FACULTY OF ENGINEERING

DEPARTMENT OF WATER RESOURCES AND MINING ENGINEERING

FINAL YEAR PROJECT REPORT

DEVELOPMENT OF A POLLUTANT TRACKING MODEL FOR THE MITIGATION OF FECAL MATTER MOVEMENT INTO GROUND WATER.

By

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Final year project report submitted to the department of Water Resources and mining Engineering in the partial fulfilment of the requirement for the award of a Bachelor of Science in Water Resources Engineering at Busitema University

ABSTRACT

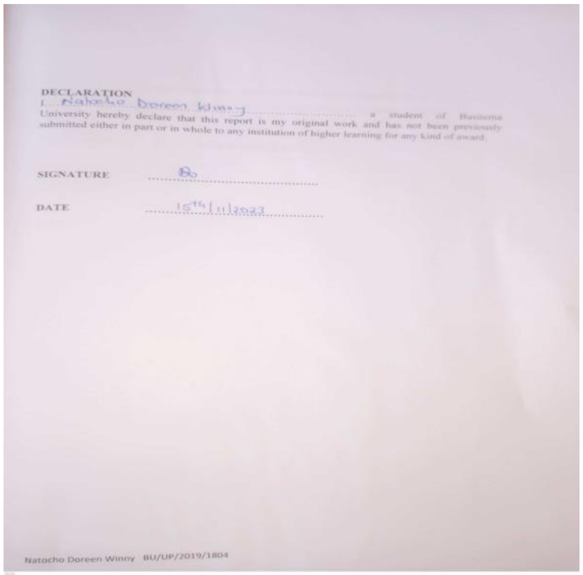
Fecal matter contamination poses a significant threat to public health and the environment, leading to waterborne diseases and ecological disturbances. To address this issue, a pollutant tracking model has been developed with the primary objective of mitigating the movement of fecal matter into the ground. This research integrates cutting-edge technologies in hydrology, geospatial analysis, and environmental engineering to design an innovative approach for identifying, monitoring, and controlling fecal pollutant pathways.

The pollutant tracking model utilizes Geographic Information Systems (GIS) to map and analyze the spatial distribution of potential contamination sources. Additionally, it incorporates hydrological simulations to predict the movement of pollutants within the groundwater, considering factors like soil characteristics, land use, precipitation patterns, and hydraulic conductivity.

Furthermore, the model incorporates real-time data from sensor networks and remote sensing technologies to enhance its accuracy and reliability. It continuously collects information on water quality parameters and enabling adaptive management strategies for efficient mitigation.

The findings of this study provide valuable insights into the sources and pathways of fecal pollution, aiding policymakers and environmental agencies in making informed decisions. By identifying critical hotspots of contamination and evaluating potential mitigation measures, this pollutant tracking model contributes significantly to safeguarding water resources, enhancing public health, and preserving ecosystems.

Keywords: pollutant tracking model, fecal matter, ground contamination, waterborne diseases, hydrology, geospatial analysis, GIS, groundwater water quality, adaptive management, pollution control, public health.



DECLARATION

I …Natocho Doreen Winny……… a student of Busitema University hereby declare that this report is my original work and has not been previously submitted either in part or in whole to any institution of higher learning for any kind of award.

SIGNATURE ………[signature]………

DATE ………15th/11/2023………

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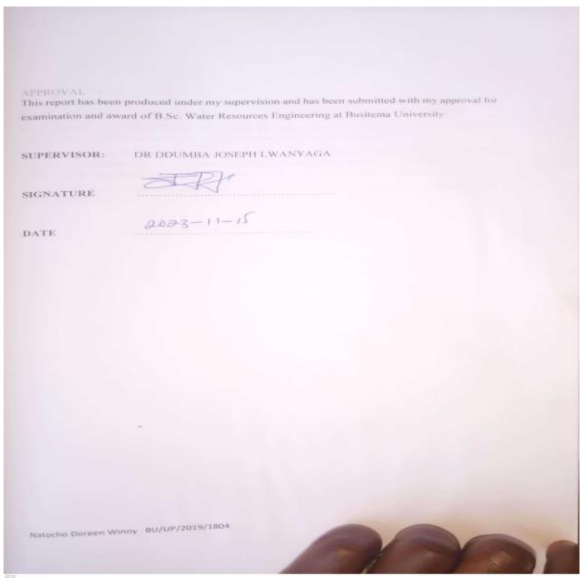
APPROVAL

This report has been produced under my supervision and has been submitted with my approval for examination and award of B.Sc. Water Resources Engineering at Busitema University.



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DATE 2023-11-15

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1.0 CHAPTER ONE: INTRODUCTION

This chapter includes; back ground to the study, statement of the problem, and objectives of the study, scope of the study which includes the conceptual scope, geographical scope and time scope research questions and finally the significance of the study.

1.1 Back ground

Groundwater contamination by fecal matter is a significant public health concern affecting many countries globally of about 80% (Quispe, 2023). Fecal matter can contain a range of pathogens, including bacteria, viruses, and parasites that can cause waterborne illnesses such as diarrhea, cholera, and typhoid fever (Wook, 2004).

Over two billion people globally lack access to safe drinking water, and poor sanitation practices contribute significantly to the contamination of groundwater (Wook, 2004). In many countries, including India, Bangladesh, and Nigeria, poor sanitation infrastructure and inadequate waste management systems are significant contributors to groundwater contamination by fecal matter (Wook, 2004).

Li & Srinivasamoorthy,(2021) carried out a study In India, and found that up to 80% of the groundwater in rural areas was contaminated with fecal matter due to poor sanitation practices and inadequate waste management systems. In Bangladesh, a 2016 study found that almost one-third of the country's groundwater was contaminated with fecal matter (Rahman, 2018), with the highest levels of contamination found in rural areas.

In Africa, from a study that was carried out in 2019 found that groundwater sources in rural areas of sub-Sahara were contaminated with fecal matter (E.coli) due to inadequate sanitation practices and poor waste management systems like open defecation which was 59%(n=100), unhygienic practices, livestock feces and latrine detections in proximity to water sources was found in the study ($P < 0.05$) (Gwimbi et al., 2019).This is because approximately 215 million people practice open defecation, a major source of transmission mode of pathogens that cause diarrheal diseases as a result of using unsafe drinking water in children in low-income countries.

According to the Uganda Water and Environment Sector Performance Report of 2020 (Ministry of Water and Environment, 2020), about 80% of the population relies on groundwater as the main source of drinking water. However, due to poor sanitation practices and inadequate waste management systems, groundwater sources in Uganda are often contaminated with fecal matter, which poses a risk to public health.

A 2016 study conducted by the Ministry of Water and Environment in collaboration with the World Health Organization (WHO) found that over 80% of the groundwater sources tested in rural areas of Uganda were contaminated with fecal matter. The study also found that the contamination levels were higher in areas with a higher population density and where there were no proper sanitation facilities.

The contamination of groundwater by fecal matter in Uganda can lead to waterborne illnesses such as cholera, typhoid fever, and diarrhea. These illnesses are particularly dangerous for vulnerable populations(WHO/UNICEF, 2017) such as children, pregnant women, and the elderly.

Busitema located in Busia District, Uganda, is one of the many rural communities facing significant challenges related to access to clean water and sanitation facilities. Groundwater contamination by fecal matter is a widespread problem in the area due to inadequate sanitation facilities, such as pit latrines and sewage systems, leading to the pollution of groundwater sources (WHO/UNICEF, 2017).

The lack of access to clean water and sanitation facilities poses significant health risks to the local population, with waterborne diseases such as cholera, typhoid, and dysentery being common (Byonanebye et al., 2014). Furthermore, the contamination of groundwater sources also impacts the local economy, as farmers are unable to grow crops due to the poor water quality (Moses, 2019).

Despite efforts by the government and non-governmental organizations to address the issue, including the construction of boreholes and the distribution of water treatment tablets through setting up the National Water and Sewerage Corporation (NWSC) , the problem persists (Moses, 2019). The lack of resources and infrastructure remains a significant barrier to addressing the issue adequately.

1.2 Problem statement

60% of patients in Shanyonja HCIII Busitema sub county test positive of water related diseases such typhoid, diarrhea. This has been found in annual laboratory report written by Dr. Bwire Kennedy. Presence of active and abandoned unlined pit latrines and also sewer line leakages could be the source of fecal matter. Studies on groundwater have been done for example Engström,(2015) recommended the installation of improved latrines and the promotion of safe livestock management practices, investigation of the sustainability of the groundwater supply (Peter, 2014) and mitigation of mercury movement into groundwater(Gloria et al., 2022) but none has looked at groundwater vulnerability to fecal matter yet groundwater is the main source of drinking water.

1.3 Study objectives

1.3.1 Main objectives of the study;

To develop a pollutant tracking model for the mitigation of fecal matter that move into groundwater.

1.3.2 Specific objectives;

1. To characterize ground water within Busitema sub county
2. To develop a pollutant tracking model for the mitigation of fecal matter movement ground water.
3. To determine the magnitude of vulnerability of ground water contamination by fecal matter

1.4 Justification

This study assessed the extent of groundwater contamination fecal matter, determined ground water vulnerability to contamination which helped in coming up with measures of mitigating. This as its stated in the section of recommendations since time factor did not allow putting them into place. This has contributed in attainment of SDG 3 (good health and well-being), SDG 6 (clean water and sanitation for all. The study also helped the community to know the safe water for drinking. It also helped policy makers to establish and enforce the safe methods of construction of pit latrines and sewage lines and also regulate the distance between those places relative to a water source (borehole)

It was therefore important to investigate the movement of fecal matter into groundwater and recommend mitigation measures to minimize vulnerability of groundwater to fecal matter.

1.5 Scope of the study

Geographically, this project was limited to Busitema University community in Busia district. Conceptually, this project was limited to developing the pollutant tracking model of fecal matter into the ground water using a software called MOD flow. This involved testing for fecal coliform and Ecoli since they are harmful to humans (Farooqui et al., 2009).

