USE OF GIS TOOLS IN GROUNDWATER MODELING STUDIES

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INTRODUCTION

Hydrological modeling is a powerful technique for hydrologic system investigation for both hydrologists and practicing water resources engineers involved in planning and development of water resources. Such models are conceptual descriptions or approximations that describe physical systems using mathematical equations. By mathematically representing a simplified version of a hydrological system, reasonable alternative scenarios can be predicted, tested, and compared.

The use of groundwater models is prevalent in the field of environmental science. Models have been applied to investigate a wide variety of hydrogeologic conditions. More recently, groundwater models are also being applied to predict the transport of contaminants for risk evaluation.

Groundwater models describe the groundwater flow and transport processes using mathematical equations based on certain simplifying assumptions. These assumptions typically involve the direction of flow, geometry of the aquifer, the heterogeneity or anisotropy of soil or bedrock within the aquifer, the contaminant transport mechanisms and chemical reactions. Because of the simplifying assumptions embedded in the mathematical equations and the many uncertainties in the value of data required by the model, a model must be viewed as an approximation and not an exact duplication of field conditions. Groundwater models, even as approximations, are a useful investigation tool for a number of applications.

Remote sensing (RS) and Geographical Information System (GIS) are playing a rapidly increasing role in the field of hydrology and water resources development. Remote sensing provides multi-spectral, multi-temporal and multi-sensor data of the earth's surface. One of the greatest advantages of using remote sensing data for hydrological investigations and monitoring is its ability to generate information in spatial and temporal domain, which is very crucial for successful analysis, prediction and validation.

The water on the surface which has a bearing on ground water circulation are distinguished in the near infrared region owing to low reflection of water. Synoptic view, repetitive coverage and capability to view the scene in several spectral bands are some of the special characteristics that have made remote sensing an effective tool in ground water search. The clue to ground water search is based on the fact that subsurface geologic elements forming aquifers have surface expressions which can be discerned by remote sensing techniques. Significant hydrogeomorphic units can be demarcated based on tone, texture, shape, size, pattern, association, etc. Delineation of all linear features and their classification in to fractures, faults, shear zones, etc. can be attempted.

However, the use of remote sensing technology involves large amount of spatial data management and requires an efficient system to handle such data. Information from satellites is becoming more and more important for environmental research. The GIS technology provides suitable alternatives for efficient management of large and complex databases.

GIS is one of the most important tools for integrating and analyzing spatial information from different sources or disciplines. It helps to integrate, analyze and represent spatial information and database of any resource, which could be easily used for planning of resource development, environmental protection and scientific research and investigation. GIS is built upon knowledge from geography, cartography, computer science and mathematics and can be applied in any field, directly or indirectly. Its ability to perform complex spatial analysis like map overlay, creation and integration of various types of databases and integration with simulation models makes it an efficient tool for analysis and interpretation of spatial and non-spatial datasets.

In the early days, GIS was mainly used as hydrological mapping tools. With the progress of technology, GIS started to play an important role in hydrological modeling studies. Their applications span a wide range from sophisticated analyses and modeling of spatial data to simple inventories and management tools. The introduction of GIS has enhanced the capacity of models in data management, parameter estimation and presentation of model results. Due to its data handling and manipulation capabilities, GIS is increasingly being used as an interface and data manager for hydrologic models.

Several associations between hydrological modeling and GIS can be distinguished, each representing a different level of coupling and integration. Three types of GIS systems can be identified: models linked to a GIS, models coupled with a GIS and models embedded in a GIS. Parameter calculation for the models, when linked to a GIS, becomes very quick, so it is possible to have scenario analyses more effectively in combination with a GIS.

GIS in Groundwater Modeling

Groundwater models are used to predict the movement of contaminant plumes, used to place limits on the volume of water pumped from an aquifer, and predict where groundwater resources are most likely to be found. These types of models require many large, complex data sets be combined into a useable form. Data layers showing soils information, rainfall, bedrock features, topography, land use, and land cover can be combined in GIS and used to develop recharge and resource models and mapping. Each data layer is given a weight relative to its importance, and the data layers combined to predict the areas where groundwater is most abundant. This allows for resources to be taped more efficiently.

