A DISSERTATION

ON

MODELLING OF NITRATE TRANSPORT IN GROUNDWATER USING MODFLOW IN MUKTSAR DISTRICT, PUNJAB, INDIA

SUBMITTED IN THE PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE AWARD OF DEGREE OF

MASTERS OF TECHNOLOGY IN ENVIRONMENTAL ENGINEERING

SUBMITTED BY

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CANDIDATE DECLARATION

I, Akshay Singh Slathia, Roll No. 2K21/ENE/03 student of M. Tech (Environmental Engineering), hereby declare that the project Dissertation titled "**Modelling of Nitrate transport in Groundwater using Modflow In Muktsar District, Punjab, India**" which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**Modelling of Nitrate transport in Groundwater using Modflow In Muktsar District , Punjab India**" which is submitted by Akshay Singh Slathia, Roll No. 2k21/ENE/03, Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision.

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AKSHAY SINGH SLATHIA

SUMMARY

Groundwater is vital to the Indian economy. According to a World Bank research, groundwater contributes 9% of India's GDP. Groundwater has become increasingly important as a source of drinking water and crop irrigation due to its abundance and lower risk of pollution compared to surface water. As a result, the world's dependency on this resource has grown over time.

The source of the NO_3 in groundwater includes industrial effluents and extensive use of fertilizers, and seepage from excreta waste from humans and animals. It can seep into the soil and contaminate groundwater. In India, more than 50% of districts have nitrate levels that exceed permissible limits. This means that the water in these districts is not safe for drinking. Nitrate contamination is a widespread problem in many parts of India. Punjab is one of the states in India that uses an excessive amount of chemical fertilisers, with a per hectare usage of 243 kg/year, the highest of any state in the country.

This study has used groundwater level and nitrate data to simulate the contaminant transport model and groundwater flow model which is applied to unconfined aquifer at a depth of 30 meter below ground level. The data collected from the CGWB and INDIA-WRIS revealed the concentration of nitrate in range of 24mg/l to 480mg/l. This study was conducted at 6 different locations of Muktsar district i.e. Bhaliana, Balocha Khera, Doda, Kuttianwali, Lambi , Muktsar. MODFLOW and MT3DMS is the model used to assess the groundwater flow movement and the contaminant transportation process of nitrate. The results showed an increase in nitrate concentration for Kuttianwali and Bhalaina area at 300 meter away from point source as 66mg/l and 48mg/l respectively after a period of 1100 days. ArcGIS software is used for generation of spatial distribution of nitrate over years and generation of elevation contour maps.

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INTRODUCTION

1.1 GROUNDWATER OVERVIEW

Groundwater is available in abundance as fresh water that seeps into the soil from rainfall by infiltration, melting of snow and ice also percolates into groundwater and is stored in the rock zone as freely available water. Groundwater present below the earth surface has accounted for for nearly 95% of the country's fresh water availability.

Groundwater is majorly present in earths two different zones. The unsaturated zone, which is found just below the earth's surface, contains both water and air in its open gaps, or pores. The saturated zone, which is an area where water fills all of the pores and rock fractures, is underneath the unsaturated zone. Highest point which available in the saturated zone is termed as water table. The water table could be a few feet or hundreds of feet below the surface of the ground. Groundwater extraction is subject to constraints due to the unpredictability of its occurrence, distribution, and quality as well as the energy needed to withdraw it.

Ground water is one of the important and essential component of our life sustaining system. Drinking water, irrigation, and industrial applications all rely on groundwater resources. It is a key natural resource for providing drinking water which is both affordable and safe. Its availability, which makes it an integral component of the hydrological cycle, is dependent on rainfall pattern and recharge of the groundwater from natural sources.

Groundwater present in India’s village areas has emerged as main progressive source of water and a tool for reducing poverty. It is India's most popular source of water for meeting the needs of different user sectors because to its almost universal availability, dependability, and low capital cost. India's economy has grown significantly and ground water has been a major factor in the socioeconomic progress of the country. In India more than 85% of domestic water needs is in village areas, urban area require 50% for the domestic purpose and more than 50% of the water is required for the purpose irrigation, mostly come from sources of the ground water such as wells, pumps etc. Thus ground water tells us about significance of this natural resource from the India’s perspective.

The increased dependency on ground water as a reliable source of water has resulted in its widespread with little concern for aquifer recharging capacities or other environmental factors.

There has been water scarcity in many states of the India due to rising demand for water over the years. Water scarcity in India impacts hundreds of millions of people. The majority of people do not have access to a regular and stable source of water for their daily needs. The problem of water pollution or contamination aggravates the situation. India is on the verge of a freshwater crisis, owing to poor water resource management and environmental deterioration, which has resulted in millions of people without having access to clean and safe water to drink.

Quality of water available in the ground has deteriorated to the point where its use could be harmful. Fluoride, nitrate, arsenic, hardness and the presence of a few toxic metal ions have all been found in the ground water in considerable portions of the Indian states. For decades, groundwater extraction has been on the rise. Since the 1960s, the government's backing for the "green revolution" to maintain food security has shown a significant increase in the requirement of water for agriculture. Result of the rapid electrification in rural areas with the accessibility of new and modern pump technologies, there are more borewells available to satisfy that demand.

1.2 CONTAMINATION OF GROUNDWATER

Contamination of groundwater and its quality has now become a major challenge in recent decades. Pesticides, fertilizers, and other hazardous substances are widely used in industry and manufactured goods, which has increased their harmfulness for flora and fauna. Any impurity or pollutant that might diffuse in ground water will flow with the water and could reach in drinking water source, thus combination of movable ground water with a steady origin of pollution can contaminate large areas of ground water.

The most difficult and challenging environmental issue is water pollution, and nitrate is one of the most widespread contaminant in the groundwater. Increased nitrate concentrations in groundwater are typically caused by dispersed contamination from livestock and agricultural operations. Through seepage and percolation, these agricultural practices contaminate groundwater as well as surface water systems. In addition to contributing to economic and ecological issues, fertilizers have an impact on water quality. The usage of fertilizers has been affected by the introduction of high yield crops and agricultural methods in the preceding century, which has increased the nitrate concentration in groundwater.

Nitrate in excess concentrations in ecosystems can have major environmental problems, such as increase in the nutrients resulting in eutrophication of associated water bodies on the surface, can ultimately result in algae growth and fish mortality will also rise. Many plant species including a majority of food plants require nitrate to grow, but it creates a problem when it enters water where it is not required. This causes a serious environmental concern as well as a health risk.

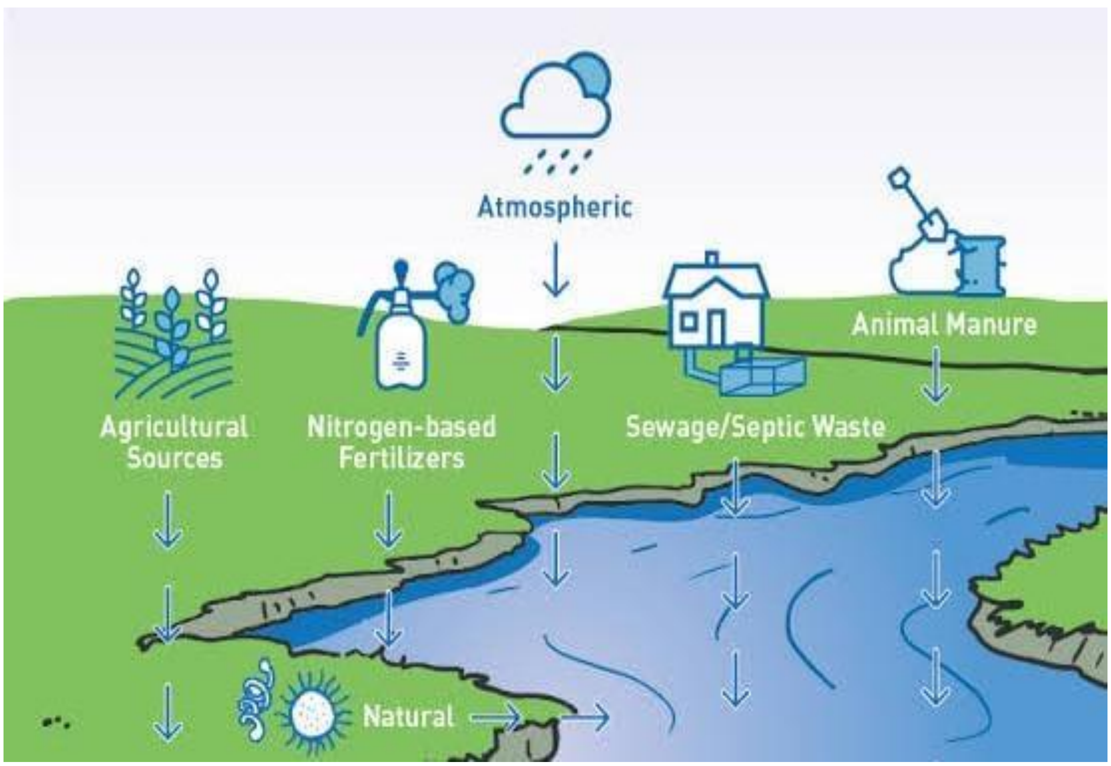


Figure1: Different sources of nitrate contamination

1.3 GROUNWATER MODELING

The groundwater model is a valuable tool in environmental studies. Use of groundwater models is critical in studying ground water flow movement and transportation process of the contaminant along the ground water flow. A wide range of hydro-geologic situations have been investigated using groundwater models. Ground water models have been used for anticipating transit of contaminant in order to know the risk of ground water quality.

