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Solute Transport Modelling using SUTRA and Physio-Chemical Analysis in Ghogha taluka, Bhavnagar District

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Abstract: Water plays non replaceable role in human life most required for healthy population. In the present study of ground water samples from different wells have been carried out for investigation. Groundwater resources are hidden systems and dynamic; their quality and quantity are often hard to measure and understand. Numerical modelling of flow and solute transport has received increased attention during the last three decades. The major findings in this study are that groundwater models should consider a series of hypothesizes, assumptions, constraints, and simplifications based on the model objective, modelling techniques, model reliability, solution complexity, data availability, and characteristics of the modelled area. Another problem is that the advection-dispersion equation suffers from several conceptual limitations, especially in large scale heterogeneous systems. To overcome these difficulties, advanced groundwater models can solve complex problems, either one- or multidimensional, that often involve multiple chemical species, diverse transport processes, material heterogeneity, complex boundary conditions, and time-varying stresses. Water samples from Ghogha Taluka of Bhavnagar were analyzed for physio-chemical study for its suitability for human consumption and agriculture. All the data result of the present study has been compared with water quality parameters of Indian standards. In this study physical parameters of transport modelling & how they relate to each other is examined and To identify the worst area, which are highly suspected to ground water contamination and estimate the solute transport in Ghogha taluka of Bhavnagar district using SUTRA Model and contamination concentration. pH of all the samples was shown alkaline. All over study represents that some of samples have poor quality for consumption and required regular monitoring for avoid further contamination. Almost all the samples have suitability for irrigation according their SAR and RSC values.

Keywords: Groundwater, Saturated porous media, SUTRA, Physio-chemical analysis, Contamination, Ghogha taluka of Bhavnagar district, drinking and irrigation purpose.

1. INTRODUCTION

Groundwater is water located under the ground surface in soil pore spaces and in the fractures of rock formations and ground water is the second largest fresh water available on earth and is the major contributor to fresh water resource. But in recent days, due to various reasons, lots of contaminants are being added to groundwater system in different part of the world. Groundwater contamination occurs when contaminants are discharged directly or indirectly into water bodies without adequate treatment to remove harmful compounds. The widespread use of chemical products, coupled with the disposal of large volumes of waste materials, poses the potential for widely distributed groundwater contamination.

1.1 Solute transport modeling

Analysis Of Solute transport in ground-water systems involves a complex, multi-discipline study that requires intensive and costly investigation . In this study the physical mechanisms of solute transport, advection and dispersion, and explains how they relate to one another and the scale of study. A step-by-step framework for conducting a study of the physical mechanisms is given that encourages the use of simulation to help understand the ground-water system under study. Solute-transport problems are very complex and generally involve large degrees of uncertainty in defining the relevant physical and chemical parameters. This high level of uncertainty in defining solute-transport problems is worthy of emphasis.

1.2 Application of solute transport models

The solute transport modeling in porous media deals with hydrogeological, hydrological, climatological, agricultural, industrial, geoecological, geographical, environmental, hydraulic engineering, water economics, and health issues. The specific and regulatory purposes of these models in hydrogeology include:

- To interpret concentration data.
- To describe the bulk and large scale motion of chemicals (advection or convection); or random, small scale motion of chemicals (diffusion).
- To assess the degree of mixing or dilution along the flow path (longitudinal dispersion) and perpendicular to the flow path (transverse dispersion).
- To predict chemical processes and the changes in chemical concentration taking place by dissolution, retardation, and degradation (e.g., adsorption, precipitation, hydrolysis, cation exchange, bioaccumulation, biodegradation, redox reaction).
- To develop a monitoring strategy and risk assessment.
- To estimate the cleanup time using remediation plans.
- To manage and protect groundwater quality.

1.3 Groundwater Modeling

Groundwater resources are hidden systems and dynamic; their quality and quantity are often hard to measure and understand. The state of any hydrogeological system can change over time, and in this regard, model designers, and operators are repetitively developing new scientific models and solution techniques to evaluate these systems. Groundwater models can help hydrogeologists explain the behavior of the whole or a part of a groundwater system, understand the processes, make predictions, make management decisions, and test a hypothesis.