Ground water depth and quality data can be digitized in a GIS. After digitization, error removal and attributation, groundwater prospects and quality maps can be integrated to prepare ground water prospective zones map.

GIS databases of groundwater data can be used as simple models to show groundwater attributes. For example a GIS database with groundwater level readings from wells in a given area can be used to develop groundwater contours. In addition groundwater contours can be extrapolated to areas where data is sparse. This is a simple, but important groundwater modeling application of GIS.
Groundwater vulnerability mapping is used as a guide in determining which areas are more susceptible to groundwater contamination within the mapped area. The use of GIS techniques for groundwater contamination risk mapping is primarily due to the automatization of certain operations thereby working time and the working personnel are reduced. The database that is attached to each layer can be updated at any time. In addition, the use of GIS facilitates the rapid visualization of some elements in the map through selecting them from the attribute table. Vulnerability digital maps, together with the land use maps, data on contamination sources and groundwater quality can be used in view of a rapid and correct evaluation of pollution risk.

The GIS is used as additive tool to develop supportive data for numerical groundwater flow modeling, integration, analysis and presentation of image processing and modeling results. The thematic layers of landforms, land use, hydrology, infrastructure and climate are developed using a GIS. The RS data is used to analysis surface hydrological conditions and land cover / land use status in order to conceptualize the recharge/discharge sources involved in groundwater system and to observe the behaviour of water logging and salinity in the area.

The main task is to bring all the appropriate data together into a GIS database. Basically, all the available spatial data are to be assembled in digital form, and properly registered to make sure the spatial components overlap correctly. The data will be in different formats and from different sources such as; Remote Sensing Data, Survey of India (SOI) toposheets, and other Ancillary Data (meteorological data, Statistical abstracts, Census handbook, available ground water literature etc., and Ground water depth and quality data).

Digitizing of existing data and the relevant processing such as transformation and conversion between raster to vector, griding, buffer analysis, box calculating, interpolation and other format can be conducted. This produces derived layers such as annual rainfall, lithology, lineament density, topography elevation, slope steepness, drainage density, land use and soil type. Spatial Data Analysis stage will process all input layers in order to extract spatial features which are relevant to the groundwater modeling.

GROUNDWATER INFORMATION SYSTEM

Accurate and reliable groundwater resource information is critical to planners and decision-makers at all levels of government, researchers, developers and the business community. Most of the developing countries including India are focusing on improved data management, precise analysis and effective dissemination of data, and initiated steps towards meeting these demands. In order to cater these requirements, a comprehensive Ground Water Information System is required with extensive capabilities of GIS. The data/information requirements are usually at macro to micro levels viz River basin and Watershed as well as administrative units (State, District, Taluk and Village).

A groundwater data management and analysis software (or Groundwater Information System) should be capable of comprehensively manage, evaluate and present most types of ground water information both spatially and non-spatially. This system enables us to organize the different aspects of ground water related data viz. hydrological, lithological, meteorological, hydrochemical, geophysical, well inventory, Pump test etc. Figure 1 shows a pictorial representation of a Groundwater Information System.

Groundwater development program needs a large volume of multidisciplinary data from various sources. Integrated remote sensing and GIS can provide the appropriate platform for convergent analysis of diverse data sets for decision making in groundwater management and planning. In many cases groundwater data is widespread geographically. GIS provides the platform to do this because of its power in displaying spatial data. Data from a large number of wells can be viewed on a single map and patterns can be observed.

