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APPLICATION OF VISUAL MODFLOW AND GIS IN GROUNDWATER MODELING

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ABSTRACT

It is universal tendency to tap groundwater, which has resulted in serious falls in water levels in many parts of the world. Farmers have met this situation by incurring heavy expenditure by way of deepening the tube wells and lowering of pump sets, which in turn caused disastrous reflex at least in certain areas in the form of seawater intrusion. It is necessary that such developments should be taken note off and tackled in a systematic manner, so that extreme attractiveness of groundwater as resources should not be its own enemy. With the advent of powerful personal computers and the advances in other technologies, efficient techniques for water management have evolved of which GIS (geographic information system) and groundwater modeling is of great significance. The applications of GIS and Visual MODFLOW changed our thoughts and ways to manage water resources in the present situation. This paper presents the result of ground water model done with the application of GIS & Visual MODFLOW developed for the Thirukkazhukundram block in Tamilnadu. The main intent of this study is to highlight the usage of Visual MODFLOW and GIS techniques to present a comprehensive review on their applications to groundwater hydrology.

KEYWORDS: Digitization, Command & Non Command Areas, GIS, Groundwater Model, Visual MODFLOW

INTRODUCTION

More than 90% of our rural population is primarily dependent on groundwater (Chandrasekhar, Adiga, Lakshminarayana, Jagdeesha, & Nataraju, 1999). The quality of groundwater is as important as that of quantity because it is the only source of drinking water in most of urban areas of India. The drinking water quality in Indian cities has been deteriorating in recent years mainly due to the high growth of population, unplanned growth of cities, mixed land use patterns, no proper sewage system, and poor disposal of the wastewater both from household as well as industrial activities. This has led to the pollution of shallow aquifers in and around Indian cities in general and Aligarh in particular (Rahman, 2003, 2008). According to the reports from the state & Central Ground Water Board, Tamil Nadu has already exploited 60 to 65% of the replenishable groundwater resources and its one of the states which faces acute water shortage. Lot of research studies have been conducted in and around Thirukkazhikundram Taluk and Palar River in Kancheepuram District, Tamil Nadu on pollution transport, surface water assessment, groundwater assessment, water quality assessment etc. These show the importance of Groundwater and how we need to conserve it to make use of the future needs. This paper is the groundwater assessment study involved in these regions as part of the conservation of the Groundwater resources.

GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

The history of using computers for mapping and spatial analysis shows that there have been parallel developments in automated data capture, data analysis and presentation in several broadly related fields (DeMers, 2000; Clarke, 2001; Lo and Yeung, 2003). Essentially all disciplines are attempting the same kind of operation: to develop a powerful set of tools for collecting, sorting, retrieving, transforming and displaying real-world spatial data for particular purposes. This set of tools constitutes a *'Geographic Information System (GIS)'*. The first geographic information system (also known as Geographical Information System) when first developed in the early 1960s in Canada (called 'Canada Geographic Information System'), they were no more than a set of innovative computer-based applications for map data pro-cessing that were used in a small number of government agencies and universities only (Lo and Yeung, 2003).

GIS is generally defined as a computer-assisted mapping and cartographic application, a set of spatial-analytical tools, a type of database systems, or a field of academic study. In order to provide a simple working definition of GIS, the two widely-used definitions are: (i) "GIS is a system of hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data for solving complex planning and management problems" (Rhind, 1989); and (ii) "GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information" (USGS, 1997).

As GIS is a computer-based information system that is designed to work with data referenced by spatial or geographic coordinates. Therefore, it is both a database system, with specific capabilities for spatially referenced data, as well as a set of operations for working with these data. Since its inception, GIS technology has been strongly associated with the mapping and management of natural resources. Although GIS continues to be used for automating the making of forest maps, attention is largely focused on developing and using the modeling capabilities of GIS software to analyse natural resource issues and concerns.

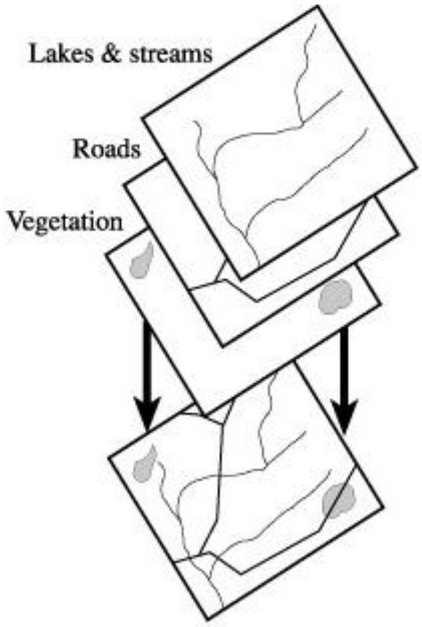

Figure 1: Overlays

What GIS can do?