To depict groundwater flow and transport processes, groundwater models include a variety of equations based on simplifying presumption. It assumes flow direction, aquifer shape, heterogeneity in sediments, pollutant transport pathways, and chemical concentrations.

Steps involved in developing a groundwater transport model is to create a ground water model that appropriately reflects the ground water movement. Second stage involves the combination of ground water flow model with the contaminant transportation.

1.4 NITRATE CONTAMINATION IN GROUNDWATER

In most cases, nitrogen sources are found in soil or upper subsurface zones, where wastes are buried which are nitrogen rich, are where nitrate from ground water originates. The primary source of nitrate entering the ground water system comes from fertilizer that has been applied to the soil surface. In other situations, organic nitrogen is converted to nitrate. Processes in ammonification and nitrification usually take place in soil zone, above the water table, where there is an abundance of organic matter and oxygen.

1.4.1 Sources of nitrate pollution:

1. The overall nitrate concentration of natural streams is governed by various environmental related factors, including the atmosphere, lithological features, anthropogenic activities, nitrogen fixation. Contaminants like chloride, nitrate have been found to flow significantly more quickly in soil containing sand with water retention capacity very less and clayey soil having higher permeability.

Since nitrate is extremely soluble, it easily travels through the soil profile with water. Nitrate leaches down in plant's root in locations with excessive rainfall or irrigation, and thus reach the groundwater eventually.

2. The usage of fertilizer in agriculture areas has expanded dramatically in the recent decades to meet rapidly rising population's food and living needs. Nitrate present in fertilizers is a major source of contamination of groundwater.

3. Water present at the surface, groundwater and in wells can all become contaminated by nitrate in ground water, which can come from natural and sources such disposal systems and.

Nitrate present in excess in drinking water causes human health issues such as methemoglobinemia found in new born babies and cancer in adults.

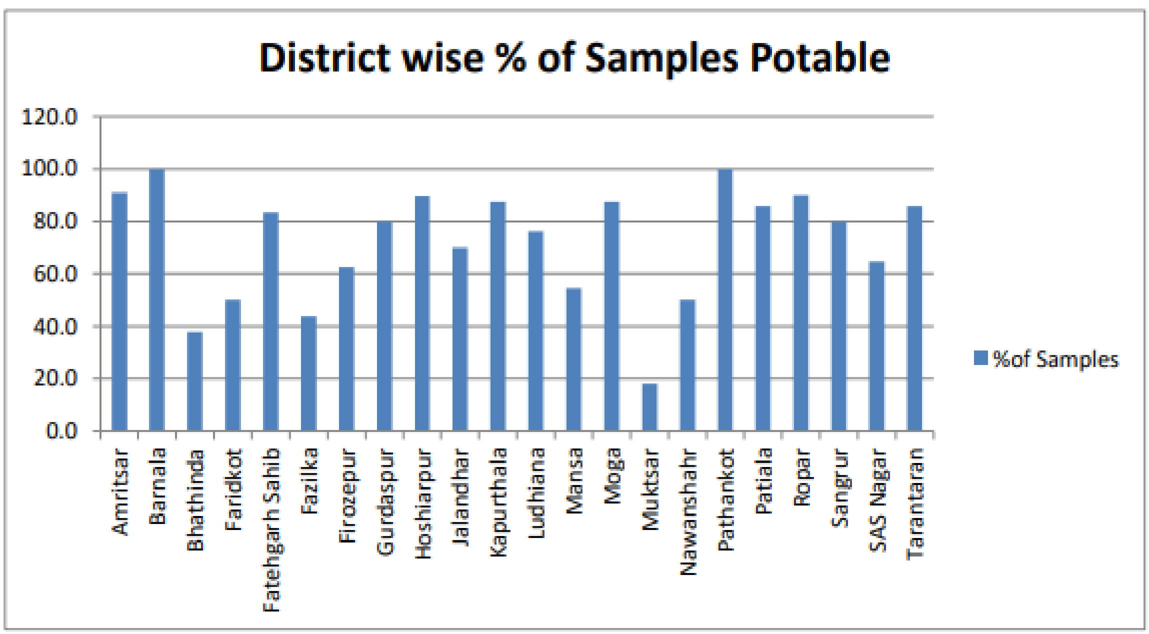


Figure3: Percentage Of Potable Sample In Punjab

Source: CGWB YEAR BOOK 2020

Southern districts of Punjab like Bhatinda, Faridkot, Fazilka, Mansa, Muktsar have poor drinking water quality as percentage of total water samples tested that are suitable for drinking purpose are less than 50%. Muktsar district have only 20% of the samples that are useful for drinking purpose and remaining sample doesn't meet the prescribed standards.

S.No.	% wise classification	Name of the districts	Remarks
1.	>80	Amritsar, Barnala, Firozpur, Kapurthala, Pathankot, Patiala, TaranTaran	Classification based on EC, Cl, NO_3 & F
2.	50-80	Fatehgarh Sahib, Gurdaspur, Hoshiarpur, Jalandhar, Ludhiana, Moga, Pathankot, Ropar, Sangrur, SAS Nagar	Classification based on EC, Cl, NO_3 & F
3.	<50	Bhatinda, Faridkot, Fazilka, Mansa, Muktsar, Nawanshahar	Classification based on EC, Cl, NO_3 & F

Table 1: Water Quality of Punjab Districts

The major characteristics that are generally examined for evaluating quality of ground water for drinking purpose are **salinity, chloride, fluoride, and nitrate.**

Ground water of **unsuitable** quality is found in the **southern** and **southwestern** regions, whilst ground water of suitable quality is found in the northern and central regions.

1.5 OBJECTIVES

- Simulation of steady groundwater flow and transient groundwater contaminant flow using the US Geological Survey three-dimensional finite difference code , and the three-dimensional advective-dispersive transport code. **(MODFLOW** and **MT3DMS)**

- To use MODFLOW to investigate the changes in hydraulic heads in the groundwater of 6 distinct locations in the Muktsar area of Punjab.

- To examine the movement and distribution of nitrate in the groundwater at 6 different sites throughout the Muktsar area of Punjab using MT3D.

CHAPTER 2

LITERATURE REVIEW

S.K Singh et. al. 2012[1] investigated the sustainable groundwater resources in Gurgaon district, Haryana, India by utilizing the "processing MODFLOW for Windows (PMWIN)" model. The key contributions of this study encompass the following: 1. Furnishing an appraisal of the groundwater recharge and pumping trends of Gurgaon district in the past, present, and future. 2. Utilizing the Modflow model to spatially depict data and replicate saturated flow in three dimensions. 3. Demonstrating the wide applicability, extensive testing, and verification of the versatile and open structure of the MODFLOW model. 4. Accentuating the crucial significance of adequate assessments of groundwater resources to manage them optimally. 5. Displaying the implementation of PMWIN in the analysis of sustainable groundwater resources in Gurgaon district, Haryana, India.

S.K. Singh et. al. 2015[2] aims to locate areas in Punjab, India affected by fluoride, iron, and nitrate, and provide information on their sources and concentrations. They suggest remedial measures through legislation and mass awareness to control activities like unplanned deforestation, overgrazing, and uncontrolled human activities. They too talk about groundwater pollution triggered by agricultural expansion, industrialization, and urbanization, and provide data on major canals and rivers in Punjab. Their study includes identifying affected areas, providing information on contaminants, and recommending measures to control groundwater contamination.

S.K Singh et al. 2016[3] conducted an analysis on the groundwater flow and transport of arsenic in the English Bazar block of Malda district in West Bengal. The study aimed to simulate water and arsenic movement using a 3D solute transport model, examine the variation of hydraulic heads in the groundwater of English Bazar Block using MODFLOW, and investigate the distribution and movement of arsenic in the groundwater of English Bazar Block using MT3D. The objectives were met by simulating steady and transient groundwater flow using the US Geological Survey three-dimensional finite difference code, MODFLOW, and the three-dimensional advective-dispersive transport code, MT3D. The study also discusses the model calibration and validation runs to achieve an agreement between the computed and observed static water table.

Md. Ali. Akbar et. al. 2019[4] The concentration of nitrate in dug wells in a rural area of Bangladesh was evaluated in this study. The health risk of consuming water from these wells with high nitrate levels was also determined. This research is the first to assess nitrate concentration in dug wells in rural Bangladesh. The results are anticipated to aid in improving drinking water supply in rural areas of Bangladesh.

S.K. Singh et. al. 2022[5] collected samples of groundwater from North-West Delhi, India, which were subsequently subjected to an analysis of their physicochemical parameters, major ion chemistry and contaminant sources. The hydro-chemical facies were ascertained by means of multivariate analysis, whilst the potential health risks posed by nitrate and fluoride were calculated for males, females and children. The total hazard index was then established as the sum of the hazard quotients derived from oral and dermal exposure to nitrate and fluoride. Furthermore, a water quality indicator was utilized to evaluate the groundwater's appropriateness for both drinking and watering uses.

Shiva R et. al. 2022[6] investigated changes in groundwater resources in Hashtgerd aquifer, Iran. The effects of management schemes based on the national plan were evaluated using MODFLOW and MT3DMS models. The average storage deficit and water quality decrease were identified. Proposed management schemes include blocking unlicensed agricultural wells and modifying licenses for licensed agricultural wells. Artificial recharge of the aquifer with treated wastewater was found to reduce pollutants and improve water quality, but had no effect on groundwater level. They provides insights for decision-makers to protect and restore groundwater resources.