Such a system provides tools that help to manage, visualize, and analyze groundwater data and support groundwater analysis and modeling. It will be able to create maps of hydrogeologic systems showing spatial features such as aquifers, wells, geologic formations, and springs. It is also possible to map and animate time-varying phenomena such as changes in groundwater levels, concentrations, and particle tracking.
The U.S. Geological Survey provides unbiased, timely, and relevant data on the groundwater resources of the Nation:

- Aquifer Basics: A collection of data and maps of the principal aquifers throughout the United States.
- Real-time groundwater level network: Map-based data from over 1,000 wells where data typically are recorded at 15- to 60-minute intervals.
- Ground Water Atlas of the United States: Groundwater resources of regional areas in the United States.
- Groundwater response to climate: Map-based data from about 550 wells that monitor the effects of droughts and other climate variability on groundwater levels.

- Recent groundwater level networks: Map-based data and information from more than 20,000 wells that have been measured by the USGS or cooperators at least once within the past 365 days.

DEMARCATION OF GROUNDWATER POTENTIAL ZONES

The remote sensing technology and GIS tools have opened new paths in groundwater studies. The integration of the two techniques enhanced the automation of geologic exploration, mapping and identification of groundwater aquifers or groundwater potential zones.

Monitoring of groundwater can be done by identification of phreatophytic vegetation, wider sandy channels, sinkholes and faults. RS data provide a large area synoptic view with high observational density. Using geomorphological features, as seen from the space as guide, areas with high, medium and low potential of finding underground aquifers capable of being tapped can be delineated.

The advent of Satellite Technology and GIS has made it very easy to integrate various databases which can help in delineating areas favourable for groundwater development. All these information layers can be integrated through GIS analysis and the criteria for groundwater prospective zones mapping and artificial recharge site selection can be defined as given in Figure 2.

- In order to demarcate the groundwater potential zones of an area different thematic maps are prepared from remote sensing data, topographic maps and resistivity data.
- The thematic maps on hydrogeomorphology and lineaments are prepared using RS data by visual interpretation.
- Drainage map is prepared from SOI toposheet & satellite data.
- Contour map and spot elevation map are prepared from SOI toposheets.
- All primary input maps (hydrogeomorphology, lineament, contour & spot elevation, drainage and geo-electrical sounding location) are digitized in GIS and slope map was prepared from digital elevation data.
- Using inferred lithology and thickness from geoelectrical parameters at respective locations, aquifer layer thickness and overburden thickness maps are prepared through GIS.
- The different polygons in the thematic layers are labelled separately and then they are registered. In the final thematic layer, initially each one of the polygons are qualitatively visualized into one of the categories like (i) very good (ii) good to very good (iii) good (iv) moderate and (v) poor, in terms of their importance with respect to groundwater occurrence and suitable weights are assigned.
- Finally thematic layers are converted into grid with related item weight and then integrated and analysed, using weighted aggregation method. The grids in the integrated layer are grouped into different ground water potential zones by a

suitable logical reasoning and conditioning. The final ground water potential zone map thus generated can be verified with the yield data to ascertain the validity of the model developed.

IDENTIFICATION OF RECHARGE SITES

Application of RS and GIS are the most applicable means to identify the artificial water recharge sites. Using the soil, slope, aspect and land use maps, water feeding sites can be identified using a GIS system.

The various thematic maps such as Geomorphology, Geology, Soil, Slope, Land use, Drainage, Drainage density, Lineament density, Runoff isolines, Depth to weathered zone, Groundwater level fluctuations and Water quality are used for this analysis. The above maps can be prepared using satellite data and other collateral information collected from the field and digitized. Criterion tables can be generated considering the importance of different themes and necessary ranks and weights can be assigned to each theme. Using suitable GIS software, the above themes can be integrated and the areas suitable for artificial recharge can be identified. Figure 3 shows the detailed flow chart for the identification of recharge sites.

MAPPING OF GROUNDWATER VULNERABILITY ZONES

Vulnerability mapping is an important GIS application to groundwater modeling. Data layers can be developed, such as soils and bedrock data. This data is ranked according to its importance in determining groundwater vulnerability. The layers can be overlayed and the vulnerability of different areas can be viewed. This type of modeling is used to determine if an aquifer is at a high risk of being contaminated.

