK2	23.8	24.06763	0.26763	1.71E-17
TK7	13.9	18.34519	4.44519	4.93E-18
PK6	18.7	18.68758	0.01242	4.51E-05
PK7	20.8	19.58559	1.21441	4.51E-05
PK8	17.7	18.55118	0.85118	2.45E-17
PHG1	24.65	24.64034	0.00966	4.51E-05
PHG2	18.75	20.77704	2.02704	4.51E-05
HG 18	9.13	9.412408	0.28241	4.51E-06
PHG4	27.8	29.01816	1.21816	4.51E-05
HG 14	16.5	16.06793	0.43207	9.25E-18
HG 7	23.9	25.75972	1.85972	9.86E-18
HG 8	26.2	25.26638	0.93362	4.44E-17
HG 11	14.1	14.92565	0.82565	6.38E-05
HG 10	24	23.36471	0.63529	0.000128
WS1	46.1	38.68721	7.41279	0.000202
WS2	28.7	27.94478	0.75522	4.51E-05

Table A. 2: After calibration for irrigated season

Well name	Measured	Modeled	residual	Sensitivity
PK1	25.1	25.29121	0.19121	0.009192622
PK2	23.2	23.36731	0.16731	0.007564672
TK7	13.6	17.74092	4.14092	0.000110591
PK6	18.4	17.75015	0.64985	0.00024729
PK7	20.7	19.00074	1.69926	0.000186153

PK8	17.7	18.08179	0.38179	0.001038421
PHG1	24.1	23.9698	0.1302	0.01342601
PHG2	18.5	19.82743	1.32743	0.001121469
HG 18	8.4	8.456039	0.05604	0.012332592
PHG4	27.1	27.83926	0.73926	0.000180595
HG 14	16.2	15.85072	0.34928	0.009741355
HG 7	23.6	24.89735	1.29735	0.002313627
HG 8	25.9	25.36916	0.53084	0.015860132
HG 11	13.8	14.31847	0.51847	0.004281751
HG 10	23.5	22.67129	0.82871	0.00137166
WS1	45.8	37.10138	8.69862	0.000437733
WS2	28.6	27.16859	1.43141	0.000285546

The measured and modeled values of the model for Scenario analysis

Table A. 3: After calibration for constant pumping and recharge rate

well name	**Measured**	**Modeled**	**residual**	**Sensitivity**
PK1	25.1	25.17276	-0.07276	4.51487E-05
PK2	23.2	23.5912	-0.3912	0.000100956
TK7	13.6	18.07912	-4.47912	0.000100956
PK6	18.4	18.40325	-0.00325	9.02974E-05
PK7	20.7	19.42354	1.27646	4.51487E-05
PK8	17.7	18.3957	-0.6957	9.02975E-05
PHG1	24.1	24.15507	-0.05507	0.000873135
PHG2	18.5	20.4558	-1.9558	9.02975E-05
HG 18	8.4	8.687559	-0.28756	5.41785E-05
PHG4	27.1	28.37913	-1.27913	0.000413795
HG 14	16.2	15.76196	0.43804	4.51487E-05
HG 7	23.6	25.34863	-1.74863	0.000100956
HG 8	25.9	24.79851	1.10149	0.000100956

HG 11	13.8	14.6208	-0.8208	0.000162786
HG 10	23.5	22.92101	0.57899	9.02976E-05
WS1	45.8	38.25709	7.54291	0.000285546
WS2	28.6	27.66442	0.93558	0.000142773

Table A. 4: After calibration for decreased pumping and constant recharge

well name	**Measured**	**Modeled**	**residual**	**Sensitivity**
PK1	25.1	26.13561	1.03561	0.00013294
TK7	13.6	16.51826	2.91826	0.000242714
PK8	17.7	17.73444	0.03444	7.67529E-05
PHG2	18.5	19.55895	1.05895	0.000637557
HG 18	8.4	8.648927	0.24893	8.3021E-05
PHG4	27.1	28.60212	1.50212	0.001009526
HG 14	16.2	16.67365	0.47365	0.000153506
HG 8	25.9	25.3817	0.5183	0.00021709
HG 10	23.5	23.07006	0.42994	0.000242714
WS 1	45.8	39.80027	5.99973	0.000466869

Table A. 5: After calibration for increased pumping and constant recharge

well name	**Measured**	**Modelled**	**Residual**	**Sensitivity**
PK1	25.1	25.1135	-0.0135	2.25744E-05
PK2	23.2	23.94761	-0.74761	5.04778E-05
TK7	13.6	19.47492	-5.87492	6.385E-05
PK6	18.4	19.6973	-1.2973	5.52957E-05
PK7	20.7	20.18884	0.51116	2.25744E-05
PK8	17.7	18.99461	-1.29461	4.51488E-05
PHG1	24.1	23.38382	0.71618	0.00012968
PHG2	18.5	19.62643	-1.12643	5.52957E-05