Chowdhury et. al. 2023[7] to model groundwater flow and contaminant migration in Rajshahi City. The study used MODFLOW and MT3DMS codes to simulate the travel distance of five selected contaminants from a landfill site over 1 to 50 years. Results showed that migration distance of contaminants increases over time and follows a logarithmic trend. Chromium and lead were found to be the primary contaminants polluting groundwater in the future. This study provides a tool for monitoring groundwater contaminant transport for a specific location and contributes to the field of groundwater pollution assessment and management.

S.K Singh et. al 2023[8] conducts a study of groundwater quality in Ludhiana district of Punjab, India. They collect water samples from 152 locations and analyze 18 parameters to calculate the drinking water quality index. The study uses interpolation maps to depict spatial variability. The paper suggests that both carbonate weathering and silicate weathering significantly affect groundwater chemistry, with carbonate weathering having a slight dominance. The study concludes that groundwater in the study area is suitable for drinking in most regions, with exceptions. The paper helps prevent further contamination and sustain the resource for the future.

Krishan et al., 2015[9] conducted a study on groundwater quality by analysing that the fluoride affects 11 districts in Punjab, iron affects 9 districts, and nitrate affects 17 districts. Nitrate is the most intense and extensive of the three contaminants. Because it is tied to human actions and can be controlled by taking appropriate steps. In order to make the water safe for drinking and irrigation, fluoride, iron, and nitrate-impacted locations in Punjab have been identified in this study.

Craner et al. 2006[10] has used MODFLOW to run a steady-state model to investigate groundwater flow direction in Southern Willamette, Oregon, USA. According to the study, it could take up to ten years in some places to notice a measurable drop in groundwater nitrate.

Almasri and Kaluarachchi et al. 2007[11] has also developed a dynamic model for soil nitrogen for assessing the movement of nitrate in ground water. These calculations were used to create a ground water nitrate and transportation model.. The framework considers both single sources and multiple sources of nitrogen across different land use zones. The method was utilised in the heavy dairy business and in areas with a high concentration of berry plantings. To assess the overall effects of present land use patterns and the effectiveness of recommended mitigation strategies on the contamination of nitrates in the artesian basin, simulations were run using the created framework..

Bedient et al, 1994[12] has developed groundwater models that can be used as analytical and statistical instruments to forecast potential circumstances or the influence of a proposed measure on already existing groundwater regime conditions. They can also be used as general or preliminary assessment instruments in regulatory mode to generate management rules and regulations.

El Fakharany et al. 201313] employed The MT3D and Visual MODFLOW models were used as a tool to forecast future changes in the amount and quality of groundwater in the Nile Delta aquifer's southern section. MT3D models and the visual MODFLOW and explored three pumping scenarios with varying abstraction rates from 2000 to 2030. MT3D was used to study the mass transfer of total dissolved solids, SO4, Na, Cl, Fe, Mn, Al, and NO3.

Gurunadha Rao and Gupta et al. 2000[14] has discussed the sewage discharge from the Duff-nala stream of Shahibaug, and another discharge from hutments south of French well by studying the ground water flow and mass transport models using Visual MODFLOW software and groundwater velocities using MODPATH programme porosity values under two different scenarios. The French well's pollutant movement from sources was calculated using the Mass Transport Model (MT3D). The results of the model supported the migration of pollutants in that direction.

Surinaidu et al.2014[15] MODFLOW 2005 was used to develop the most effective groundwater withdrawal methods for mine pits in order to ensure safe mining. The Srirampur coal mines beneath the surface are located in Andhra Pradesh's Adilabad district.

Groundwater Properties

The vertical and horizontal dispersion of groundwater are its defining characteristics. Groundwater is divided vertically into two primary zones: saturated and unsaturated zone. The water table typically acts as a barrier between these two areas. The water's horizontal distribution below the surface has a number of deciding factors that are traits of both groundwater and the porous media. The rate and direction of groundwater flow are determined by these variables

Porosity

The proportion of volume of voids to the total soil volume is known as porosity.

P = Vp / Vm

(Where P = porosity of the medium,

Vp = volume of void

Vm = the total volume of the soil

The porosity of the saturated zone, which occurs under the water table is a direct measure of the amount of water stored in the soil zone per unit of volume. Porosity is measured between 0 and 1, with solid granite requiring less than 0.01 and peat and clay requiring more than 0.5. Most aquifer systems have an average of 0.25 to 0.35.

Hydraulic Conductivity, Transmissivity

A characteristic of soil called hydraulic conductivity, K [$L.T^{-1}$], describes how easily water may pass through pore spaces. It is determined by the permeability of the material as well as the saturation level.

The amount of water an aquifer can transfer horizontally is measured by its transmissivity, or T [$L^2.T^{-1}$]

Storage Coefficient

The storage coefficient S is the quantity of water that an aquifer releases or stores per unit surface area per change in piezometric head. S values for a limited aquifer range from 0.00005 to 0.005, demonstrating that significant pressure changes result in minute changes in storage volume. The storage coefficient of an unconfined aquifer typically ranges from 0.07 to 0.25.

Transport Processes Of Contaminant

Transport mechanisms are the systems that control how a contaminant moves through the aquifer. Advection, Diffusion, and Dispersion are the three main mechanisms controlling solute transport.

Advection

Advection is the term used to describe the movement of a solute along with groundwater flow. The contaminant concentration that is being transported depends on the amount of groundwater flowing and the concentration of the dissolved contamination in the water. For a one-dimensional flow normal to a cross-sectional area of porous material, the amount of groundwater is equal to the average linear velocity times the effective porosity.

Diffusion

Molecular diffusion is the process by which a solute in water flows from a location of higher concentration to a region of lower concentration. Diffusion happens because of a concentration gradient even when a fluid is not moving, which causes spreading and random motion. The first law of Fick, which applies to the crowd, is represented as follows in one dimension:

$F = -Dd\ \{dC\ /dx\}$

F = per unit area mass flx $[M.T^{-1}\ .L\text{-}^{2}]$

Dd = coefficient of diffusion

C = solute concentration

dC / dx = concentration gradient

Dispersion

Dispersion is the process by which a solute is transported as a result of minute variations in groundwater velocity as it moves across heterogeneous porous media. When groundwater solutes come into contact with water that doesn't contain a solute, mixing takes place throughout the flow channel, which dilutes the solute at the leading edge of flow.

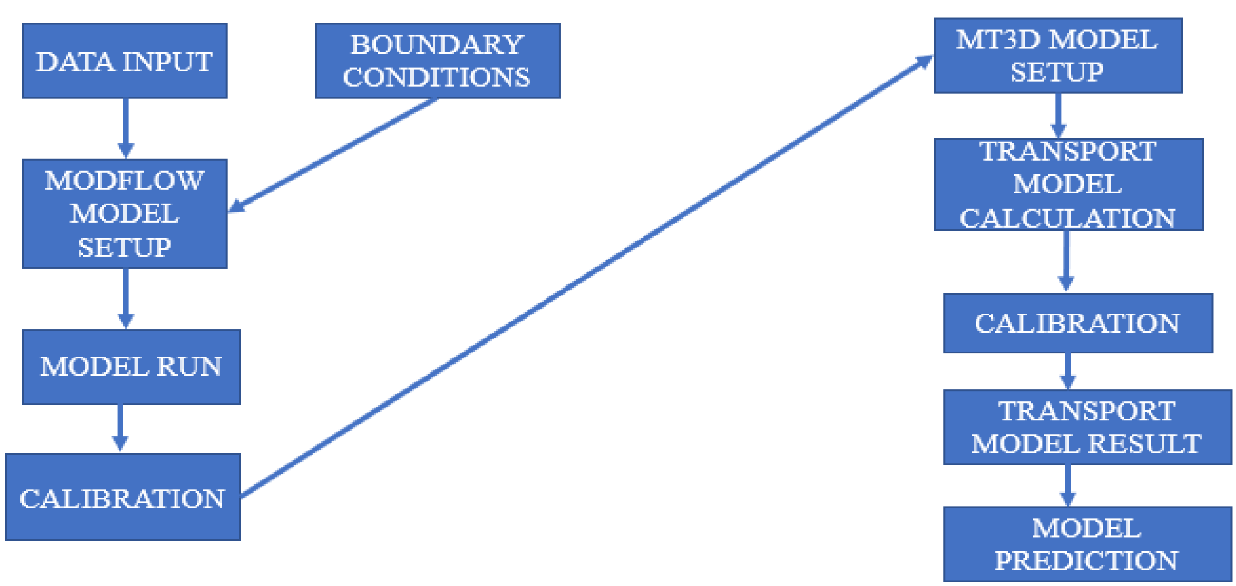
CHAPTER 3

METHODOLOGY

The groundwater model is a valuable tool in environmental studies. Use of ground water models is critical for studying ground water flow and transmission of contaminant. A wide range of hydro-geologic situations have been investigated using groundwater models. Recently, ground water models have been used in forecast of transportation of pollutant in earth in order to assess the risk of groundwater quality.

Groundwater models use mathematical equations to describe groundwater flow and transport mechanisms based on simplified assumptions. These assumptions often include the direction of flow or anisotropy of sediments, aquifer geometry, aquifer heterogeneity or bedrock, pollutant transport pathways, and chemical reactions.

Based on simplified assumptions, groundwater models use different mathematical equations to describe the flow and transport mechanisms of groundwater. These presumptions frequently involve the flow direction or sediment anisotropy, geometry of the aquifer, heterogeneity of aquifer, pollutant transport pathways, and chemical processes.



Different parameters like porosity, hydraulic conductivity, transmissivity, storage coefficient are used in the MODFLOW and different boundary conditions such as head available at both the ends are used to setup the MODFLOW .

Once the model is ready, it is run for studying the steady state groundwater flow movement in the area. Output from the model is head distribution and drawdown which is used to study the groundwater flow movement.