A graphical representation of vulnerable aquifers, combined with graphical representations of potential sources of contamination and public water supplies would allow decision makers to evaluate current land use practices and make recommendations for changes in land use regulations which would better prevent the groundwater from contamination. Another potential benefit from mapping vulnerability is that it aids in the prioritization of remediation sites.

DRASTIC is an empirical model developed by U.S. Environmental Protection Agency. It is widely used for evaluating relative groundwater pollution susceptibility by using hydro geological factors. DRASTIC is an acronym for the most important hydro geologic features which control groundwater pollution. These features are:

D - Depth to water table
R - (Net) Recharge
A - Aquifer media
S - Soil media
T - Topography (slope)
I - Impact of Vadose Zone Media
C - Conductivity (Hydraulic) of Aquifer.

Each DRASTIC factor is assigned a weight based on its relative significance in affecting pollution potential. Each factor is further assigned a rating for different ranges of the values or significant media types based on its impact on pollution potential. The typical ratings range from 1 to 10 and the weights from 1 to 5. DRASTIC index is calculated by overlaying the maps for each of the above index as shown in Figure 4. Geographic Information System (GIS) is used to compile the geospatial data, to compute the DRASTIC indices, and to generate the final vulnerability map. The higher the DRASTIC index, the greater is the relative pollution potential.

GROUNDWATER FLOW AND CONTAMINANT FATE AND TRANSPORT MODELING

Modeling is a difficult task, requiring a large amount of data, from varying sources and of varying type, to be combined. GIS is used in groundwater modeling in one of two ways; development of models within GIS, and pre or post processing of model data in GIS.

Groundwater modeling often involves handling of large-scale spatial and non-spatial input and output datasets. Geographic Information System (GIS) provides an integrated platform to manage, analyse and display these datasets and facilitates modeling efforts in data compilation, calibration, prediction and display of results. Groundwater models need datasets of various parameters such as surface elevation, bottom elevation, percolation, seepage, etc. in ASCII format. Preparation of input files of these parameters is a difficult task and time-consuming, which can be made simple with the use of GIS. However, an interface program is necessary to couple the GIS with the groundwater model as shown in Figure 5.

The creation of GIS databases (similar to a Groundwater Information System) containing land use data, soils information, and other geologic data are essential to groundwater modeling. After the model has been run, the results can be exported into GIS for post processing. Post processing allows for data layers to be developed and displayed in map form. This allows model results to be examined easily, in their spatial context. In some cases, modeling may be done directly in a GIS program, by using overlayed data layers to determine relevant groundwater properties, such as recharge rates and contaminant plume migration.

Groundwater flow and contaminant fate and transport modeling is an important component of most aquifer remediation studies. This task becomes extremely time consuming, when the modeler is required to analyze complex heterogeneous aquifers and faces manipulation of large amounts of input and output data structures, which are model specific. Geographic Information Systems (GIS), on the other hand, provide a platform in which layered, spatially distributed databases can be manipulated with ease, thereby simplifying the implementation of data management tasks of model building and model calibration significantly. GIS databases of groundwater quality data and contaminant concentrations can be developed and used as inputs into groundwater models, in particular contaminant transfer models.

Salt-water intrusion is a major issue for coastal communities reliant on groundwater. Groundwater modeling using GIS can be used to help predict and therefore limit pumping thresholds for coastal wells. Prediction of maximum pumping rates can be computed by models developed with the aid of GIS, rather than through extensive field work. Water quality data can be displayed in its spatial context and used to determine areas where historically salt water intrusion has been a problem. This helps to limit salt water intrusion, which can damage potable water systems.