1.8 Conceptual diagram

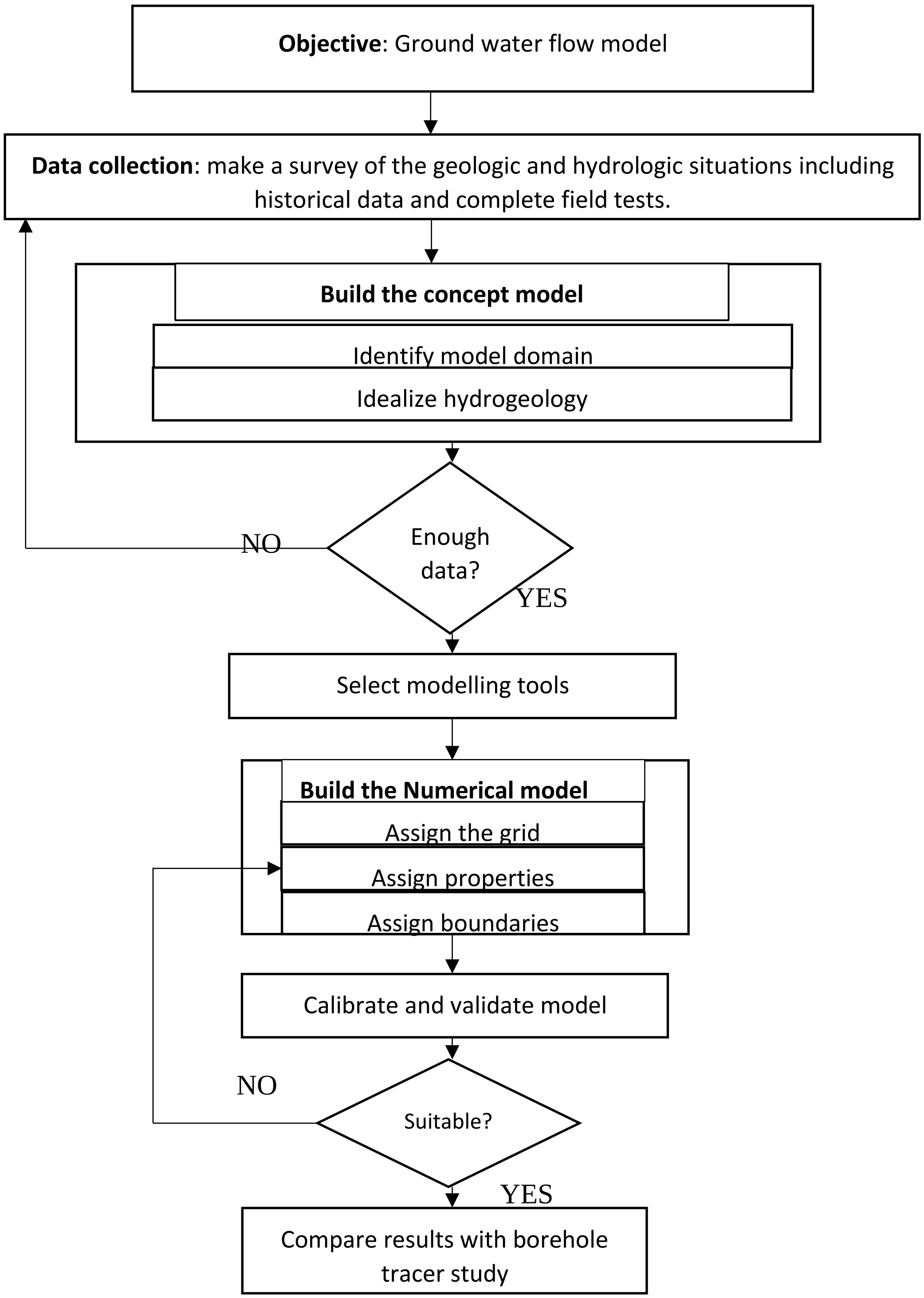


Figure 1showing conceptual diagram

2.0 Literature view

2.1 Drinking water

Water used, or intended to be available for use, by humans for drinking, cooking, food preparation, personal hygiene or similar purposes (WHO/UNICEF JMP, 2015)

2.1.1 Groundwater contamination

The contamination of groundwater occurs when pollutants are released to the ground and make their way into groundwater. This type of water pollution can also occur naturally due to the presence of a minor and unwanted constituent, contaminant, or impurity in the groundwater, in which case it is more likely referred to as contamination rather than pollution. Pollution (or contamination) can also occur from naturally occurring contaminants, such as arsenic or fluoride. Using polluted groundwater causes hazards to public health through poisoning or the spread of disease (water-borne diseases) like typhoid.

The pollutant often creates a contaminant plume within an aquifer. Movement of water and dispersion within the aquifer spreads the pollutant over a wider area. Its advancing boundary, often called a plume edge, can intersect with groundwater wells and surface water, such as seeps and springs, making the water supplies unsafe for humans. Different mechanisms have influence on the transport of pollutants, e.g. diffusion, adsorption, precipitation, decay, in the groundwater(Talk, 2010)

2.1.2 Concentration of fecal matter contamination in Ground water

Fecal matter contain *Salmonella* typhi which is one of the most important causes of gastroenteritis worldwide. The symptoms of infection include fever, abdominal pain, diarrhea, nausea, and sometimes vomiting. They usually appear 12–72 h after infection and last for 4– 7 days, without any consequences for most patients (Quispe, 2023). The outbreaks usually occur due to the consumption of contaminated food and water(Walters et al., 2013).

2.1.3 Sources of fecal matter as a ground water contamination

Toilet is a fixed receptacle into which a person may urinate or defecate, typically consisting of a large bowl connected to a system for flushing away the waste into a sewer or septic tank.

2.1.4 Categories of toilet

Toilet types can be broadly split into two categories; on-site and off-site systems

2.1.5 Onsite systems

These are isolated and provide some level of treatment or containment at the toilet location and avoid the need for further treatment (Upatyaka & Limited, 2017).Example of onsite toilet systems are the sewer lines.

2.1.6 Off-site systems

These are associated more with the developed world, cities and high density areas and often take on the form of sewerage systems which require a reliable water supply and the provision of ground water treatment. An example of offsite toilet system is the simple latrine.

2.1.7 Septic tank and aqua privy as a source of contamination to ground water eptic tanks and aqua privies have a water-tight settling tank with one or two compartments. Waste is flushed into the tank by water from a pipe that is connected to the toilet. If the septic tank is under the latrine, the excreta drop directly into the tank through a pipe submerged in the liquid layer (aqua privy). If the tank is away from the latrine (septic tank), the toilet usually has a U-trap.

Neither system disposes of wastes: they only help to separate the solid matter from the liquid.

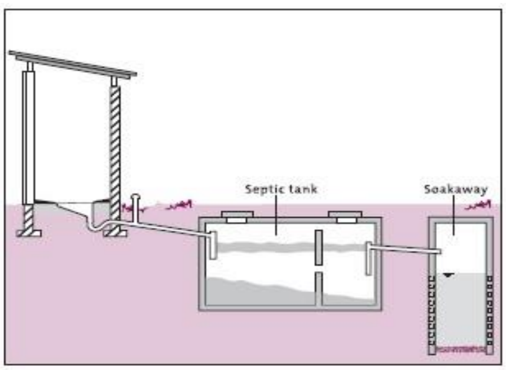


Figure 2: shows a septic tank and aqua privy

2.1.8 Methods for Sampling/Analysis of fecal matter in ground Water

Sampling and analysis of fecal matter in groundwater is important for identifying sources of contamination and assessing the risk to the public health and should be done by trained personals.

- Collection of samples: Ground water samples should be collected using sterile techniques and sampling devices. The collection site should be identified and the water should be characterised before samples collection. Multiple samples should be collected from different locations and depths.
- Enrichment: The collected samples should be enriched using appropriate media to promote the growth of faecal matter. A commonly used enrichment medium is selenite broth.

- Selective media: Once enrichment is has occurred, selective media should be used to isolate Salmonella typhi. Examples of selective media include salmonella shigella agar, xylose Lysine Deoxycholate agar and brilliant green agar.
- Identification: Once Salmonella typhi has been isolated in the faecal matter, it can be identified using a variety of techniques. These include biochemical tests, such as the API 20E system, and serological tests such as the Widal test.
- Molecular method: Molecular methods such as PCR and QPCR can also be used for the detection of salmonella typhi in ground water. These methods are highly sensitive and specific and can detect very low levels of the bacteria.

Enumeration: Enumeration of the number of faecal matter in ground water can be achieved using either colony counting or PCR based quantification.

2.2 Pollutant Modelling

2.2.1 Ground water pollutant transport Modelling

Groundwater models are computer models of ground water flow systems, and are used by hydrologists and hydrogeologists. Groundwater models are used to simulate and predict aquifer conditions.

The employment of models to predict the movement of contaminants in groundwater systems has received more attention in recent years due to the expanding popularity of subterranean waste disposal. When dealing with nuclear waste, prediction is very important. Many field scenarios have been used using contaminant transport models that take the effects of dispersion into consideration.

However, considerations like the difficulty of figuring out the field coefficient of dispersion and the computational challenges encountered while solving the dispersion equation restrict the common usage of these models. Due to the dearth and low quality of field data, regional size models that ignore the impacts of dispersion have had only modest success. Current understanding on the quantification of chemical reaction terms is lacking, which presents another challenge in the creation of contamination transport models. The creation of contaminant transport models, their application to real-world issues, the challenges associated with gathering the necessary data, and the state of modeling efforts are all examined in this paper. The whole process for modeling can be shown on the chat below.

2.2.4 Objectives of modeling using a MODFLOW(Harbaugh, 2005)

To enable one to understand how the system works geologically, hydrologically and its chemical point of view (for example, estimating the ground water sources, how contaminants spread out).

To enable the prediction of a system behavior in response to excitations that aids in decision making.

To give the relevant information so that to comply with regulations

To offer information for the design of a monitoring network or field experiment through prediction of the future system behavior.

2.3.1 Groundwater vulnerability modeling

Groundwater vulnerability modeling is a critical tool for identifying areas that are at risk of contamination from various sources. One particular area of concern is the potential intrusion of fecal matter into the groundwater, which can lead to serious public health risks. In recent years, there has been a growing body of research on groundwater vulnerability modeling for fecal contamination, with various methods used to mitigate and assess their performance.

Several methods have been employed to model the vulnerability of groundwater to fecal contamination. One such method is the DRASTIC (Depth to water, Recharge, Aquifer media, soil media, topography, Impact of vadose zone, and conductivity) approach, which uses a series of parameters to calculate a vulnerability index for an aquifer. Another widely used method is the GOD (Groundwater Occurrence and Depth) approach, which considers the occurrence and depth of groundwater in combination with land use and topography to estimate the vulnerability of the aquifer.

To mitigate the intrusion of fecal matter into the groundwater, various methods have been employed. One common approach is the use septic systems, which separates solid and liquid waste and allow for the proper treatment and disposal of wastewater. Other methods include the use of permeable reactive barriers, which consist of a layer of reactive material that can remove contaminants from groundwater, and the application of best management practices (BMPs) to reduce the amount of fecal matter entering groundwater.

Several studies have been conducted to assess the performance of these methods in mitigation of the intrusion of fecal matter into groundwater. For example, a study by Zhang et al., (2019) found that permeable reactive barriers were effective in reducing the concentration of fecal indicator bacteria in groundwater. Another study by Köninger et al., (2021) found that BMPs such as proper manure management and soil conservation practice, were effective in reducing the amount of fecal matter entering groundwater.

In Busia, Uganda, there is need for more research on the effectiveness of mitigation strategies for reducing fecal contamination in groundwater. (Engström, 2015) recommended the installation of improved latrines and the promotion of safe livestock management practices, but more research is needed to determine the effectiveness of these strategies in reducing contamination. Additionally, there is a need for more research on the socioeconomic and cultural factors that influence the adoption of mitigation strategies in the region.

Despite these advances, there are still several research gaps in groundwater vulnerability modeling for fecal contamination. One major gap is the need for better data on the sources and pathways of fecal contamination in groundwater. Additionally, there is a need for more research on the effectiveness of BMPs in reducing fecal contamination, particularly in agricultural settings. Finally, there is a need for more research on the long term effectiveness of mitigation methods, as well as their potential impacts on groundwater quality and ecosystem health.