Once the model is calibrated, the contaminant transportation process in the groundwater can be done with the help MT3DMS. Various packages such as advection, dispersion, diffusion, sink and source package is applied to the point source(i.e. wells) to study the contaminant transportation in the area.

3.1 MODELING OF GROUNDWATER CONTAMINATION

Groundwater modelling has recently became an important component of numerous extraction of groundwater, protection, and restoration projects. Models play an increasingly important part in highly quantitative applications as computer technology and software advance and become inexpensive.

Environmental studies are growing in popularity. It is critical to understand the constraints of any groundwater model before it can be properly interpreted and used. Aside from technological constraints such as calculation accuracy the following is reliable for any model:

Numerous presumptions about the actual natural system being simulated are the foundation of this model. The model's distribution of the hydrologic and hydro-geologic parameters is always only an approximation; it is never entirely accurate. The theoretical differential equations are replaced by theoretical systems of algebraic equations that explain groundwater flow.

3.2 GROUNDWATER MODELS USE

Several uses for groundwater models include:

1. Predictive tools: Here, the models are used to forecast either future conditions or the effects of a planned action on the subsurface conditions that already exist. The vast majority of models employed in hydro-geologic practice are predictive models.

2. Research tools: Models are employed in context to better understand system processes and its dynamics

3. Screening tools: The models are used in this situation to develop management concepts and practices. These models frequently take uncertainty in aquifer parameters into consideration.

3.3 GROUNDWATER MODEL DEVELOPMENT

The following steps can be used to create a groundwater flow model:

1. Establish a conceptual model based on the biological, chemical, and physical processes that will govern the system's behaviour.

2. Transform the above model into a mathematical model, which consists of a number of partial differential equations and associated boundary conditions.

3. The answer is an analytical model if the mathematical model can be solved analytically. Only simple geometry, homogeneous aquifers, and basic boundary conditions are required for this to be possible.

4. A numerical model is the result of solving the mathematical model using numerical methods.

5. The computer model is the numerical model that has been implemented by a computer programme.

3.4 ERRORS

Mainly there are two types of error,

3.4.1 Computation Error

Such types of mistakes occur as a result of numerical approximation approaches employed in solving the governing equations. They are calculated either using the mass conservation principle or the continuity equation.

3.4.2 Calibration Error

Such form of error occurs as a result of model assumptions and parameter estimation limits. These mistakes can be evaluated by comparing the anticipated values of the model to the observed values.

3.5 MODELLING ADVANTAGE AND DISADVANTAGE

The primary drawback of a model is that it demands a large amount of data and is too expensive to construct and operate. In addition, predictions are not always correct

However, for others, the model is a godsend because it performs complex analysis and produces logical outcomes. Also, these types of models make the best use of available data and serve as key for analyzing and evaluating the consequences of proposed actions at the field scale.

3.6 GROUNDWATER FLOW MODELS

MODFLOW, a three-dimensional model created by the United States Geological Survey, is the most extensively used numerical groundwater flow model (McDonald and Harbaugh, 1988).

For the saturated zone, it adopts a block-centered finite difference approach. MODFLOW's advantages include many data preparation characteristics, simple transmission of information in traditional format, huge global expertise, ongoing enhancements, code availability, and at an affordable price. Because surface runoff and unsaturated flow are not included, MODFLOW cannot be employed in transitory scenarios where the flux at the groundwater table depends on the projected head and its function is unknown in advance of time.

3.6.1 MODFLOW

(Ground-water flow model in three dimensions using finite differences)

The USGS Modular Three-Dimensional Ground-Water Flow Model is known as MODFLOW. MODFLOW has become the world's standard ground-water flow model due to its capacity to model a wide range of systems, extensive freely available documentation, and rigorous USGS evaluations by peers. MODFLOW is used to simulate water delivery, containment removal, and mining dewatering systems.

MODFLOW is the recognized standard model when properly implemented. A main programme and a number of modules—highly independent subroutines—make up MODFLOW's modular structure. Packages are used to group the modules. Each package focuses on a particular aspect of the hydrologic system that needs to be modelled, such as flow into or out of drains, or on a particular approach to solving the linear equations that describe the flow system.

A block centered finite-difference method is used in MODFLOW to simulate ground-water flow within the aquifer. Layers can be represented as either contained or unconfined or as both at once.

3.6.2 MT3D

(A Modular Three-Dimensional Solute Transport Model)

MT3D is a complete three-dimensional numerical model for modelling solute transport in complex hydrogeologic situations. The modular design of MT3D allows for standalone or collaborative simulation of transport processes. MT3D is capable of simulating advection in complex steady-state and transient flow fields, anisotropic dispersion, first-order decay and production reactions, and linear and nonlinear sorption.

For modelling solute transport in challenging hydrogeologic conditions, MT3D is a comprehensive three-dimensional numerical model. MT3D's modular architecture enables solitary or group simulations of transport operations. Anisotropic dispersion, first-order decay and production reactions, linear and nonlinear sorption, and complicated steady-state and transient flow fields can all be accurately simulated by MT3D.

An addition to the MT3D is the MT3DMS. Multi-Species structure for adding-on reaction packages is known as MS.

The MT3DMS transport solution strategies include higher order finite-volume methods, element tracking-based Eulerian-Lagrangian techniques and the fundamental finite difference approach.

3.6 STUDY AREA

My study area is Muktsar District which is located southwestern area of Punjab, between latitudes $29^0$54' 20" and 30^0 40' 20" and longitudes 74^0 15' and 74^0 19'. According to the 2011 census, the entire area has a total population of 9,02,702 individuals, with a mean density of populations of 348 people per square kilometre. The district has been divided across three tehsils, two sub-tehsils, and four development blocks for administrative purposes, namely Kotbhai, Lambi, Malout, and Muktsar.

Prevalence of nitrate in groundwater has become major concern because of their potential health impacts. There have been numerous reports of high quantities of nitrate in rural areas of southwest districts Punjab.. With rapid increase in population , agricultural practices and industrialization has cause many problems in state of Punjab.

The district borders Faridkot district in the north and north east, and Ferozpur district in the north west and east. Bathinda district of Punjab borders it on the east. On the south are the districts of Rajasthan's Hanumangarh and Haryana's Sirsa.

Muktsar is famous for its wheat and paddy farming. Except for some blocks and to a lesser extent shallow boreholes along the canals, the district's ground water quality is unfit for drinking. Due to easy access through tube wells, which serve as the primary source of irrigation, ground water is regularly pumped for irrigation reasons. The region is covered by an unconsolidated deposit made up of sand, silt, clay, and other materials.

Unconfined aquifer is around 30 m (bgl), there is an extensive, somewhat thick unconfined to confined aquifer. With the exception of a few small places, the district's ground water is majorly saline at all levels. The depth of a tube well is typically between 25 and 55 m.(bgl). In the district, there are 12184 tube wells that are powered by electricity and 17136 by diesel.

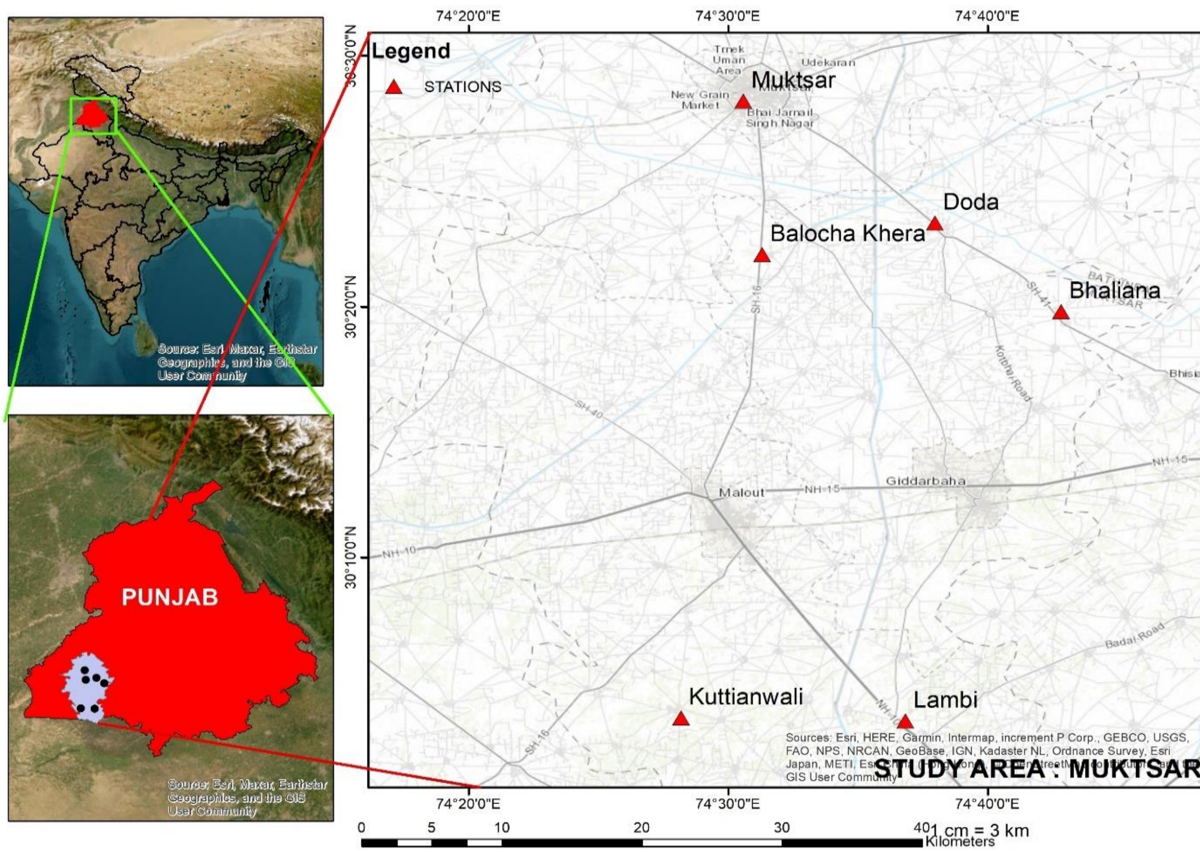


Figure4: Study Area Muktsar

Above figure shows the 6 different locations of the study area namely Muktsar , Balocha Khera Doda, Bhaliana, Kuttianwali, Lambi which are plotted using ARCGIS. The shapefiles of the Indian districts were plotted by importing them from Survey Of India to ARCMAP and then using them to plot outline of Punjab and Muktsar district.