Some of the typical groundwater model applications are:

- To improve hydrogeological understanding by analysis of data and existing literature (characterization and planning);
- To evaluate the aquifer behavior through simulation (prediction);
- To identify practical solutions to meet objectives (engineering construction and design);
- To optimize designs for maximum performance, minimum costs and environment conservation (control and optimization);
- To assess input, output, and water balance factors (water availability assessment);
- To estimate predevelopment conditions of an aquifer system (development and enhancement);
- To predict the behavior of the groundwater system under different hydrogeological stresses (management and decision-making);
- To quantify the sustainable and safe yield (water allocation policies);
- To analyze the sensitivity and optimization of parameters (uncertainty or risk analysis);
- To visualize the behaviors, processes and ongoing and upcoming events of a groundwater system (scaling and representation);
- To point out the strengths and weaknesses of other research, and evaluating other studies and theories through modeling (learning and teaching).

1.4 Objectives of the study

- To identify the worst area, Which are highly suspected to ground water contamination as per BIS & USGS Drinking water quality and Irrigation quality standards.
- To estimate solute transport in gogha taluka of Bhavnagar district using SUTRA model.
- To project the various scenarios and propose the practical solution to improve the ground water quality.

2. STUDY AREA AND DATA COLLECTION

Bhavnagar is a peninsular district of Western Gujarat. Bhavnagar city is the administrative headquarters of the district. It had a population of 2,469,630 of which 37.86% were urban as of 2001. It covers an area of over 9940Km^2 . There are close to 800 villages in the district. Ghogha Taluka of Bhavnagar district has total population of 100,977 as per the Census 2011. Bhavnagar is a peninsular district of Western Gujarat. Bhavnagar city is the administrative headquarters of the district. It had a population of 2,469,630 of which 37.86% were urban as of 2001. It covers an area of over 9940Km^2 . There are close to 800 villages in the district. Bhavnagar Boarders with Ahmedabad and Surendranagar districts of the North, the Gulf of Cambay to the East and South and Amreli and Rajkot district to the west.

Naturally the district is divided in three parts:

1. The part of the district is having leveled land saline soil, which is similar type to the Amreli district and also similar to the soil of Bhal area.
2. The part of the district is rocky and undulating in which area of Palitana and Shihor Taluka is included where as some part is hilly.
3. The coastal area of Bhavnagar, Ghoga, Talaja and Mahuva is flat and sloppy as compared to other.

Ghogha Taluka of Bhavnagar district has **total population of 100,977** as per the Census 2011. Out of which 51,861 are males while 49,116 are females. In 2011 there were total 17,985 families residing in Ghogha Taluka. As per Census 2011 out of total population, 12.1% people lives in Urban areas while 87.9% lives in the Rural areas. The average literacy rate in urban areas is 80.3% while that in the rural areas is 77.7%. Also, the Sex Ratio of Urban areas in Ghogha Taluka is 1,045 while that of Rural areas is 934.The population of Children of age 0-6 years in Ghogha Taluka is 14433 which is 14% of the total population.

Figure: Selected location (Sample collection)

Table: Details of collected sample from Bhavnagar District

Well no.	Village	Taluka	District	Geology	Latitude	Longitude	Elevation (m)
1	Tagdi	Ghogha	Bhavnagar	MAR	21.676	72.1693	30
2	Lilasapir dargah-Tagdi	Ghogha	Bhavnagar	MAR	21.668	72.1866	30
3	Bhumbhli	Ghogha	Bhavnagar	GLS	21.659	72.1873	24
4	Avaniya	Ghogha	Bhavnagar	GLS	21.686	72.2020	16
5	Rampara	Ghogha	Bhavnagar	BAS	21.646	72.2170	14
6	Thordi	Ghogha	Bhavnagar	BAS	21.6616	72.2217	28
7	Bhuteshwar	Ghogha	Bhavnagar	GLS	21.6859	72.2076	14
8	Ghogha	Ghogha	Bhavnagar	MAR	21.4057	72.1538	12
9	Chhaya	Ghogha	Bhavnagar	BAS	21.30386	72.1214	49
10	Morchand	Ghogha	Bhavnagar	MAR	21.3244	72.1248	55

2.1 Graphical Analysis

Water samples from Ghogha Taluka of Bhavnagar were analyzed for physio-chemical study for its suitability for human consumption and agriculture. All the data result of the present study has been compared with water quality parameters of Indian standards. The following Graph shows the water sample result obtain during experiment. In each variation shows the contamination value at different well location.