In conclusion, groundwater vulnerability modeling is a crucial tool identifying areas at risk of contamination from fecal matter. Several methods have been employed to mitigate the intrusion of fecal matter into groundwater, and these methods have been found to be effective in reducing contamination. However, there are still several research gaps that need to be addressed to improve the effectiveness of these methods and better protect groundwater resources.

2.3.2 Groundwater vulnerability assessments

Despite the threats from potentially polluting activities, groundwater is often surprisingly resilient and water quality over large areas of the world generally remains good. This is because, many aquifer systems possess a natural capacity to attenuate and thereby mitigate the effects of pollution. Though groundwater is not easily contaminated yet once this occurs, it’s difficult to remediate. The replacement cost of a failing local aquifer is generally high and its loss may stress other water resources looked to as substitutes. Further, in the developing world, such remediation may prove practically impossible. Thus it is important to identify which aquifer systems are most vulnerable to pollution.

Thus defined vulnerability is different from pollution risk, which depends not only on vulnerability but also on the existence of significant pollution loading entering the subsurface environment. It is possible to have high aquifer vulnerability but also on existence of significant pollutant loading entering the subsurface environment. It is possible to have high aquifer vulnerability but no risk of pollution, if there is no significant pollutant loading or to have high pollution risk in spite of low vulnerability, if the pollutant loading is exceptional.

It is important to clarify the distinction between vulnerability and risk. This is because risk of pollution is determined not only by the intrinsic characteristics of the aquifer, which are relatively static and hardly changeable, but also on the existence of potentially polluting activities, which are dynamic factors that can, in principle, be changed and controlled. The seriousness of the impact on water use will depend not only on aquifer vulnerability to pollution but also on the magnitude of the pollution episode, and on the value of the groundwater. For the purpose of this review, we are assessing the vulnerability of the communities in and around Busitema University over groundwater contamination.

3.0 METHODOLOGY

Study area description

A study was conducted in Busitema sub county which is found in Busia district, Eastern region of Uganda with Latitude 0º32'43.54"N and Longitude 34º01'10.88"E at elevation of 3725ft. The sub county consists of 8 parishes and 57 villages, Selected villages for the study are; Syaule, Syanyonja, Nangudi, Ngochi, Manyanya, Nambewo, Ajukete, Akobwait, Busitema College etc Having about 40 boreholes and 10 shadoofs, Out of these water sources, only 30 boreholes are selected together with neighboring pit latrines and sewer points as shown on the elevation map.

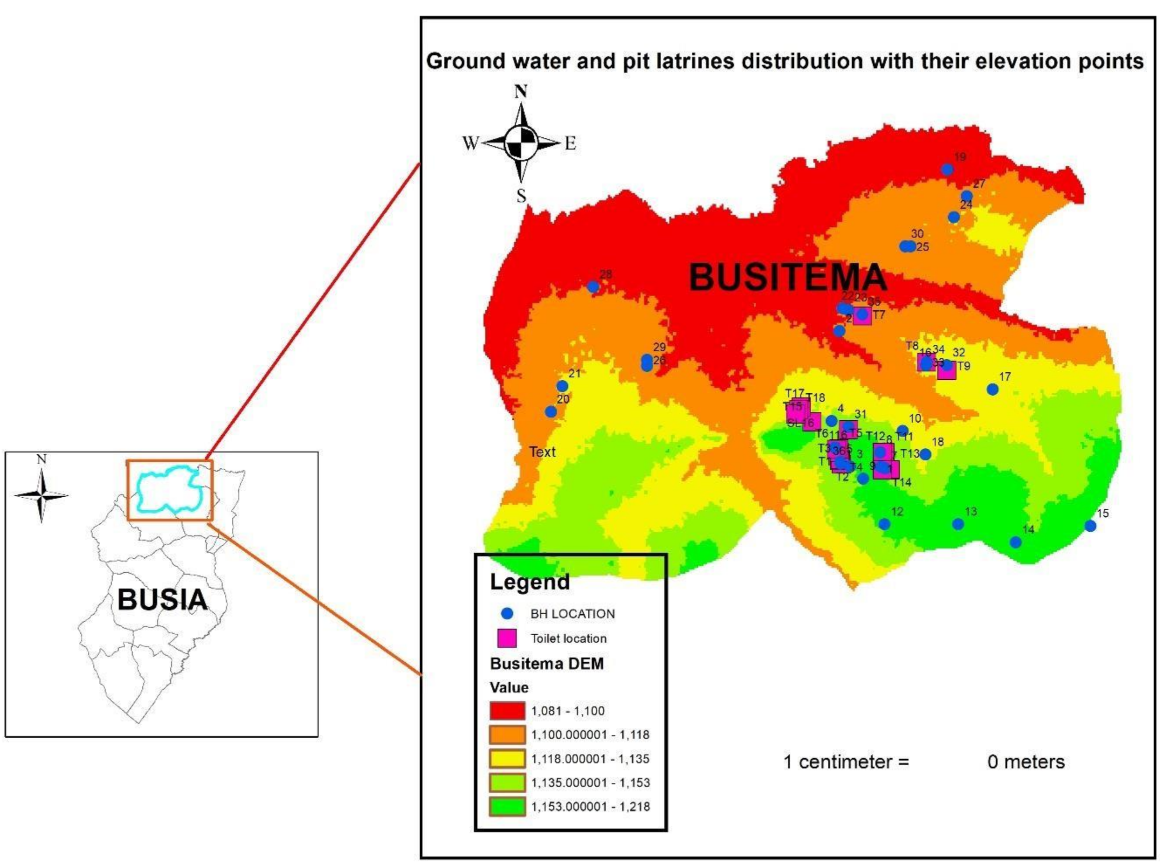


Figure 3 showing study area description

Data types and sources

Primary data collection methods.

Oral interviews was applied to know the depth to which each pit latrines were constructed and also whether they are lined or unlined. This helped to know the vulnerability of these water sources to contamination as some pit latrines' depth which were unlined were as well within the aquifer depth.

Secondary data collection methods

Secondary data included the information obtained from available published records such as textbooks, different data sets, articles, theses and the internet. This data was used to obtain information about how characterization has been done.

Materials and Equipment

The materials that were used in this study include; Borehole data obtained from the district water office, hydrological data from Uganda National Meteorological Authority (UNMA), geological data from the Directorate of Geological Survey and Mines (DGSM), Busitema Sub county human and animal population data from UBOS in conjunction with the district authorities, location of existing boreholes in the study area as well as the GPS coordinates of the boreholes and the toilets both unlined and unlined as well as their GPS coordinates in Busitema Sub county.

The equipment used

A Global Positioning System (GPS) was used during the survey to locate the geographical coordinates of the existing boreholes in the study area.

Computer

Field record sheets for record keeping

Software's employed

ArcGIS 10.2 for derivation of thematic maps

Micro soft office packages, (word and excel)

MODFLOW for pollutant transport model

Methods employed

The methods that were used in this study include;

- Thematic map integration
- Geo-referencing
- Spatial analysis

3.1 Methodology to objective one: To characterize the ground water within Busitema sub county.

3.1.1 Source of data and methods of data collection.

3.1.1.1 Data Types and Sources

The study used both Primary and Secondary Data.

Secondary data collection methods

Secondary data include the information obtained from available published records. Secondary data was obtained from reports from the district water office, journals, articles and the internet and it is majorly used for desk study. This data was used to obtain information about how GIS has been used in ground water exploration

Primary data collection methods

Primary data include the information collected from the field. The source of this information was District water office, Ministry of Water and Environment (MWE); Directorate of Water Resources Management (DWRM), Ministry of energy and mineral development (MEMD), National Forestry Authority (NFA) and National Agricultural Research Organization (NARO). The following methods was used in primary data collection.

Interviews

Oral interviews to the residents concerning the depth of the pit latrines, the period they have stayed, the number of both lined and unlined pit latrines, how deep each pit.

Consultations

Some of the data for this research was obtained by consulting individuals such as supervisors, lectures, fellow students, as well as key individuals from the places where data was collected from such as DWO.

Field visits

Field visits were conducted in the study area to ascertain the existence of the geographical features, to find out the various ground water sources, their characteristics; those functional and nonfunctional, their distance from the contaminant sources such as unlined and lined pit latrines.

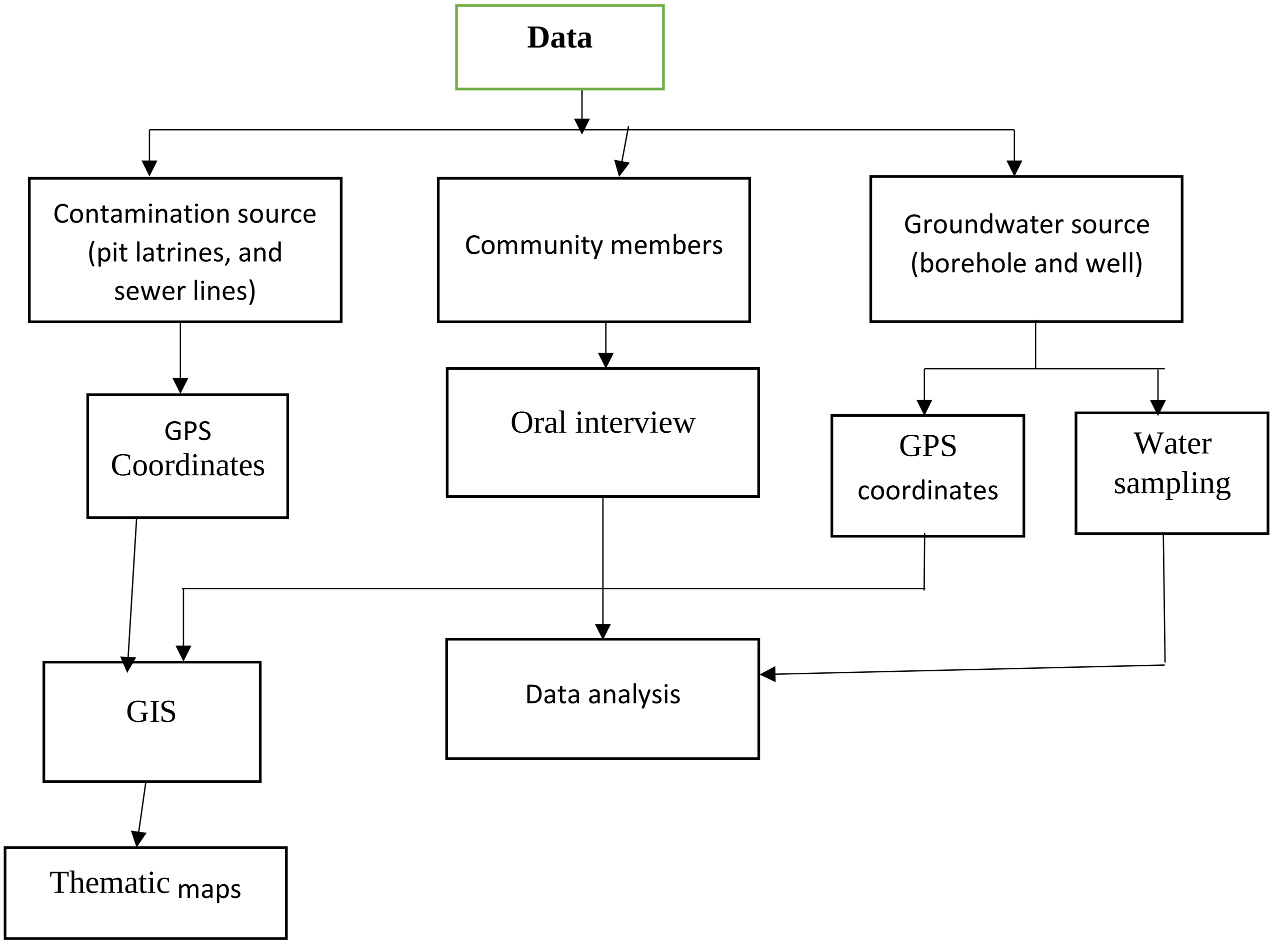


Figure 4 gives the systematic outline of how the data collection and analysis was carried out.