Coordinates of all the 6 locations were located into google earth and then were imported as shapefile into to ARCGIS to map all the locations of study area.

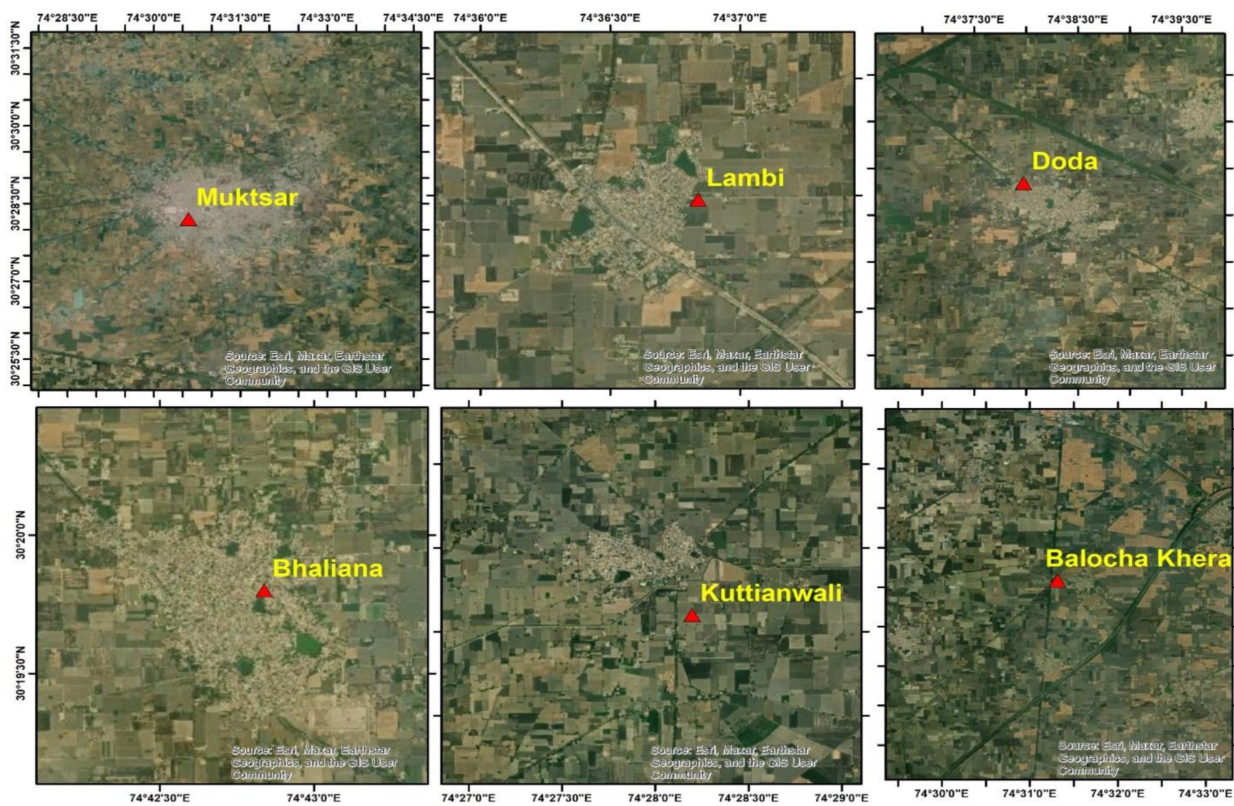
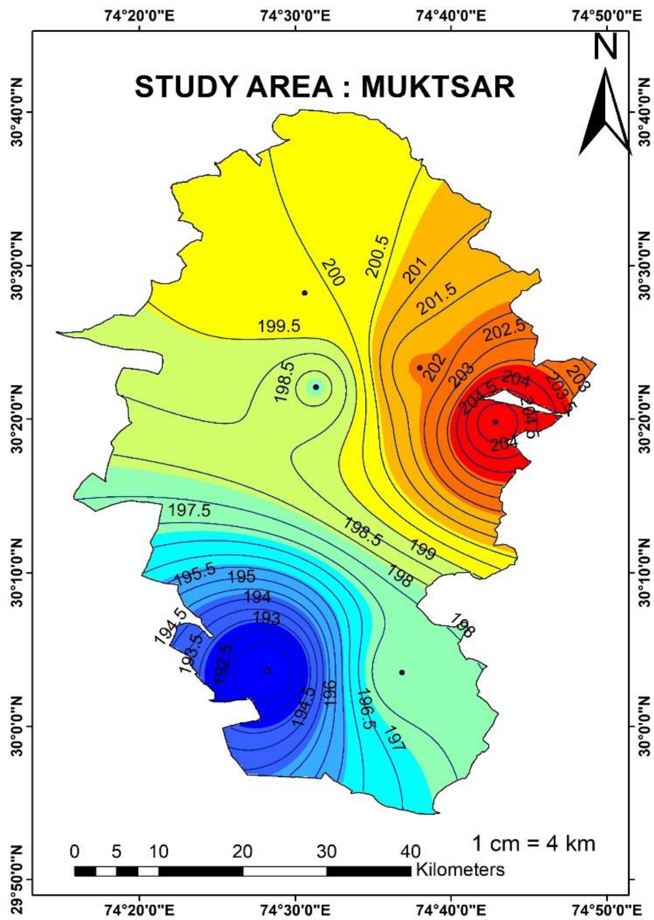


Figure5: Study Area Mapping In ARCGIS

I have chosen the study area as Muktsar because major component that are generally used in evaluating the ground water suitability for potable water is salinity present in the water, chloride , fluoride and nitrate concentration.

Ground water of unsuitable quality is found in the southern and southwestern regions, whilst ground water of suitable quality is found in the northern and central regions.

The nitrate concentration in all the locations is exceeding the BIS and WHO standards that are 45mg/l and 50mg/l. Nitrate concentration in Bhaliana , Doda and Kuttianwali location are above 400mg/l whereas in Muktsar and and Lambi the nitrate concentration is 78mg/l and 66mg/l respectively. It shows that groundwater present is highly contaminated and is unfit for drinking purposes as it can cause gastric cancer, many health-related problems in infants and in pregnant womens.



STATION	ELEVATION (m)
Balocha Khera	198.32
Bhaliana	204.8
Muktsar	200
Lambi	197.8
Doda	201.88
Kuttianwali	192

Table2: Study Area Elevation

Figure 6: Contour Mapping of Muktsar District

The elevation profile is needed to calculate the head available at the wells. The elevation profile shows that Bhaliana region is having an elevation of 204.8m above mean sea level whereas at Kuttianwali the elevation is 192m above mean sea level.

Ground water also flows from higher elevation to lower elevation depending on the groundwater table and thus by knowing the groundwater water table elevation below the ground surface we can calculate head distribution at all the locations.

Nitrate <45mg/l	Nitrate>45mg/l
Amritsar	Bhatinda
Barnala	Faridkot
Bhatinda	Firozpur
Gurdaspur	Fatehgarh Sahib
Hoshiarpur	Fazilka
Jalandhar	Muktsar
Kapurthala	Mansa
Ludhiana	SAS Nagar
Patiala	Sangrur
Ropar	
Tarantran	
Pathankot	

Table 3: District Wise Nitrate distribution in Punjab State

Station	Latitude	Longitude	Nitrate
Balocha Khera	30.368	74.522	200
Bhaliana	30.33	74.714	460
Muktsar	30.47	74.51	78
Lambi	30.058	74.614	66
Doda	30.389	74.633	420
Kuttianwali	30.06	74.47	482