CONCLUSION

Until recently, GIS was a tool for managing and analyzing spatial data and hydrologists were using it to make the database in a format specifically to work with a particular model. The integration of GIS and modeling began slowly as GIS was used to perform overlay functions of model parameters and further analyses using interface programmes. However, now significant developments have already taken place for the integration of GIS and hydrological modeling with the use of satellite digital data. GIS has become a valuable tool for use in parameterization for large scale physically distributed models. These would result in corresponding increase in operational use of such models. There is however, need for considerable efforts to obtain data and information which represent the groundwater system completely, for use in such applications. Advanced GIS abilities to manage real time data, including remotely sensed digital data, are desirable.

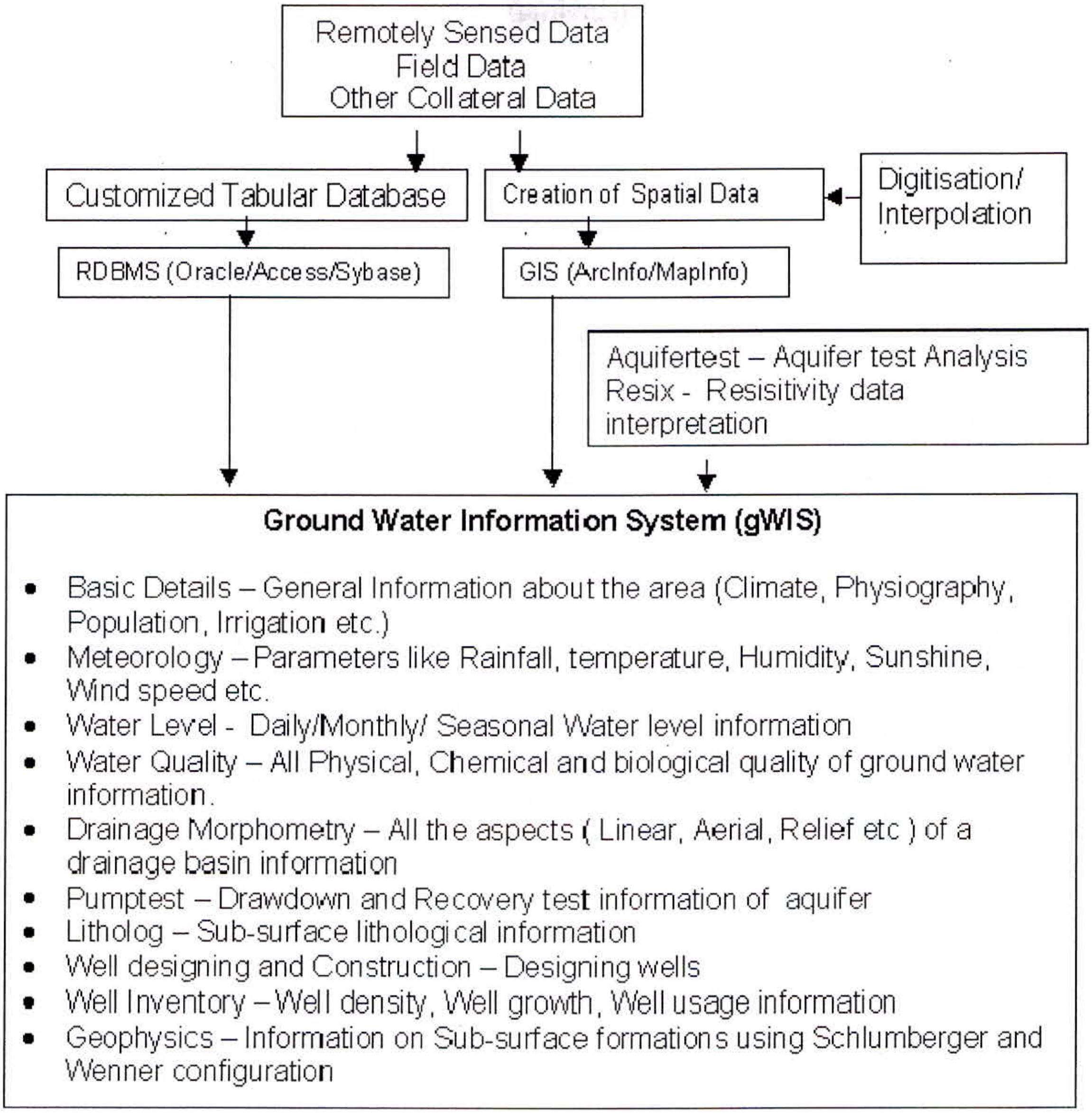

Figure 1: Characteristics of a Groundwater Information System

Weightage of different parameter for groundwater prospects

Sl.No.	Criteria	Classes	Weight	
1.	Hydrogeomorphology	BPP-M	3	Good
		BPP-S	2	Moderate
		DPT	1	Poor
2.	Aquifer thickness	> 25 m	4	Very Good
		16 m - 25 m	3	Good
		6 m - 15 m	2	Moderate
		<= 5 m	1	Poor
3.	Clay thickness (Top impermeable layer)	> 25 m	4	Very Good
		16 m - 25 m	3	Good
		6 m - 15 m	2	Moderate
		< = 5 m	1	Poor
4.	Slope (degree)	0 - 0.5	4	Very Good
		0.6 - 2	3	Good
		2.1 - 4	2	Moderate
		4.1 - 9.2	1	Poor
5.	Lineament	Present	2	Moderate to Very Good
		Absent	1	Poor