HG 18	8.4	9.153127	-0.75313	2.77399E-05
PHG4	27.1	28.1921	-1.0921	0.000327134
HG 14	16.2	16.21445	-0.01445	2.25744E-05
HG 7	23.6	25.00459	-1.40459	5.04778E-05
HG 8	25.9	24.73382	1.16618	5.97262E-05
HG 11	13.8	15.88831	-2.08831	0.00012968
HG 10	23.5	23.00089	0.49911	4.51488E-05
WS1	45.8	37.55796	8.24204	0.000560736
WS2	28.6	24.36086	4.23914	4.51487E-05
HG1	20.1	23.20697	-3.10697	0.00012968
HG3	20.6	20.67436	-0.07436	1.39468E-17
HG4	17.1	20.96117	-3.86117	1.64114E-17
HG 6	23.7	22.92143	0.77857	3.1925E-05
HG 9	25.6	22.51916	3.08084	2.25743E-05
HG12	15.9	16.92709	-1.02709	2.25745E-05
HG13	18.1	17.25884	0.84116	3.1925E-05
HG 16	8.1	8.713917	-0.61392	3.28688E-05
HG 17	9.8	9.109089	0.690911	4.51488E-06
PK9	23.2	19.95133	3.24867	1.43746E-17
PHG3	16.1	18.59879	-2.49879	2.25744E-05
PHG5	21.1	19.12432	1.97568	2.25744E-05
PHG6	19.7	18.83661	0.86339	3.91E-05
PHG7	17	17.74522	-0.74522	2.25744E-05
PHG8	20.1	20.29922	-0.19922	4.51487E-05
PHG9	21	21.24395	-0.24395	6.77231E-05
PHG10	24.6	23.21696	1.38304	0.000115107

Table A. 6: The result for increased pumping and decreased recharge rate

Well name	Measured	Modeled	Residual	Sensitivity
PK1	25.1	25.11277	-0.01277	7.13864E-05

PK2	23.2	23.94699	-0.74699	3.1925E-05
TK7	13.6	19.47465	-5.87465	5.04778E-05
PK6	18.4	19.69718	-1.29718	2.25744E-05
PK7	20.7	20.18846	0.51154	1.72709E-17
PK8	17.7	18.9942	-1.2942	2.25744E-05
PHG1	24.1	23.38637	0.71363	0.000275555
PHG2	18.5	19.62624	-1.12624	2.25744E-05
HG 18	8.4	9.152482	-0.75248	1.73397E-05
PHG4	27.1	28.19101	-1.09101	0.000337107
HG 14	16.2	16.21381	-0.01381	1.06389E-17
HG 7	23.6	25.0038	-1.4038	2.25744E-05
HG 8	25.9	24.73308	1.16692	5.52957E-05
HG 11	13.8	15.88774	-2.08774	1.25469E-17
HG 10	23.5	23.00109	0.49891	1.62276E-17
WS1	45.8	37.55956	8.24044	0.000362598
WS2	28.6	24.3607	4.2393	5.52957E-05
HG1	20.1	23.20716	-3.10716	0.000158021
HG3	20.6	20.67417	-0.07417	1.46379E-17
HG4	17.1	20.96073	-3.86073	0.0001277
HG 6	23.7	22.92114	0.77886	1.65709E-17
HG 9	25.6	22.51907	3.08093	1.93136E-17
HG12	15.9	16.92653	-1.02653	0.00012968
HG13	18.1	17.25865	0.84135	1.52583E-17
HG 16	8.1	8.713306	-0.61331	2.01911E-05
HG 17	9.8	9.108684	0.691316	5.04778E-06
PK9	23.2	19.95094	3.24906	1.72783E-17
PHG3	16.1	18.59812	-2.49812	2.25744E-05
PHG5	21.1	19.12422	1.97578	3.1925E-05
PHG6	19.7	18.83639	0.86361	5.04778E-05
PHG7	17	17.74474	-0.74474	2.25744E-05
PHG8	20.1	20.29873	-0.19873	4.51487E-05
PHG9	21	21.24362	-0.24362	4.51487E-05

PHG10	24.6	23.21735	1.38265	6.77232E-05

Table A. 7: The result for decreased pumping and increased recharge rate

Well name	**Measured**	**Modeled**	**Residual**	**Sensitivity**
PK1	25.1	26.13577	1.03577	0.000171625
TK7	13.6	16.51898	2.91898	0.000242714
PK8	17.7	17.7351	-0.0351	7.67529E-05
PHG2	18.5	19.55975	1.05975	0.000720005
HG 18	8.4	8.649552	0.24955	7.28141E-05
PHG4	27.1	28.603	-1.503	0.00102401
HG 14	16.2	16.67475	0.47475	0.000325635
HG 8	25.9	25.38177	0.51823	0.000171625
HG 10	23.5	23.07011	0.42989	0.000171625
WS 1	45.8	39.80056	5.99944	0.000351726