Table4: Nitrate Distribution In Muktsar District

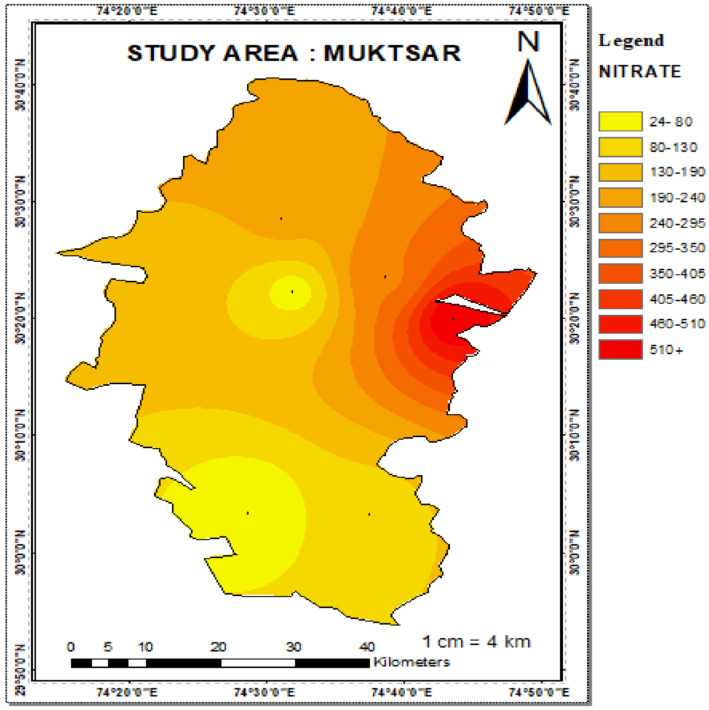


Figure7 : Distribution of Nitrate (mg/l) in 2012

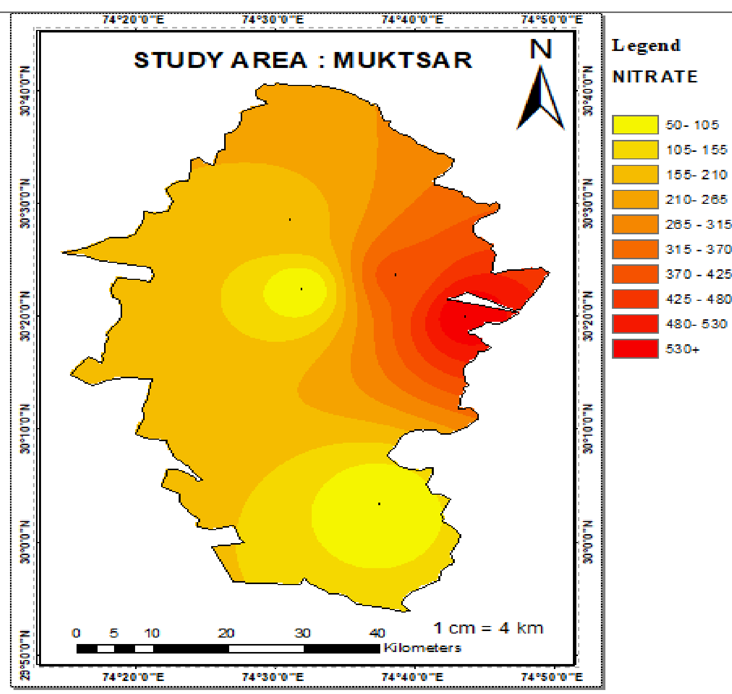


Figure8: Distribution of Nitrate (mg/l) in 2013

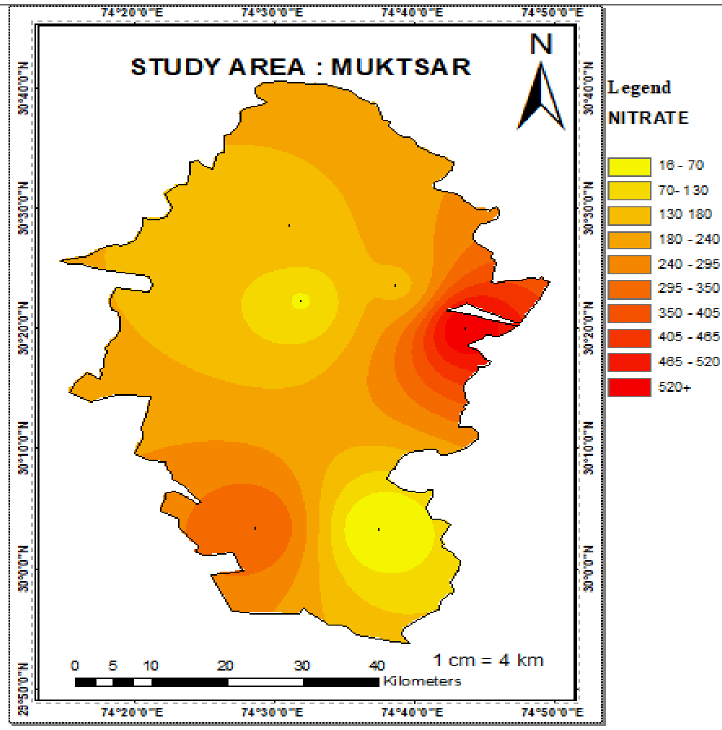


Figure9: Distribution of Nitrate (mg/l) in 2014

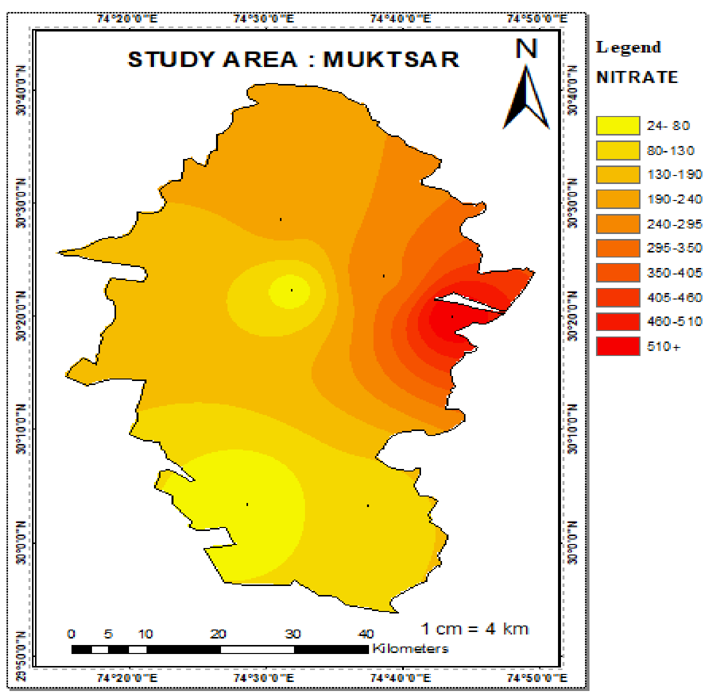


Figure10: Distribution of Nitrate (mg/l) in 2015

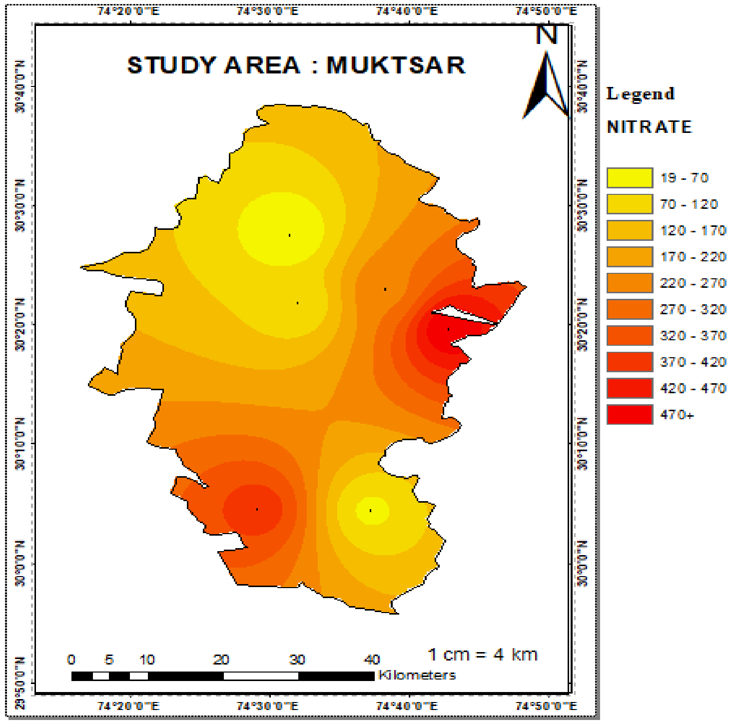


Figure11: Distribution of Nitrate (mg/l) in 2016

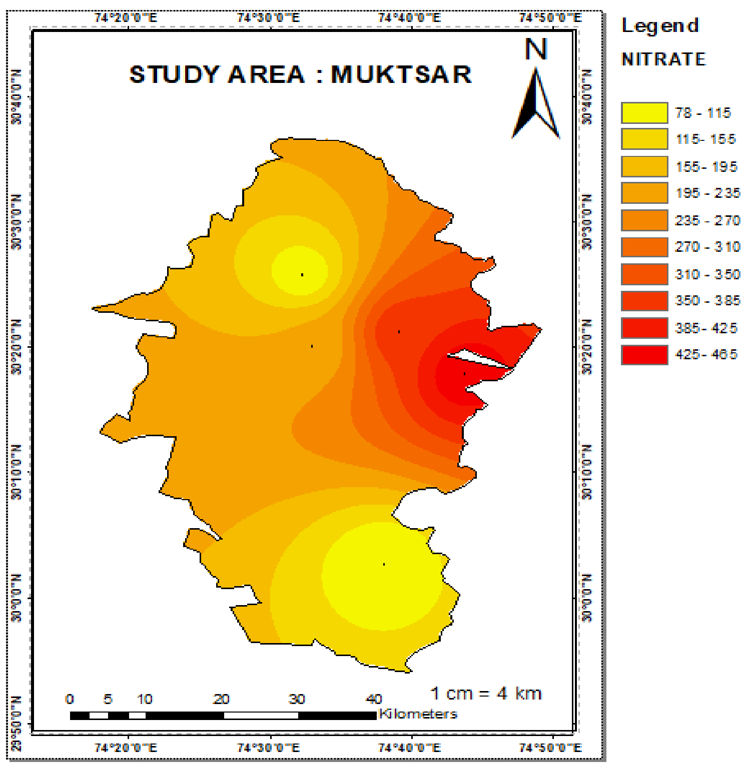


Figure12 : Distribution of Nitrate (mg/l) in 2017

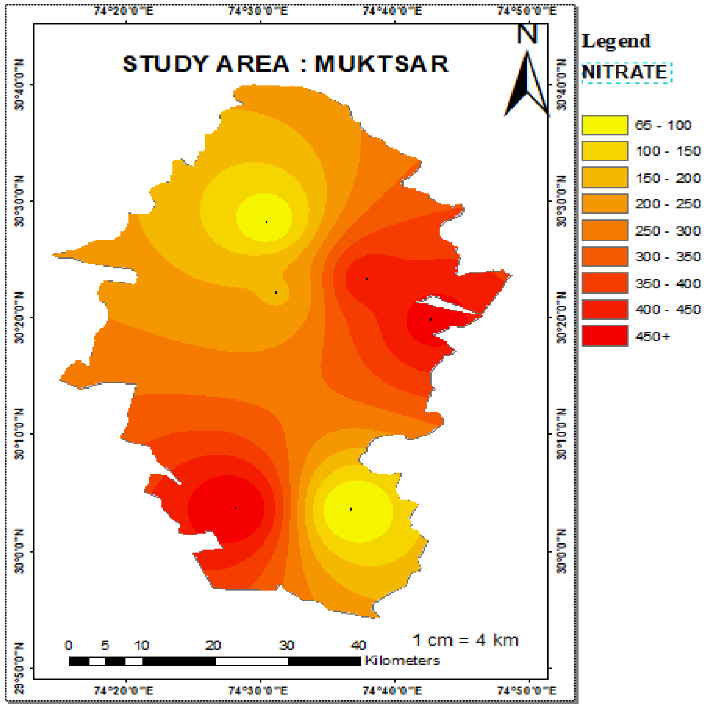


Figure13 : Distribution of Nitrate (mg/l) in 2018

RESULTS AND DISCUSSIONS