Figure 2: Criteria for Identification of Groundwater Zones

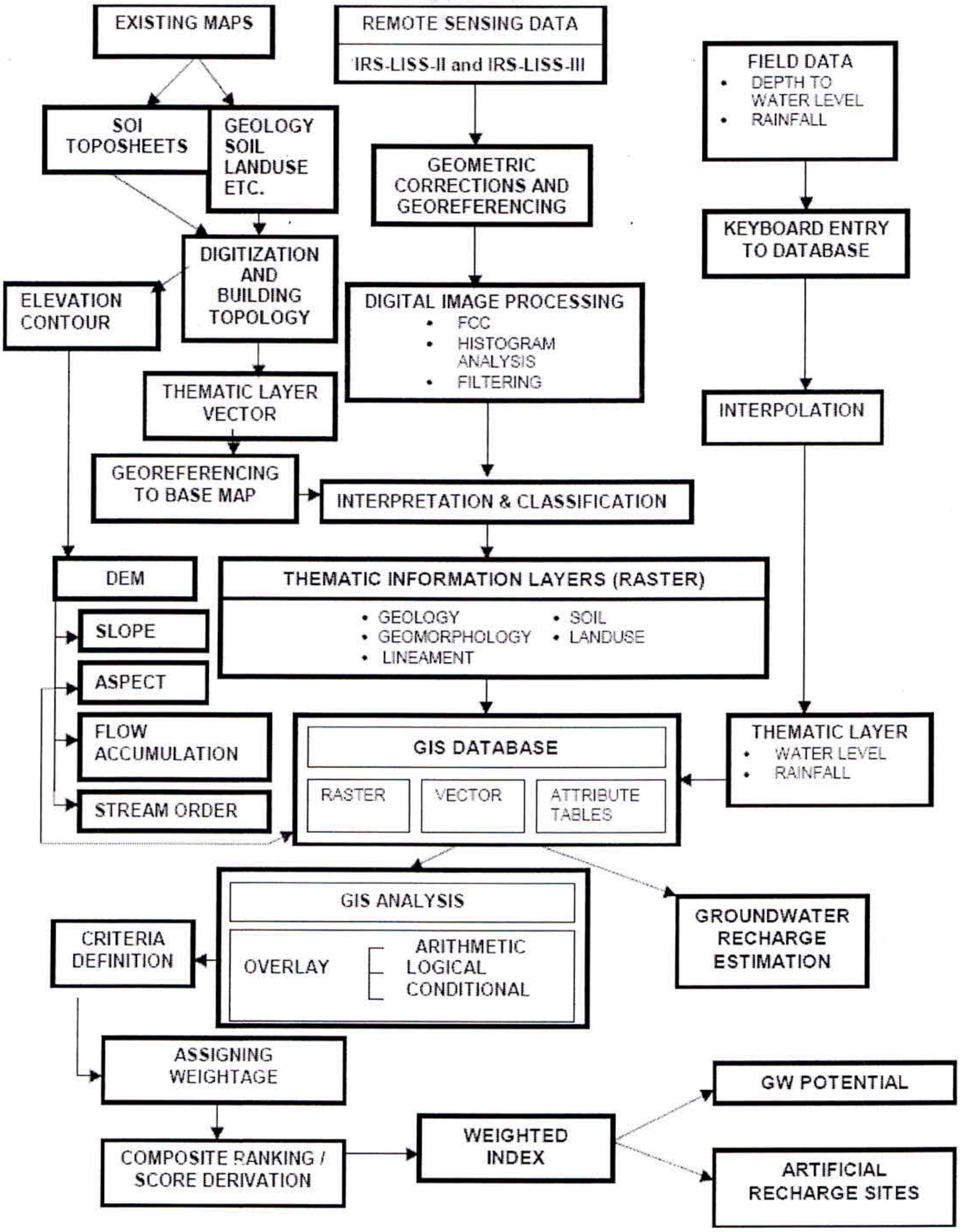

Figure 3: Flow Chart Showing