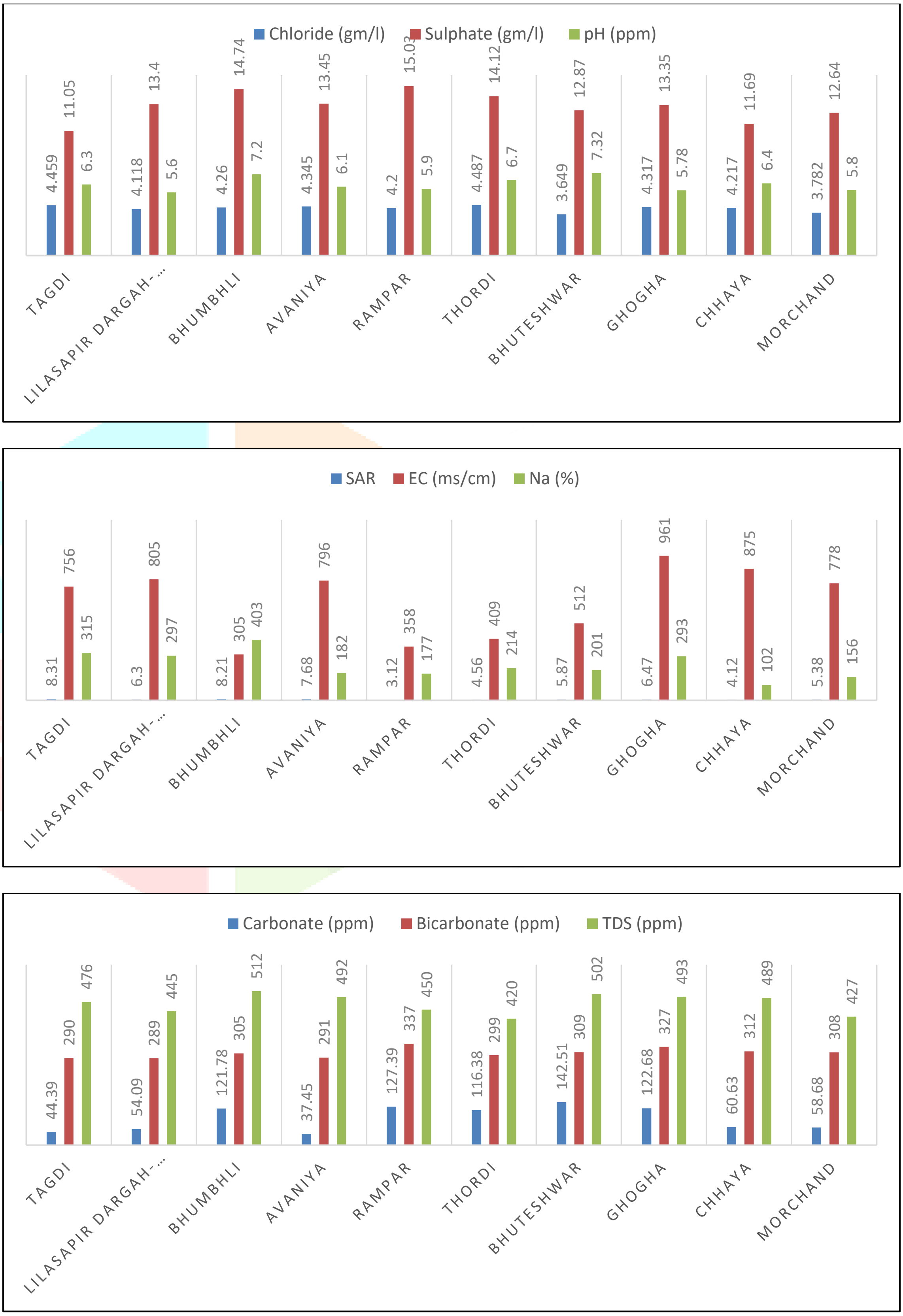


Figure: Parameters content for various well

3. MODEL GENERATION

3.1 About SUTRA

SUTRA is a groundwater saturated unsaturated transport model, a complete salt water in intrusion and energy transport model. 2D, 3D, Variable density and Variable saturated flow Solute transport model. SUTRA employs a two dimensional hybrid finite element and integrated finite difference method to approximate the governing's that describe the two interdependent process that are simulated: (1) fluid density dependent saturated or unsaturated groundwater flow and either (2a) transport of a solute in the groundwater, in which the solute may be subject to