The model was run for a period of 1100 days and time period was divided into 10 equal time steps of 110 days each. Distribution of nitrate in the whole area after 550 days showed an increase in the nitrate concentration at a distance of 300 meter away from the point for the different time intervals of 110 days each.

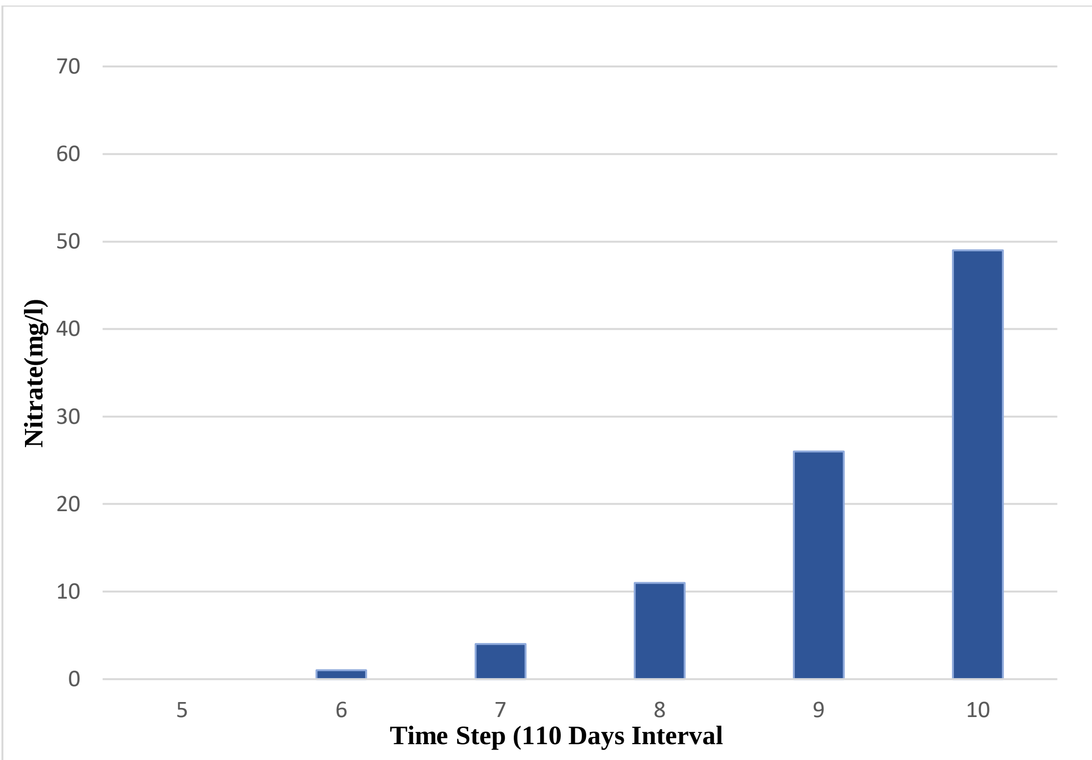


Figure14 : Computed concentration for BHALIANA at 300 meter away from point source

Result showed that an increase in nitrate concentration after a period of 1100 days was 49mg/l from 300 meter from the point source which is higher than the prescribed standard i.e. 45mg/l.

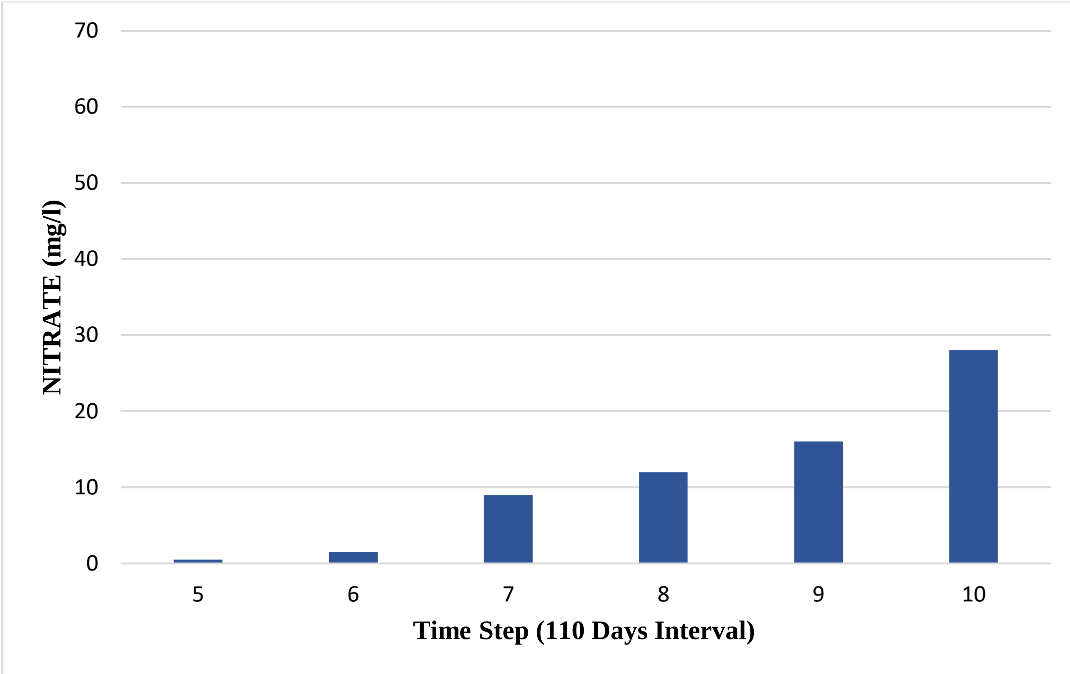


Figure15 : Computed concentration for DODA at 300 meter away from point source

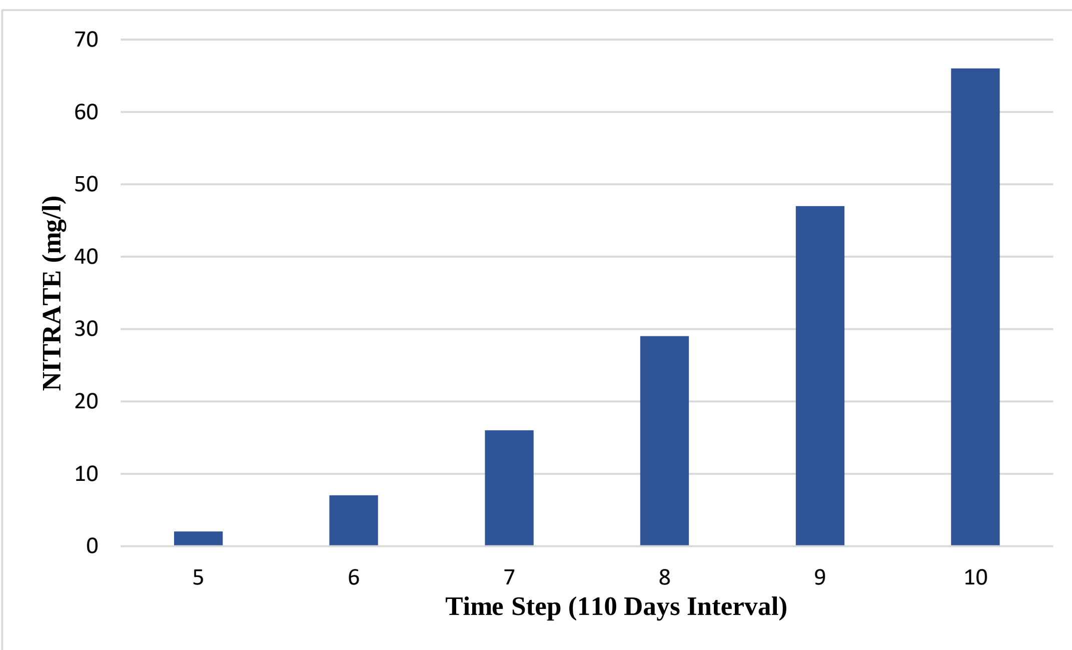


Figure16: Computed concentration for KUTTIANWALI at 300 meter away from point source