3.1.2 Materials and tools

PH meter

Laboratory analysis

Field observation

Scooper

3.1.3 Catchment Delineation

The following procedure was used for the process of delineation of the catchment;

Using ArcGIS- Click spatial Analyst extension, which provides tools for analyzing and modeling spatial data.Save the project

Load the DEM in the ArcGIS work space which shows the slope/ elevation of the area

3.1.4 Sampling

3.1.4.1 Types of samples that were collected include; Grab samples

A grab sample refers to a small representative subset of a larger quantity, concentration or measurement that is taken at a specific time. Grab samples of water was tested to determine the amount of the pollutant in the water.

Composite samples

A composite sample, also known as an integrated sample, is a sample which consists of a mixture of several individual grab samples collected at regular and specified time periods, each sample is taken in proportion to the amount of flow at that time. This was also taken and tested to determine the amount of the contaminant.

3.1.4.2 Methods for sampling that was employed include; Systematic sampling

Here points were selected at regular and even intervals, the method is statistically unbiased provided the coordinates of the first sampling point are determined by random numbers.

While sampling groundwater, Geographical and legal location, Depth of well, Diameter of well, Length of casing and position of screens, Method of collection (source), Point of collection, Water-bearing formation (s), Water level, yield of well in normal operation, Water temperature, Principal use of the water, Name of collector, Date of collection, were obtained

3.1.5 Characterization of the ground water sources

Different water samples were collected from nine sources using bottles. These samples were taken to the laboratory for analysis.

Parameter	Unit	Equipment/method/Reagents used
Fecal coliform	(CFU/ 100mls)	Membrane Laurel Sulphate Broth
E-coli (Escherichia coli)	(CFU/ 100mls)	Chromocult media
pH		pH meter

Table 1shows the different parameters tested for.

3.1.5.1 Measurement of pH (NWSC SOP et al., n.d.) Apparatus; pH meter

Procedure

- ✓ The water samples to be tested were vigorously shaken and 100mls of each sample was poured in a beaker for analysis
- ✓ Probes were rinsed with distilled water
- ✓ The probes were then immersed in the water sample to be tested
- ✓ The displayed readings were taken and noted after the PH meter has stabilized.

3.1.5.2 Determination of fecal coliform(NWSC SOP et al., n.d.)

Procedure

- ✓ The membrane filter paper was placed on the filtering unit using a sterile forceps ascetically.
- ✓ 2.0-3.0 ml of laurel sulphate broth was transferred on to the absorbent pad in the Petri dish so that it is socked just to leave a film of broth round the absorbent pad.
- ✓ The membrane filter paper was placed on the filtering jar with the gridded face up.
- ✓ 100ml or an equivalent of sample was poured into the filtration jar and all filtered through the filter paper.
- ✓ Then the filtering membrane was removed and placed on to the absorbent pad that was earlier socked with the broth (The gridded side of the filter membrane facing up).

- ✓ The petri dish was covered with the lid upper most and placed on to the petri dish carrier then transferred into the incubator. The incubator was set at 44ºC ± 0.5ºC for fecal coliform test then incubated for 12-16 hours.
- ✓ After incubation the carrier plus the petri dish was removed and allowed to cool for 10min.This was to allow false yellow color to be lost.
- ✓ A magnifying glass and a counting pen were used to count the colonies and recorded as counts/1 ml.

3.1.5.3 Determination of fecal coliform(NWSC SOP et al., n.d.)
Chromocult using membrane filtration method

Procedure

- ✓ The Chromocult agar was prepared according to the instructions on the media bottle and culture plates were made with agar only.
- ✓ 100 ml of sample was filtered through a filtration membrane.
- ✓ Then the filter membrane was placed onto the prepared agar plate and incubated it while inverted at 37ºC.
- ✓ Colonies were observed for blue shaded cunts, and results recorded as CFU/100 ml of E. coli

3.2 Methodology to objective two: Development of a pollutant tracking model for tracking fecal matter movement into groundwater.

MODFLOW software was used for groundwater contaminant transport modeling because its an open source and enables addition of packages without changing existing one. It was used to generate a groundwater flow model using packages like flow package and boundary condition package. MT3DUSGS package was used for contaminant transport and using Model muse as a GUI. Packages like MODPATH were used to track the contaminant movement in the ground. The conceptual model was developed using contours, map for wells and recharge areas and aquifer properties like hydraulic conductivity. This was followed by developing a ground water model using flow package and developing a contaminant transport model using advection package, dispersion package and sink and source package. Figure below shows the modeling process that was carried out.

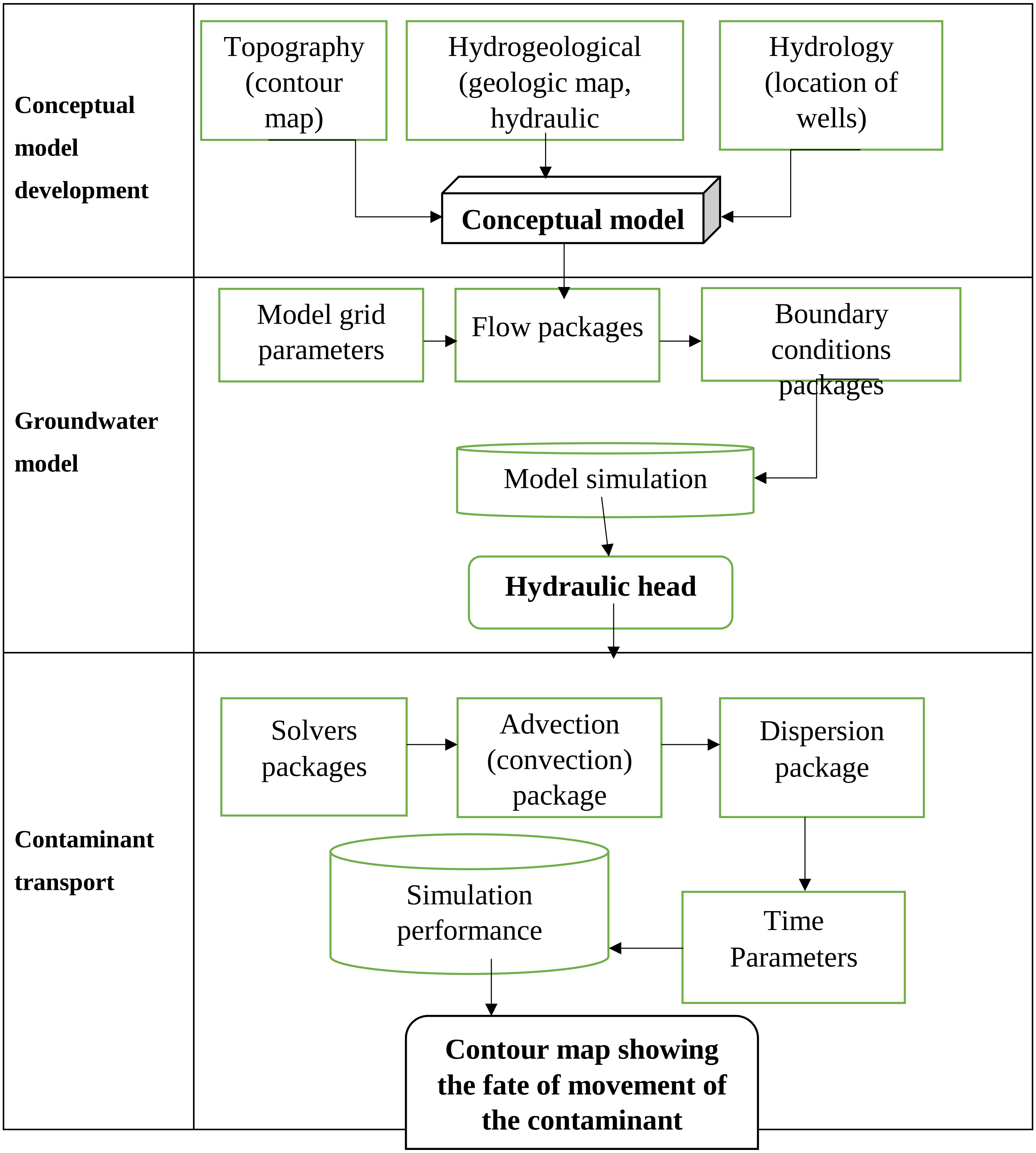


Figure 5showing the methodology for groundwater and contaminant transport modelling(Eterurho, 2007)

3.2.2 Conceptualization of the model

3.2.2.1Grid construction and layer discretization

The ground water model developed for the study was discretized with a finite difference grid that composed of 16 rows and 22 columns with uniform cell dimensions of 500m by 500m as shown in Figure 3.7. The model top was re-sampled from a 12.5m DEM resolution covering approximately 69.28km2 of area. There are a total of 352 cells in the model domain with 307 active cells and 45 inactive cells. The model domain was divided into three layers in correspondence to the geology of the study area.

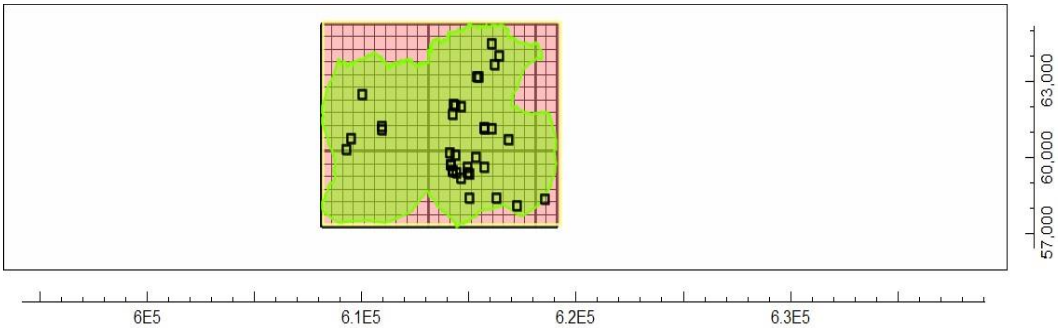


Figure 6 showing model grid of the top view for Busitema sub county groundwater

3.2.2.2 Vertical discretization of model showing the aquifer layers.

A three-layered aquifer in Figure 3. 8 was considered with a vertical exaggeration of 60. The boundary conditions and aquifer properties are summarized in the table below. These were obtained from existing geological maps, borehole logs and field reconnaissance.