Procedure for Identification of Recharge Sites

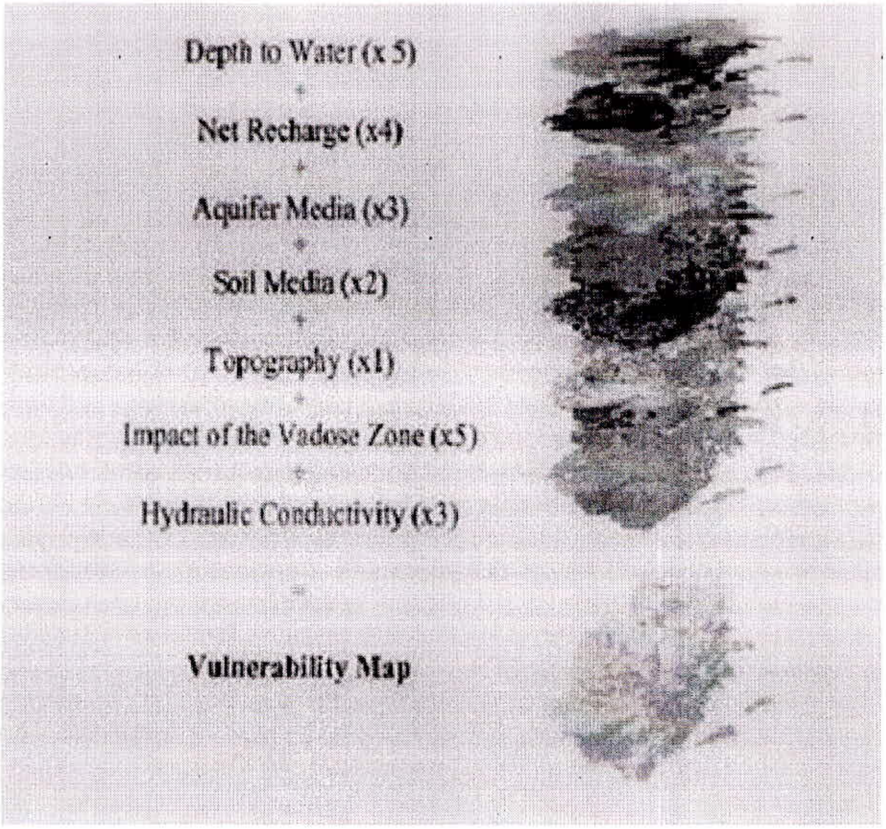

Figure 4: DRASTIC Model for Groundwater