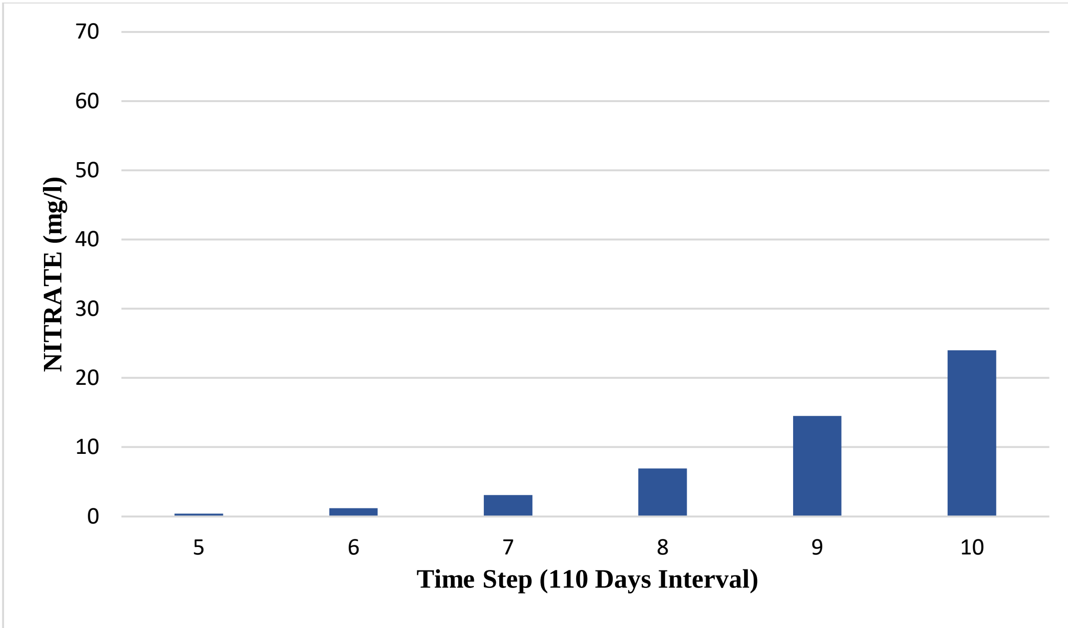


Figure17: Computed concentration for BHALOCHA KHERA at 300 meter away from point source

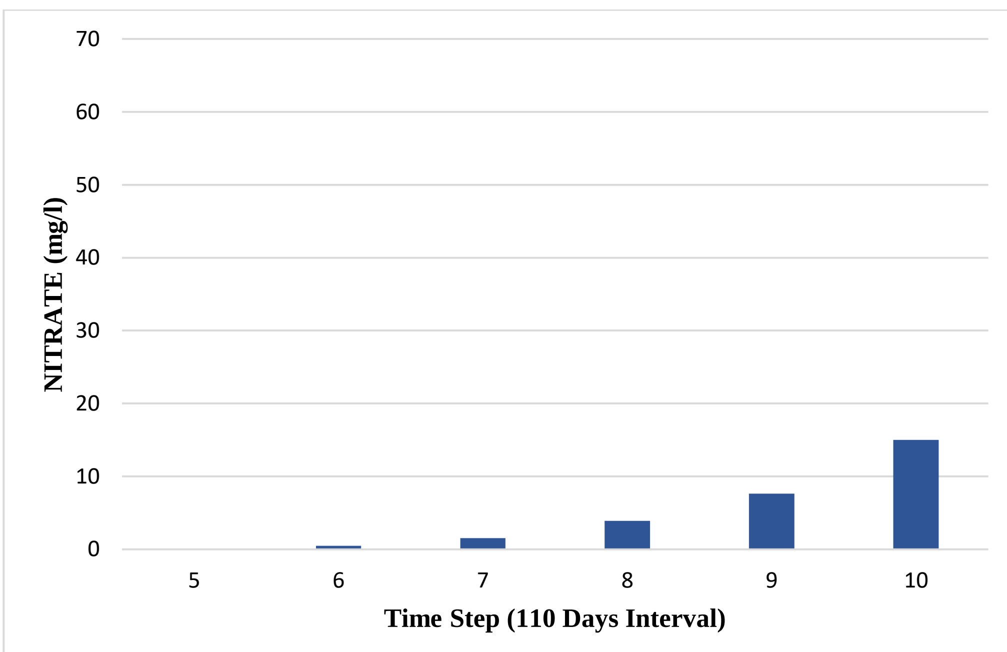


Figure18: Computed concentration of LAMBI at 300 meters away from point source

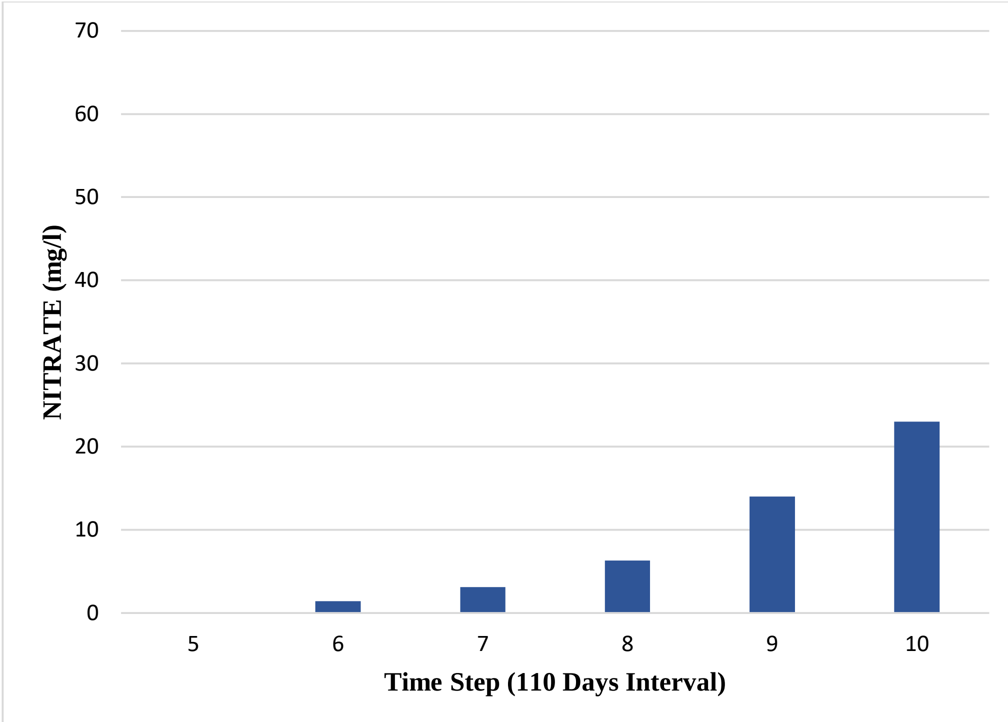


Figure19: Computed concentration of MUKTSAR at 300 meters away from point source

The results shows that nitrate contamination in all the localized areas has increased over the period of three years. Rise in the nitrate contamination is mostly along the flow direction of groundwater and the areas along the flow are more affected than the lateral ones.

Contamination has increased upto 49mg/l to 66mg/l in Bhaliana and Kuttianwali over the period of three years as the initial concentrations were also high in these two areas .

Concentration at Muktsar and Lambi were comparatively low as compared to above two stations. Nitrate concentration in Muktsar area has increased upto 23mg/l and in Lambi nitrate concentration has increased upto 15 mg/l over a period of three years.

CHAPTER 5

CONCLUSION

As the population of India is growing rapidly and there is an increase in the demand of the potable water from the natural water deposits, thus we require an alternative solution to it which can meet the demand of the growing population.

Groundwater monitoring and sustainability are key issues that have drawn a lot of interest from environmental institutions because of excessive withdrawal from these water sources and contaminant mixing in ground water. A sustainable solution to the growing issue can be found by modelling the groundwater supplies.

Nitrate present in ground water is one of the problems affecting humans and the plant life. In India Lakhs of people still drink nitrate contaminated water due to poor awareness among the people and also due to an absence of alternative reliable sources.

Time Step	Nitrate (Bhaliana)	Nitrate (Doda)	Nitrate (Kuttianwali)	Nitrate (Balocha Khera)	Nitrate (Lambi)	Nitrate (Muktsar)
5	0	0.5	2	0.4	0	0
6	1	1.5	7	1.2	0.45	1.4
7	4	9	16	3.1	1.5	3.1
8	11	12	29	6.9	3.9	6.3
9	26	16	47	14.5	7.6	14
10	49	28	66	24	15	23

Table 5: Distribution of Nitrate of each station from 550 days to 1100 days

Using MODFLOW to simulate ground water flow, it was possible to see how nitrate contamination varied throughout the area. The effects of pockets of high nitrate concentration in the study area were demonstrated by using MT3D to simulate the transport of nitrate over a stress period of 1100 days. Since the unconfined aquifer in the study area is located at a depth of 30 meters, even a small increase in the bottom layer's nitrate content might cause major issues for those who live near areas of high nitrate concentration. The risk of an increase in nitrate concentration is substantially larger in areas along the flow direction than other areas.

Some recommended measures that can be adopted are alternative drinking water sources with lower nitrate contamination must be used. People must be made aware of the risks of drinking contaminated water. Fertiliser use should be regulated and managed appropriately in order to prevent groundwater contamination. More organic manure should be utilised to reduce nitrate infiltration. Methods for removing nitrates from water should be developed and implemented in the most afflicted areas.

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