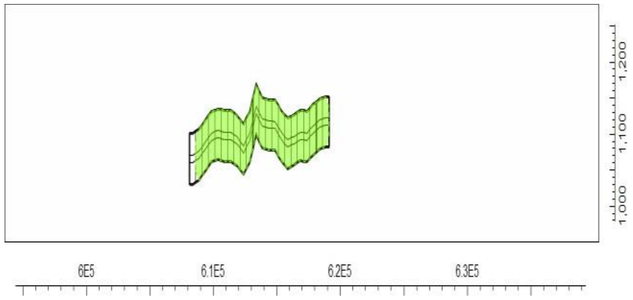


Figure 7 front view of model showing the aquifer layers

The model top layer represents where the DEM is in line with the topographic contours of the model at 0m thus it extends to a depth of 75m below the ground surface. Layer 1(weathered regolith) is an unconfined layer with a bottom elevation of -25m, layer2 (weathered rock) has a bottom elevation of -50m and is confined and layer 3(fractured rock) has a bottom elevation of 75m and is confined as shown in Table 3. 5 and Table 3. 6.

3.2.3 Aquifer properties

Layer	Type	Hydraulic conductivity	Thickness	Description
1	Weathered regolith	1e-4	<=-30	Comprised of alluvium soils, sand, silt and gravel
2	Weathered rock	1e-5	30-50	Consists of mafic and intermediate meta volcanic rock, cherty quartzite
3	Fractured rock	1e-5	>50	Consists of Masaba biotite granite rocks

3.2.4 Model details

Number	Item	Details
1	MOD Flow version	MODFlow6 and MODFlow-2005
2	GUI	Model Muse v5
3	Grid cell size	500m
4	Rows	16
5	Columns	22
6	Layers	3
7	Total number of cells	352
8	Active cells	307
9	Maximum elevation	1218
10	Minimum elevation	1078
11	Model simulation type	Steady state
12	Stress periods	1
13	Time step	1
14	Stress period duration	86400 seconds
15	Length of simulation	86400 seconds
16	Internal flow package	Layer property flow(LPF)

17	Solver package	Preconditioned Conjugate Gradient (PCG)
18	Boundary	RCH, WEL, CHD, GHB
19	Observations	Head observations

Table 2showing aquifer properties and model details

3.2.5 Model calibration

Model calibration consists of varying values of model input parameters in an attempt to match field conditions within an acceptable criterion. Calibration was carried out by trial-and-error adjustment of parameters. Model calibration requires that field conditions at a site be properly specified. Otherwise, model will not be a reliable representative of actual field conditions. The coefficient of determination (R^2) was used.

The closer R2 to 1 indicates better fit or relationship, between the two variables.

$$R^2 = \left(\frac{\left(\sum_{i=1}^{n} (Q_{Oi} - \bar{Q}_O)(Q_{Si} - \bar{Q}_S)\right)}{\sqrt{\sum_{i=1}^{n} (Q_{Oi} - \bar{Q}_O)^2} \sqrt{\sum_{i=1}^{n} (Q_{Si} - \bar{Q}_S)^2}} \right.$$

3.2.6 Topographical data

The topographic map for the catchment Figure 3. 9 was prepared by ArcGIS v10.8.2 and the altitude of the area was adapted from a 12.5m DEM resolution. The heads range from 1078m to 1218m above sea level.

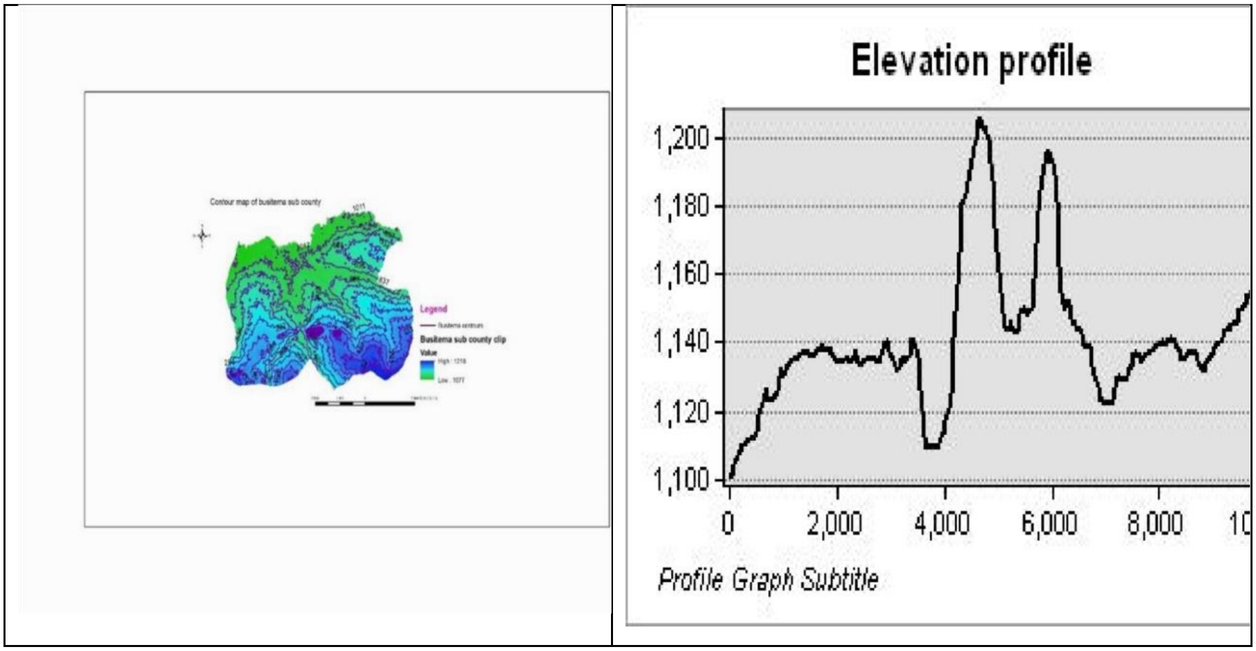


Figure 8 showing topography of the area

3.2.7 Geology of Busitema

The basement complex characterized mainly by banded acid gneisses and undifferentiated banded/acid-biotite magmatic gneisses underlie most of the area of interest. These highly weathered metamorphosed rocks form North South trending low-lying wide ridges. The trend of the ridges in/faults indicate the axial trend of faulting which control most of the drainage system. The drainage system is almost East-West trending and controlled by jointing. These geological formations gradually form North-South trending low-lying wide ridges as shown in Figure below

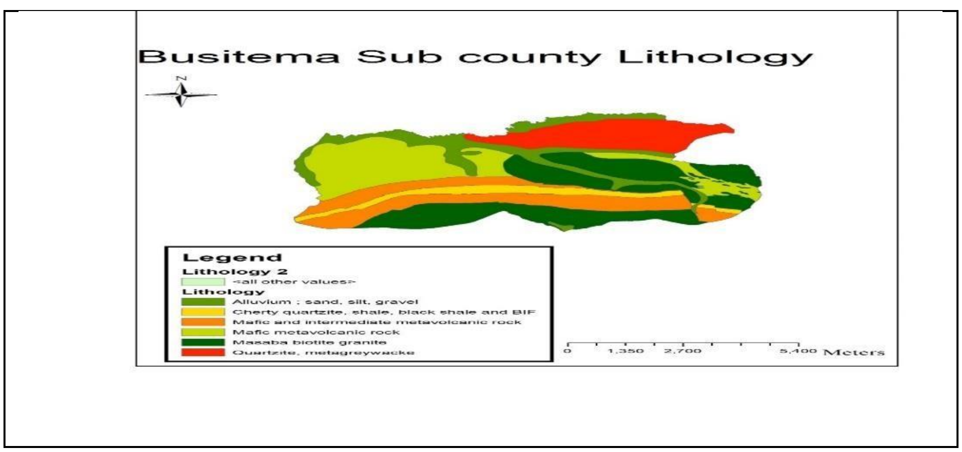


Figure 9 showing geology of the area

Groundwater recharge

This is calculated using **Chaturvedi formula.** This has been widely used for preliminary estimation of groundwater recharge due to rainfall. $R= 1.35(P-14)^{0.5}$ Where P is the total rainfall value of the area and for Busitema its 20254.51mm/day. R=5.97mm/day (6.9e-8m/s)

Recharge areas can influence the movement of contaminants by diluting them or flushing them out of the system. The higher the recharge, the lower the rate of contamination.

3.3 Methodology to objective three: Determination of the magnitude of vulnerability of ground water contamination by fecal matter

3.3.1 Vulnerability assessment

This involved application of vulnerability assessment basing on the values obtained from the calibration of the model to evaluate the susceptibility of the aquifer to fecal contamination.

DRASTIC (Depth to Water, Recharge, Aquifer Media, Soil Media, Topography, Impact of Vadose Zone, and Conductivity) method was used. This methods consider factors such as aquifer characteristics, depth to water, hydraulic conductivity, recharge, land use practices and distance from potential contamination sources.

3.3.2 Risk Mapping and Analysis:

The results from the vulnerability assessment and the groundwater contaminant transport modeling were used to create risk maps indices that depict areas of high and low vulnerability to fecal contamination. Overlaying of these maps with land use data and potential contamination sources was done to identify priority areas for mitigation and management actions.

Critical weight calculation using Analytic Hierarchy process (AHP)

Different criteria weights were assigned on different factors depending on their contributions towards contamination. This helped in coming up with the vulnerability map. This included elevation map, flow direction map, land use map and slope map.

	Elevation	Flow direction	Land use	Slope	**Criteria weight**
Elevation	0.63	0.60	0.69	0.50	0.60
Flow direction	0.13	0.12	0.09	0.21	0.14
Land use	0.16	0.24	0.17	0.21	0.20
Slope	0.09	0.04	0.06	0.07	0.06

Table 3 showing Critical weight calculation using Analytic Hierarchy process (AHP)

4 RESULTS AND DISCUSSIONS

4.1 Objective one: Ground water characteristics in the sub county

Water resources	Unit	Functionality	Non-Functionality
Boreholes	38	28	10
Springs	25	17	8
Shallow Wells	4	4	0

Table 4 showing Ground water characteristics in the sub county

4.1.1Busitema water resources

The detailed description of some water sources in the sub-county. The groundwater yield potential as indicated by table above collected from the DWO-BUSIA indicated that the yield ranges from 2.0m3/hr-18.0m3/hr. Therefore the total yield for all the boreholes was summed up to come up with 138.6m3/hr.