equilibrium adsorption on the porous matrix and both first-order and zero-order production or decay, or (2b) transport of thermal energy in the groundwater and solid matrix of the aquifer. SUTRA Version 3.0 includes generalized boundary conditions, a modified implementation of specified pressures and concentrations or temperatures, and the lake capability. SUTRA Version 2.2 allows specification of time-dependent boundary conditions without programming FORTRAN code, and offers optional output files that summarize specifications and computed results at boundary condition nodes.
SUTRA Version 2.1 allows the use of irregular meshes in both 2D and 3D simulations and offers convenient incorporation of input data from separate files, greater user control over time stepping.

The procedure for model generation is summarized below.

1. Define study area.
2. .kml file generation using google earth pro.
3. .kml file conversion into shape file.
4. Define .kml file as input using model muse in SUTRA. & Define boundary condition.
5. Use shape file as import in SUTRA model.
6. Generation of model define import parameters/properties.
7. Define initial condition.
8. Data visualization.
9. Mesh generation.
10. Run the existing model
11. Neglecting error.
12. Report generation.

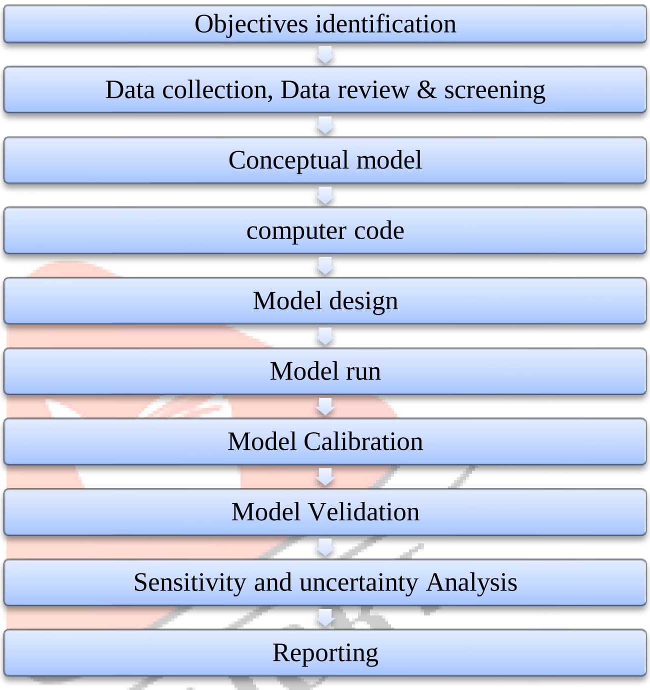
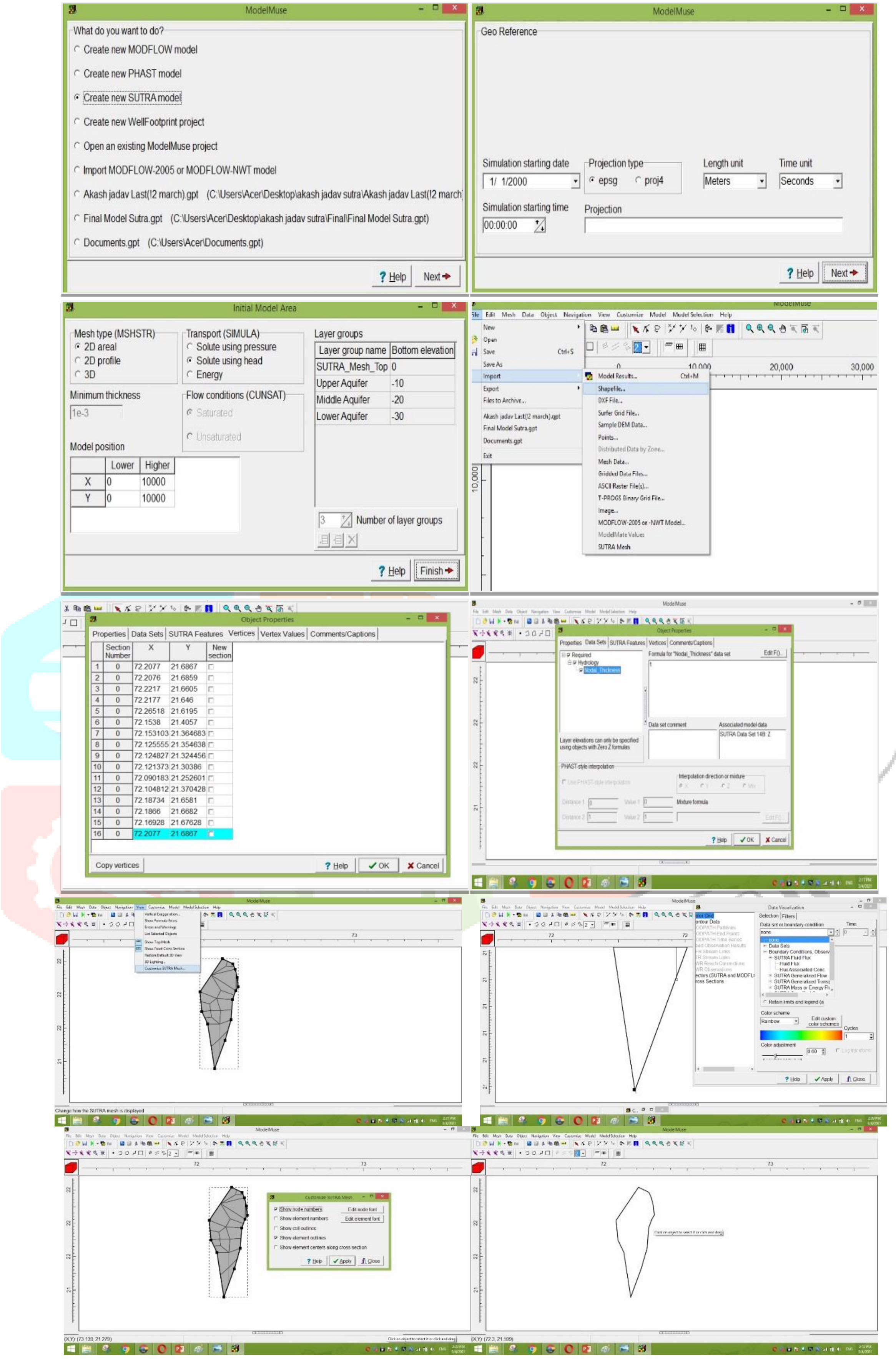