Vulnerability mapping

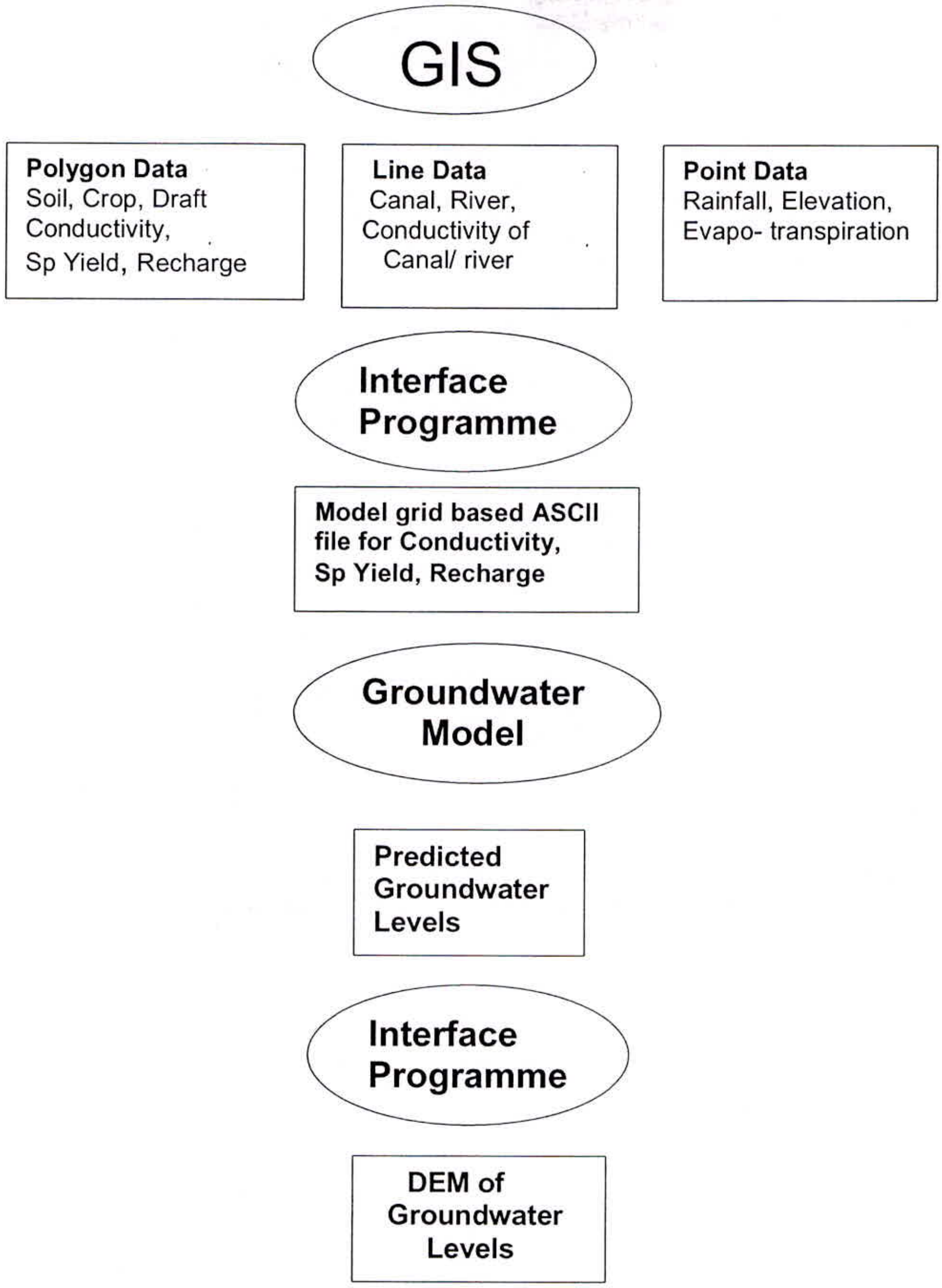

Figure 5: Example for GIS Interface for Groundwater Modeling