Therefore the Annual water yield =24 365 138.6

=1,214,136 m3/yr.t

According to the Uganda national standards, not all the water volume available should be abstracted. Hence the allowable abstraction from the ground is taken at 60%, therefore the groundwater expected to be abstracted is meant to be 728481.6m3/year which is the supply available from the boreholes on a year basis.

Latitudes	Longitudes	Depth (m)	Pumping rate m3/s	WELLYIELD	BH_Name	Elevation(m)
614944	59395	18	2.78E-05	8.17	SD1	1154
614239	61721	68	1.38E-03	4.64	BH2	1097
614422	59404	19	1.06E-03	2.02	SD3	1153
614101	60179	56	4.28E-04	18.21	BH4	1148
614249	59485	54	8.33E-05	9	BH5	1152
614156	59722	68	2.69E-04	2.3	BH6	1146
615011	59370	76	1.42E-03	6.05	BH7	1156
614928	59644	65	7.78E-04	3.45	BH8	1160
614642	59195	43	8.33E-04	8.84	BH9	1158
615317	60013	44	9.72E-05	4.08	BH10	1144

614161	59726	57	1.53E-03	5.67	BH11	1146
615010	58413	24	1.12E-03	6.37	SD12	1151
616270	58413	48	7.22E-04	2.02	BH13	1170
617258	58106	56	1.31E-03	6.14	BH14	1175
618532	58386	59	1.94E-04	10	BH15	
615714	61138	68	1.83E-04	6.5	BH16	1116
616858	60724	44	1.50E-05	8	BH17	1121
615707	59607	46	1.24E-04	7.43	BH18	1138
616084	64486	22	1.00E-04	8.9	SD19	1102
609301	60341	52	2.00E-05	10.7	BH20	1122
609499	60778	59	4.00E-02	2.34	BH21	1123
614292	62112	64	5.00E-03	4.2	BH22	1101
614391	62080	44	8.00E-04	1.43	BH23	1102

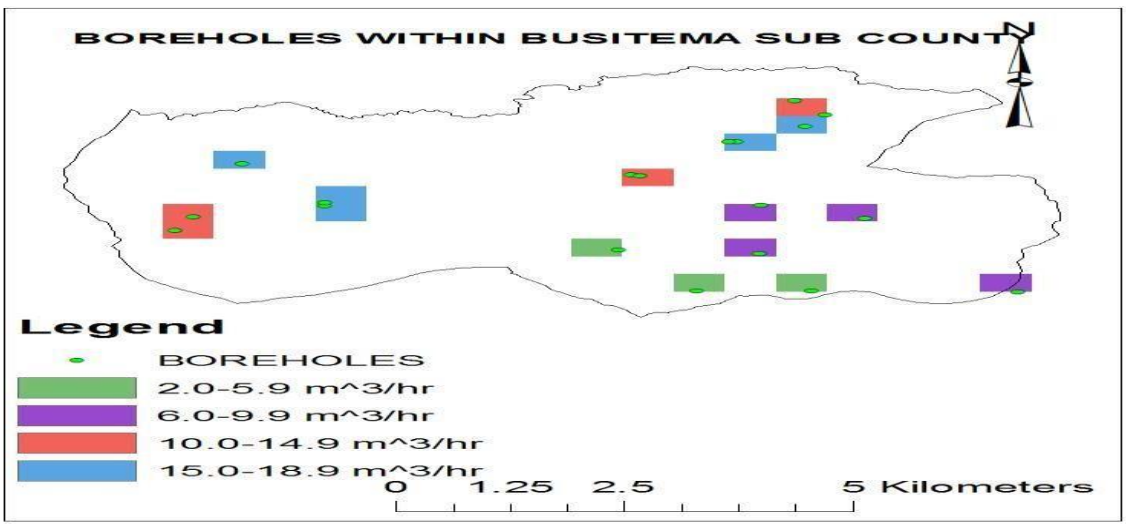


Figure 10 showing the Busitema wells

4.1.2 Quality of ground water

Nine samples were collected from different water sources and number of laboratory tests were carried out. The results were as shown in the table below

	PH	E coli (CFU/ 100mls)	Fecal coliform (CFU/100mls)

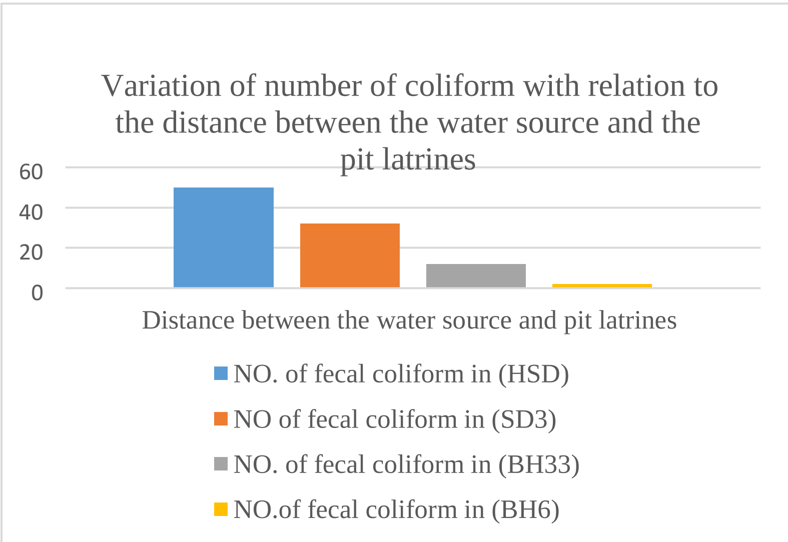
Drinking water national standards	**6.5-8.5**	**0**	**0**
Sample name			
1(BH6)	5.2	0	2
2(BH33)	5.2	0	12
3(BH8)	5.1	0	0
4(BH35)	5.2	0	0
5(SD3)	5.0	0	32
6(BH32)	5.3	0	0
7(BH7)	5.1	0	0
8(HSD)	5.2	0	50
9knb(BH5)	5.2	0	0

Table 5 showing Quality of ground water

4.1.3Effect of distance between the contaminant source and the water source

Fecal coliform (CFU/100mls)	Distance from the pit latrine(m)
2	45
12	40
32	35
50	20

Table 6 showing Effect of distance between the contaminant source and the



4.2 Objective 2: Groundwater contaminant transport modelling

4.2.1 Groundwater abstraction

This was simulated using the Well (WEL) package in MOD Flow supported by Model muse.

This package is designed to simulate wells which withdraw water from the aquifer at a specified rate, Q[m3/s]. A total of 9 wells from the well shape file in ArcGIS were used as Table 4. 3.

No_	Latitudes	Longitude	BH_Name	Elevation	vFecal coliform	Depth(m)	Pumping rate(m3/s)
1	614422	59404	SD3	1153	32	19	1.06E-03
2	614249	59485	BH5	1152	0	54	8.33E-05
3	614156	59722	BH6	1146	2	68	2.69E-04
4	615011	59370	BH7	1156	0	76	1.42E-03
5	614928	59644	BH8	1160	0	65	7.78E-04
6	615010	58413	SD12	1151	50	24	1.12E-03