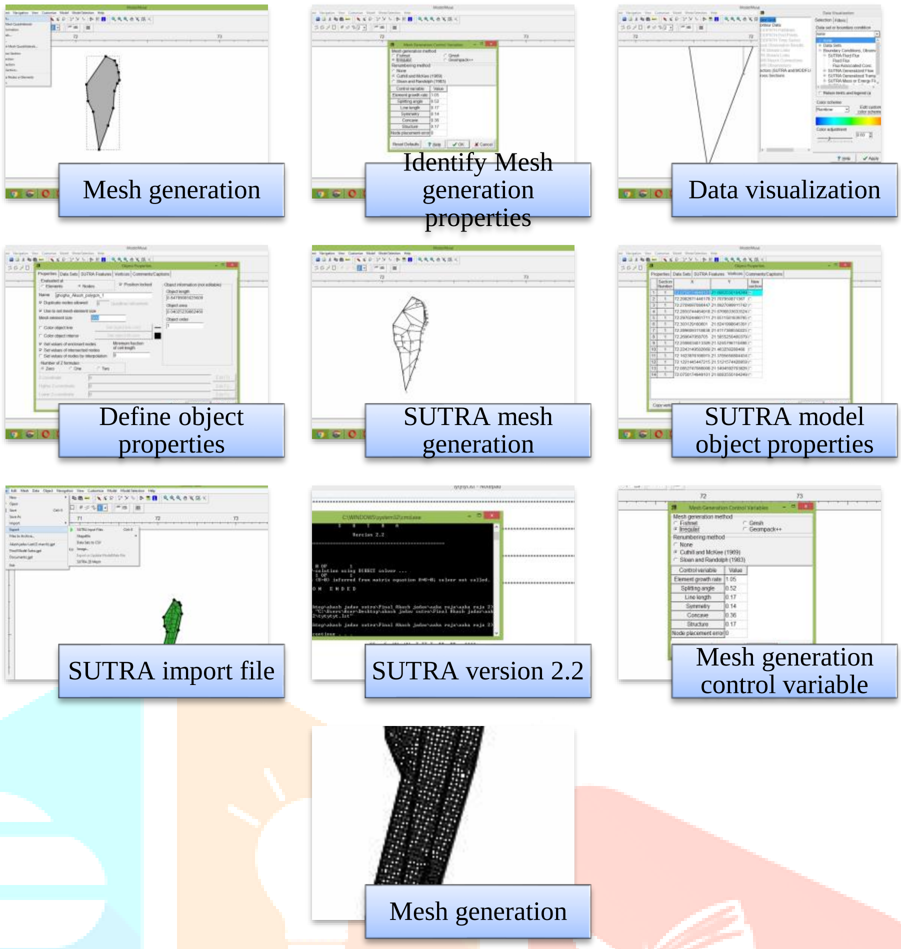
Figure: Model Procedure

Table: Input parameters for SUTRA and analytical solutions

Parameter	Value	Units
Hydraulic properties		
Porosity	0.50	-
Relative permeability	Off	-
Darcy velocity	10, 100	m yr^{-1}
Gravity	0	m s^{-2}
Water saturation	1	-
Sat. available for freezing	1 (for solution)	-
SUTRA solver settings		
SUTRA element height	0.001	m
Number of time step size	0.00001-0.0001	hr



SUTRA model procedure is shown in picture.



4. CONCLUSIONS

Groundwater modeling is a powerful tool for evaluating the quantity and quality of groundwater resources over time. The performance of a groundwater numerical model is also dependent on so many criteria such as the definition of the conceptual model, model structure, quality of input data, solution techniques, characteristics of the modeled area (spatial and temporal resolutions), operator proficiency, etc.). Comparing with flow models, the performance of solute transport models can be affected by more factors such as the domain size, viscosity and density variations, changes in hydrological stresses (e.g., extraction of groundwater by pumping wells or surface recharge), heterogeneity of the medium, physical and chemical properties of the solute, and complex chemical processes taking place in the groundwater system. Although most solute transport models have been developed to provide solutions for one- or two-dimensional transport of a single, nonreactive solute under isotropic and homogenous conditions in a steady-state regime, The advanced solute transport models can be used to solve complex problems, either one- or multidimensional, involving multiple chemical species, diverse transport processes, material heterogeneity, complex boundary conditions, and time-varying stresses. However, more investigations and computations are required to increase their robustness and to decrease uncertainty in the model results.

The following conclusion drawn from the test and model run result;

Physio-Chemical Results

- The concentration of chloride found to be higher as per permissible limits in collected sample which is shown in graph. Chloride creates unacceptable taste above the concentration of 0.25 gm/l although there is no adverse effect have been found on human for regularly consuming high concentrated chlorine water. Sulphate occurs comprehensively in both natural and anthropogenic water systems. The concentration of sulphate as shown in graph found Higher sulphate concentration in the study groundwater area may be due to spoiling of organic wastes and attribution of the discharge of domestic sewage in the region.
- The total dissolved solids was recorded for all station have higher TDS value than the permissible limits. The samples have suitability for irrigation according their SAR. The high concentration of sodium (Na) in drinking and irrigation water causes heart problems and salinity problems respectively. Bicarbonate and carbonate ions combined with calcium or magnesium will precipitate as calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$) when the soil solution concentrates in drying conditions. The concentration of Ca and Mg decreases relative to sodium & the SAR index will be bigger. This will cause an alkalizing effect and increase the PH.

Model run Results

- After entering the Boundary conditions, input parameters in the model when we run the model, we find that amount of solute concentration is to be present in the particular area and concentration of contamination is also known by us and Report is to be generated in that. In model study area is be divided in particular node vies and all the results is coming out in particular node so we should easily identify the concentration of other parameter in our study area. From model Report we can Easily say that percentage solute is too high in Malpar, padva, Bhumbhali, Tagdi, Ghogha, budheshwar wells so these wells are Prone to the pollution and this water is hazardous for irrigation and drinking purposes other well in different location are also polluted but intensity of pollution id low compare to above villages.

It concludes from report that criteria for pollution is Solute content and water quality parameters, chemical properties of water are also the governing factors.

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