Appendix B: The groundwater mass balance result

Table B. 1: The water balance time step before irrigation season

Cumulative Volumes L**3				Rates for Final Time Step L**3/T			
In flow		Out flow		In flow		Out flow	
wells	0	wells	2304.000	Wells	0	Wells	2304.00
storage	41675.109	storage	38113.203	Storage	41374.00	Storage	37928.00
Total	41675.109	Total	40417.203	Total	41374.00	Total	40232.00
	Inflow –out flow				In flow –out flow		
	41675.109 - 40417.203				41374.00-40232.00		
	1257.906				1142.00		

Table B. 2: The water balance at end of time step in after irrigation season

Cumulative Volumes L**3				Rates for Final Time Step L**3/T			
In flow		Out flow		In flow		Out flow	
wells	0	wells	839999.62	Wells	0	Wells	9333.330
Recha-	2273885.5	Recha-	0	Recha-	25265.396	Recha-	0
Storage	889747.12	Storage	2323399.7	Storage	8815.343	Storage	24747.53
Total	3163632.5	Total	3163399.5	Total	34080.74	Total	34080.85
	Inflow –out flow				In flow –out flow		
	3163632.50-3163399.50				34080.742-34080.859		
	233.0000				0.1172		

Table B. 3: Volumetric budget for constant recharge and pumping wells

Cumulative Volumes L**3				Rates for Final Time Step L**3/T			
In flow		Out flow		In flow		Out flow	
wells	0	wells	839999.62	Wells	0	Wells	9333.330
Recha-	18469006	Recha-	0	Recha-	25265.396	Recha-	0
Storage	5315880.0	Storage	18197980	Storage	8227.9062	Storage	23787.65
Total	23784886	Total	23784226	Total	33493.304	Total	33493.64
	Inflow –out flow				In flow –out flow		
	23784886-23784226				33493.304-33493.64		
	660.00				0.3438		

Table B. 4: Volumetric budget for constant recharge and decreased pumping rates

Cumulative Volumes L**3				Rates for Final Time Step L**3/T			
In flow		Out flow		In flow		Out flow	
wells	0	wells	2942828.7	Wells	0	Wells	5197.412
Recha-	18469006	Recha-	0	Recha-	25265.396	Recha-	0
Storage	2810939.5	Storage	18336468	Storage	4357.0938	Storage	24425.06
Total	21279946	Total	21279296	Total	29622.490	Total	29622.47
	Inflow –out flow				In flow –out flow		
	21279946-21279296				29622.490-29622.47		
	650				1.5625E-02		

Table B. 5: The water balance for constant recharge and increased pumping wells

Cumulative Volumes L**3				Rates for Final Time Step L**3/T			
In flow		Out flow		In flow		Out flow	
wells	0	wells	7584538.5	Wells	0	Wells	12600.58
Recha-	18463950	Recha-	0	Recha-	25235.283	Recha-	0

Storage	10452.562	Storage	18075732	Storage	7196971	Storage	23087.12
Total	25660920	Total	25660270	Total	35687.843	Total	35687.71
	Inflow –out flow				In flow –out flow		
	25660920-25660270				35687.843-35687.7109		
	650				0.1328		

Table B. 6: Volumetric budget for increased recharge and decreased pumping wells

Cumulative Volumes L**3				Rates for Final Time Step L**3/T			
In flow		Out flow		In flow		Out flow	
wells	0	wells	2942828.7	Wells	0	Wells	5197.412
Recha-	25300008	Recha-	0	Recha-	34610.136	Recha-	0
Storage	2732729.7	Storage	25089138	Storage	4050.5312	Storage	33463.06
Total	28032738	Total	28031966	Total	38660.668	Total	38660.47
	Inflow –out flow				In flow –out flow		
	28032738-28031966				38660.668-38660.47		
	772				0.1914		

Table B. 7: Volumetric budget for decreased recharge and increased pumping wells

Cumulative Volumes L**3				Rates for Final Time Step L**3/T			
In flow		Out flow		In flow		Out flow	
wells	0	wells	7584538.5	Wells	0	Wells	12600.58
Recha-	13478610	Recha-	0	Recha-	18421.6602	Recha-	0
Storage	7327601	Storage	13221049	Storage	11017.0312	Storage	16838.28
Total	20806212	Total	20805588	Total	29438.6914	Total	29438.86
	Inflow –out flow				In flow –out flow		
	28032738-28031966				38660.668-29438.86		
	624				0.1758		

Appendix C: Lab and field measurement

Figure C. 1: Water quality assessment and groundwater head measurement