7	616072	61134	BH32	1122	0	58	1.32E-04
8	615716	61139	BH33	1116	0	34	1.32E-04
9	614625	62009	BH35	1106	0	72	2.00E-06

Table showing the groundwater well where that were sampled

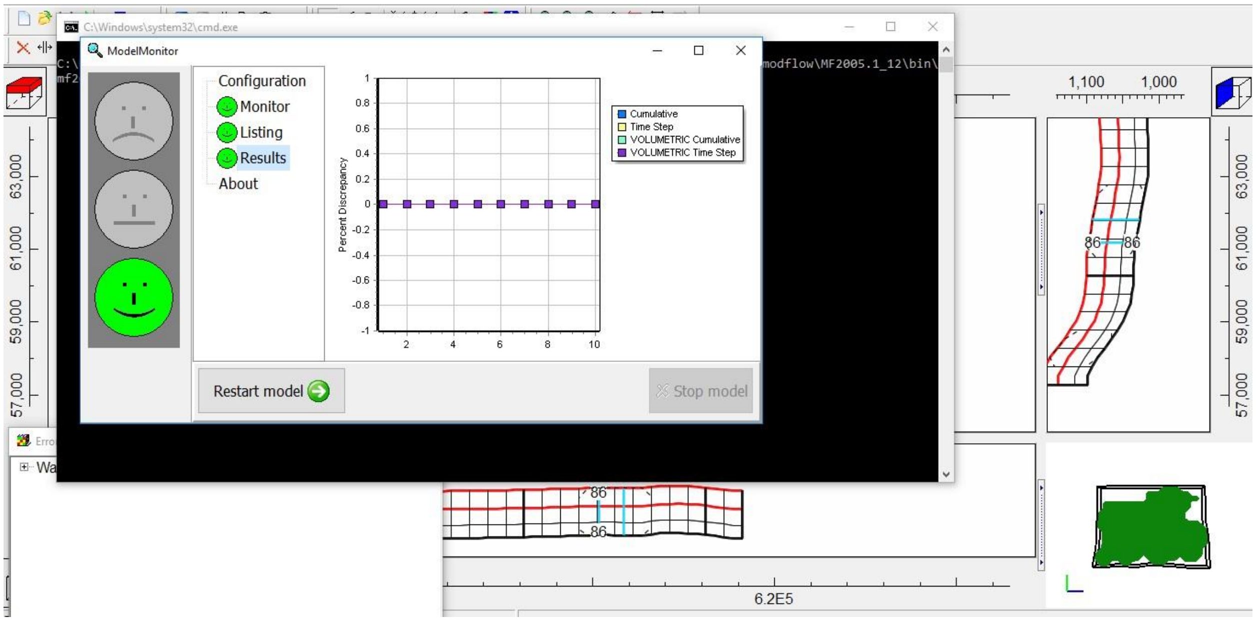


Figure 3 showing model run

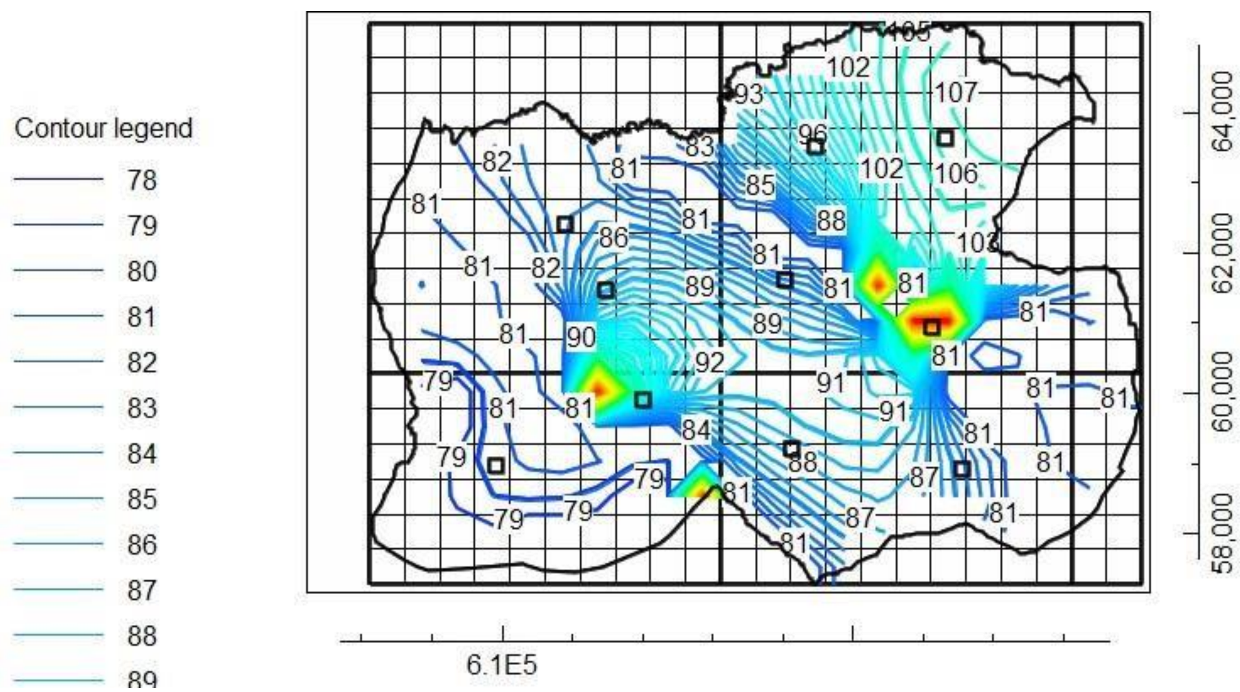


Figure showing groundwater contour grid

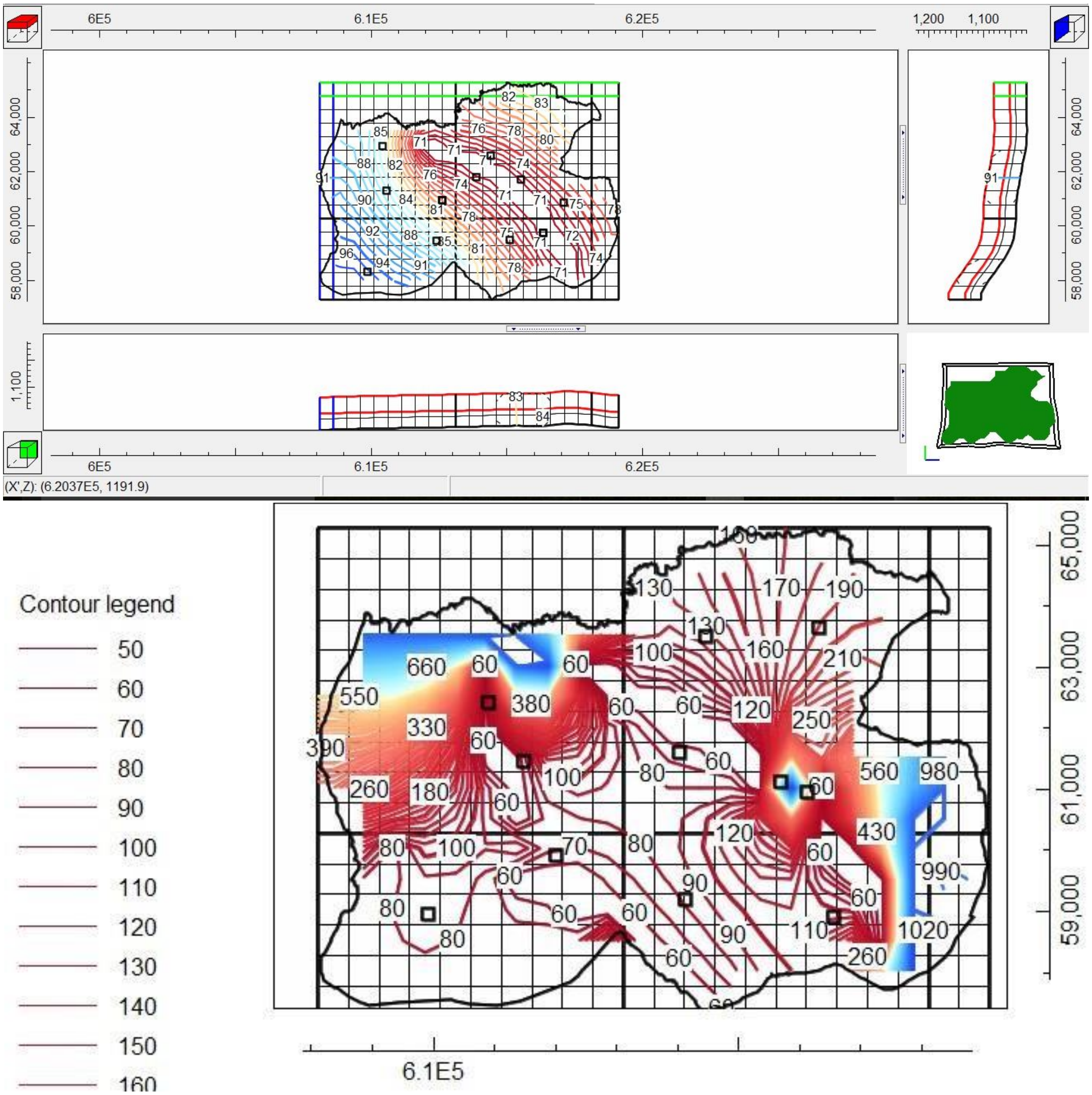
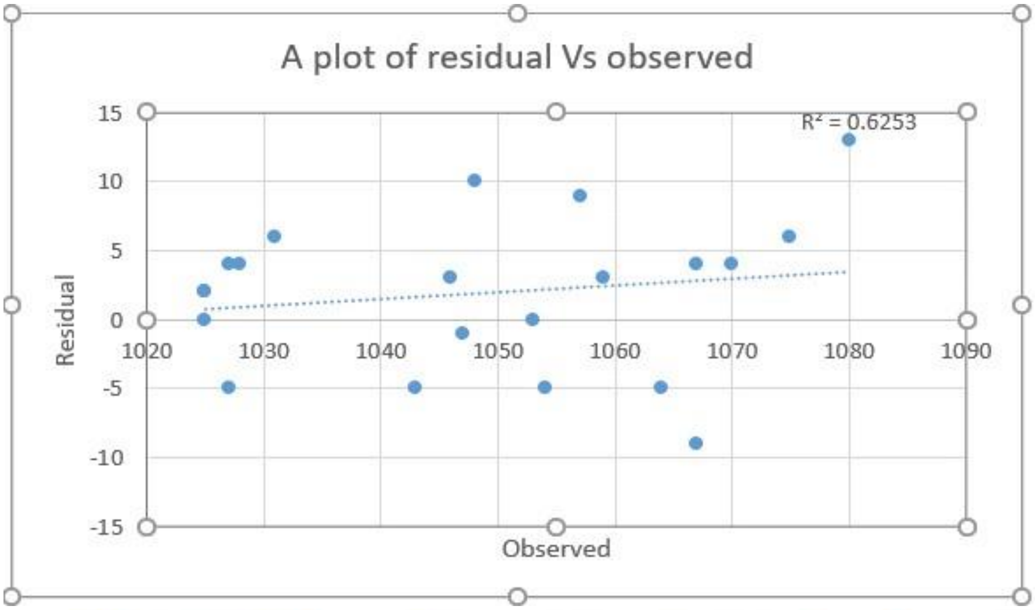


Figure4 showing contaminant contour grid



CUMULATIVE VOLUMES	L**3	RATES FOR THIS TIME STEP	L**3/T
IN:		IN:	
STORAGE =	0.2174	STORAGE =	3.445E-10
CONSTANT HEAD =	0.0000	CONSTANT HEAD =	0.0000
RECHARGE =	264871604.7742	RECHARGE =	0.2366
Wells=	5002510.7599	Wells=	2.134E-02
TOTAL IN =	3162073244.1206	TOTAL IN =	5.0161
OUT:		OUT:	
STORAGE =	9.1328E-02	STORAGE =	1.14270E-10
CONSTANT HEAD =	0.0000	CONSTANT HEAD =	0.0000
RECHARGE =	0.0000	RECHARGE =	0.0000
WELLS=	1247387401.4261	WELLS=	2.1041E-02
TOTAL OUT =	31649080.1436	TOTAL OUT =	3.0257
IN - OUT =	-5242.01	IN - OUT =	-9.17141E-06
PERCENT DISCREPANCY =	-0.00	PERCENT DISCREPANCY =	-0.00

Figure 11showing groundwater budget

```
CUMULATIVE MASS BUDGETS AT END OF TRANSPORT STEP  148, TIME STEP    1, STRESS PERIOD    2
-----------------------------------------------------------------------------------------

                                  IN                          OUT
                           ----------------            ----------------
     CONSTANT CONCENTRATION:    0.000000                   0.000000
              CONSTANT HEAD:    0.000000                   0.000000
                      WELLS:  0.1432503E+08              0.3038645E-03
                     RIVERS:    0.000000                -0.1291619E+08
    HEAD-DEPENDENT BOUNDARY:    0.000000                 0.5579934E-06
                   RECHARGE:    0.000000                   0.000000
         EVAPOTRANSPIRATION:    0.000000                   0.000000
     MASS STOR (FLOW MODEL):  0.2917281E-05             -0.1958949E-03
      MASS STORAGE (SOLUTE):    36532.09                  -1445368.
---------------------------------------------------------------------------
                    [TOTAL]:  0.1436156E+08    g        -0.1436155E+08    g

                                  NET (IN - OUT):    6.000000
                           DISCREPANCY (PERCENT):  0.4177820E-04
```

MODEL OUTPUT

Figure 12 showing contaminant mass balance

After setting up the groundwater model, it was run (Figure 4. 7), the groundwater contour grid was obtained from the model simulation results. This showed that the groundwater flows from high head to low head. Thus flows from upstream to downstream of the region under consideration for most areas.

Using the groundwater flow model as a basis, advection, dispersion and other contaminant transport related packages were incorporated to ascertain the path taken by the contaminant.

The contamination grid contours also show that the areas in the region of constant head depth, receives high recharge which shows that the rate of contamination is low. This is because recharge influence the movement of contaminants by diluting or flushing them out of the system.

After two stress periods and 148time steps, the contaminant was observed to move slowly and would increase in speed with increase in concentration at the source. Since the sampling was done from only 9 water sources, the plume can be seen increasing in a particular small area in the whole catchment. The color of the plume indicates the concentration at a particular place, with highest concentration in red.

The groundwater budget was computed from the groundwater flow model for the entire area using zone budget. Here, recharge is from rainfall is **375,122** m3 /day. Regarding outflows, an amount of 12,266 m3/day leaves the watershed through general head boundary, withdrawals from the wells it is 1818 m3 /day. Thus, the total volume of water entering the watershed is 434,466 m3 /day and leaving the watershed is 434,467 m3 /day. A sample page of MODFLOW output is presented **(Figure 4.12).**The output indicates that there is no storage in the aquifer. This necessitates immediate arrangement for recharge of groundwater by all possible means to save the ground water for future usage.

The contaminant transport mass balance was computed from the groundwater model using the MT3DMS tool in MODFLOW. A sample page of the MT3DMS output is presented. The output has nearly the same concentration as the input implying that there is storage of contaminants in the ground water thus groundwater is not contaminated.

The model was calibrated (**Figure 4. 11)** using trial and error by adjusting the hydraulic conductivity and using the head observation tool MODFLOW that stores both observed and simulated head values. The values were transferred to excel and a graph plotted whose statistics gave an R^2 value of 0.6253. This showed that the observed and computed data were in good-fit with each other since the value of R^2 value is close to1

4.2.2 Model assumptions and limitations

Busitema sub county groundwater model is not a perfect model but a representation of the naturally occurring conditions. Because of this, several assumptions were involved in developing the model while certain limitations persisted.

4.2.2.1 Limitations

1) Limits to accuracy with which groundwater systems can be simulated.
2) Model can’t be used for hypothesis analysis.
3) Models will always be constrained by computational limitations, assumptions and knowledge gaps

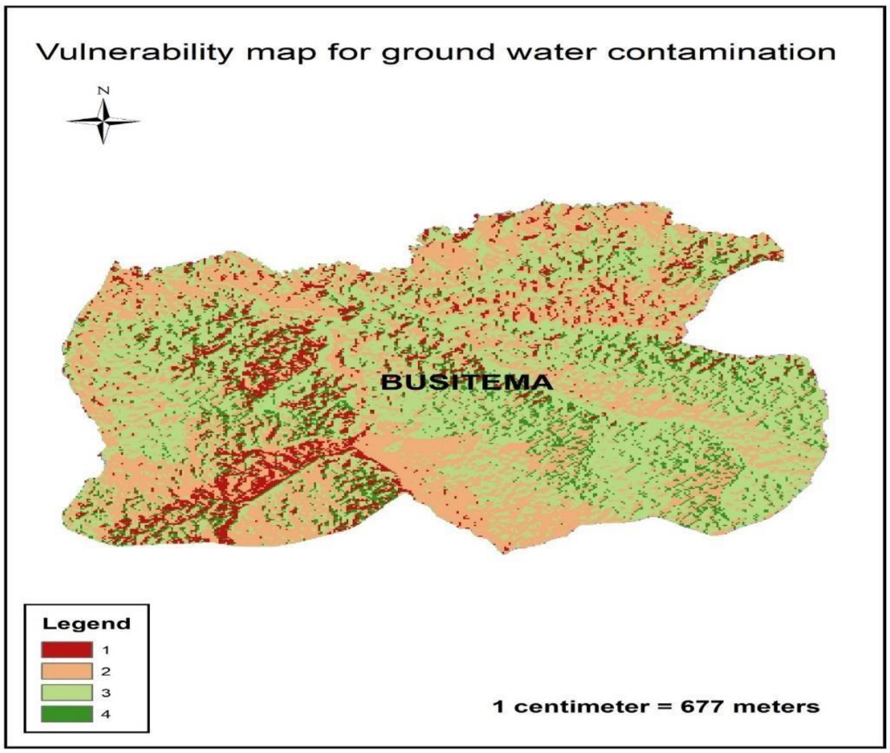
4.2.2.2Assumptions

1) Net recharge in the catchment is not spatially uniform due to heterogeneity in spatial distribution of geology, hydraulic conductivity, total precipitation and slope in the study area.
2) Fractured and weathered zones through which water flows are porous media and obey Darcy’s law when simulating the steady system.

3) For the groundwater flow, a steady state flow was assumed and for the contaminant transport, a steady state and transient state were assumed.
4) The aquifer properties are assumed to be homogeneous and isotropic. Faults are not assigned to any specific region therefore not modelled.
5) No discharge was included in the model as there is no significant discharge from area.
6) To allow interaction of the model with the surrounding environment, general head boundaries were assumed in the north and south of model domain with heads of +53m and +55 m and uniform conductance of 0.012m2/s

4.3 Objective 3

By use of weighted overlay table, a multiple criteria analysis between several raster data was calculated using GIS.



From the map, it shows that elevation as indicated by **1** has a high contribution to vulnerability, followed by land use indicated by **2** followed by flow direction indicated by **3** then finally slope indicated by **4**.

Advantages of DRASTIC method in vulnerability assessment

- ✓ Simplicity and Ease of Use: The DRASTIC method utilizes seven parameters that are relatively easy to measure or obtain from existing data sources.
- ✓ Low Data Requirements: Basic information on groundwater depth, soil type, land use, and aquifer characteristics are usually sufficient to apply the DRASTIC method.
- ✓ Cost-Effectiveness: Since it relies on readily available data and simple calculations
- ✓ Weighted Parameters: This method allow users to assign different levels of importance to each factor based on the specific hydrogeological of the area being assessed.
- ✓ Regional Comparisons: Helps to identify areas that are more susceptible to contamination. This enable better in risk management.
- ✓ Popular and Widely Accepted: The DRASTIC method has been used extensively worldwide, making it one of the most accepted and recognized tools for groundwater vulnerability assessment.
- ✓ Initial Screening Tool: The DRASTIC method is particularly useful as an initial screening tool to identify areas that require further investigation or detailed modeling.

Disadvantages of DRASTIC method ✓

It relies on assumptions.

- ✓ Lack of Temporal Consideration: The DRASTIC method does not account for changes over time, such as variations in land use, climate, or hydrogeological conditions.
- ✓ Subjective Parameter Weighting: The method allows users to assign subjective weights to each parameter based on local knowledge or expert judgment.
- ✓ Lack of Contaminant Pathways.
- ✓ Limited Validity in Different Hydrogeological Settings.
- ✓ Ignores Contaminant Characteristic

4.4 CONCLUSION

Ground water characterization was successfully done. It was found water the water sources which were in the close proximity with the contaminant sources had a high number of fecal coliform which indicated the movement of fecal matter in to the ground water. These places included well at the Harriet hostel, well in the syaule center, etc.

The models were calibrated using several obtained from the tests and found to best fit the observed data with R2 values of 0.86. The model also gave a Nash Sutcliffe Efficiency Coefficient of 0.73, implying that the model was satisfactory.

The magnitude of the vulnerability was determined using vulnerability assessment by use of DRASTIC method and was found out to be to be high in areas that were close proximity to contaminant sources and also in those in which the soil was highly permeability. Ground water susceptibility map were also developed for better estimation of groundwater contaminated aquifer.

4.5 RECOMMENDATION

- It is recommended that further studies are done on effect of surface runoff which is seemed to have a high effect on the constant head.
- It is recommended that when setting up contaminant points such as construction of pit latrines be relatively far away from the water sources.
- It is recommended that further studies be done on the effect of elevation on the flow of contaminants.
- It is recommended that further studied be done on the sources of fecal matter other than pit latrines.
- It is recommended that authorities in policy and decision-making create awareness, and put in place mitigation measures.

4.6 CHALLENGES

Lack of sufficient data for model building.

Change of weather that greatly affected the field work activity.

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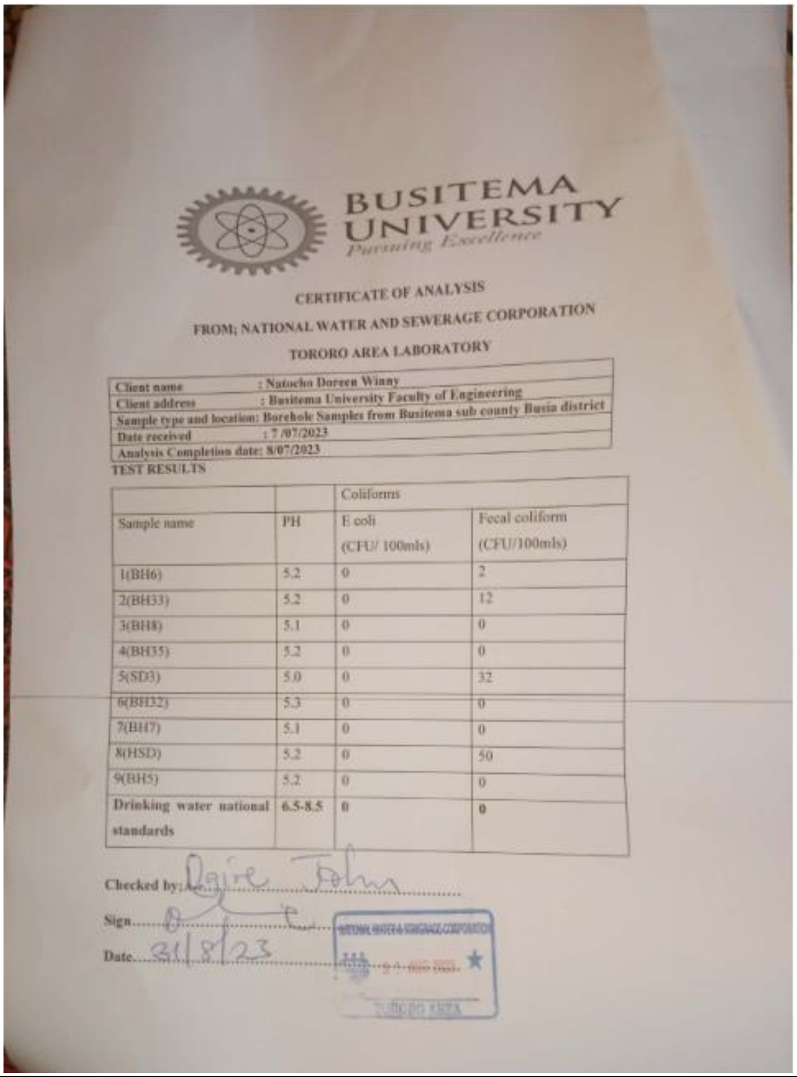
APPENDIX



BUSITEMA UNIVERSITY
Pursuing Excellence

CERTIFICATE OF ANALYSIS

FROM; NATIONAL WATER AND SEWERAGE CORPORATION

TORORO AREA LABORATORY

Client name	: Natocho Doreen Winny
Client address	: Busitema University Faculty of Engineering
Sample type and location:	Borehole Samples from Busitema sub county Busia district
Date received	: 7 /07/2023
Analysis Completion date:	8/07/2023

TEST RESULTS

		Coliforms	
Sample name	PH	E coli (CFU/ 100mls)	Fecal coliform (CFU/100mls)
1(BH6)	5.2	0	2
2(BH33)	5.2	0	12
3(BH8)	5.1	0	0
4(BH35)	5.2	0	0
5(SD3)	5.0	0	32
6(BH32)	5.3	0	0
7(BH7)	5.1	0	0
8(HSD)	5.2	0	50
9(BH5)	5.2	0	0
Drinking water national standards	6.5-8.5	0	0

Checked by:.......................

Sign.......................

Date 31/8/23

	
1.Collection of water samples	**2.Filtration of samples through the filtering membrane**

 **4.Incubation of the samples**	 **3. Placement of filtering membrane on the absorbent pad**.

Figure 13 showing data collection and laboratory analysis