There are five basic questions which a complete GIS must answer. These are:

- What exists at a particular location?

  Given a geographic reference (eg. Latitude and longitude) for a location, the GIS must describe the features of that location.

- Where can specific features are found?

This is the converse of the first question. For example, where are the districts with rainfall greater than 500mm and less than 750mm.

- Trends or what has changed over time?

  This involves answering both questions above. For example, at what locations are the crop yields showing declining trends.

- What spatial patterns exist?

  If occurrence of a pest is associated with a hypothesized set of conditions of temperature, precipitation, humidity, where do those conditions exist.

- Modeling or what if…..?

  This is a higher level application of GIS and answers questions like what would be the nitrate distribution in groundwater over the area if fertilizer use is doubled.

The abilities to separate great quantities of information about the environment into layers, explore each layer with a powerful suite of analytical tools, and then combine the layered information to use it in an integrated fashion is what makes the GIS a powerful and effective decision-support tool for agricultural and environmental management.

VISUAL MODFLOW AND ITS APPLICATION

Universal use of Visual MODFLOW groundwater modeling has been well accepted and well documented in many research journals. Visual MODFLOW interface has been specifically designed to increase modeling productivity and decrease complexities typically associated with building three-dimensional groundwater flow and contaminant transport models.

The interface is divided into three separate modules, the input module, the Run Module, and the output Module. Visual MODFLOW is one of the most popular groundwater modeling software package which bears a number of proven standards. It has several professional applications like: a) Evaluate Groundwater Remediation Systems, b) Delineate Well Capture Zones, c) Estimate the reductive Dechlorination of TCE, PCE and DCE in Groundwater, d) Design and optimize pumping well Locations for Dewatering Projects, e) Determine Contaminant Fate and Exposure Pathways for Risk Assessment.

Visual MODFLOW simulates groundwater flow in aquifer systems using block centered finite difference method. In this method, an aquifer system is divided into rectangle blocks by a grid. The grid of blocks is organized by rows, columns and layers and each block is commonly called a cell. For each cell within the volume of the aquifer system, aquifer properties and information related to wells, rivers and other inflow and outflow features are specified. MODFLOW uses the input to construct and solve equations of groundwater flow in the aquifer system.

REVIEW OF LITERATURE

Various techniques and methodologies have been developed to evaluate groundwater potential in the past. Maps are produced from a set of decisional criteria linked to a number of physical parameters but the choice depends on the model used for it. Vulnerability maps can be calculated with the aid of a GIS. GIS allows spatial data gathering and, at the same time, gives a means for data processing, such as geo-referencing, integration, aggregation, or spatial analysis (Burrough and McDonnell, 1998).

Kamaraju *et al*. (1995) evaluated the groundwater potential in West Godavari District of A.P., India using GIS. They used the existing maps and records as input data which were in different forms and scales, and created a GIS database using ArcInfo software. The descriptive information was converted into “groundwater favorability index” by rating the various groundwater-controlling characteristics according to their weightings to the output.

The groundwater potential map thus generated showed three major hydrogeologic conditions with distinct groundwater prospects. They emphasized that the GIS technique is very time-and cost-effective and could be employed successfully in the planning stage of a groundwater exploration programme.

Krishnamurthy *et al*. (1996) used remote sensing and GIS for demarcating groundwater potential areas in the Marudaiyar basin of Tamil Nadu, India. They prepared the maps of lithology, landforms, lineaments and surface water bodies from the remotely sensed data, and those of drainage density and slope from SOI (Survey of India) toposheets. These thematic maps were integrated and analyzed using a model developed with logical conditions in a GIS. Finally, the groundwater potential zone map thus developed was verified with field data, which indicated a good agreement.

Shahid and Nath (2002) analyzed the hydro geologic data obtained from remote sensing and surface geophysical techniques for evaluating the groundwater condition in a soft-rock terrain of Midnapore District, West Bengal, India. The IRS LISS-II data were used for generating the thematic map of geology. Vertical electrical sounding (VES) survey was conducted at 139 locations in the study area, and the data were interpreted using genetic algorithm and Ridge Regression techniques.

The aquifer resistivity and thickness thus obtained were used to prepare the corresponding thematic maps. Weights were assigned to different ranges of resistivity and thickness values based on their position on the geological map. Finally, the weighted maps were integrated using a GIS-based aggregation method to identify ground-water potential zones in the study area.

Srinivas Rao.k, (2002), has created the database (i.e. Spatial and Non-Spatial database) and imported into ARC/INFO as coverage. The required non-spatial database is attached to respective coverage. The module selects the relevant coverage’s and calculates the recharge or seepage of individual component/coverage. The module then combines the results of individual components and displays value of Groundwater Balance and the categorization of the watershed.

Kumar C. P. (2003) reviewed the available groundwater modeling software’s. MODFLOW (Three-Dimensional Finite-Difference Ground-Water Flow Model) has become the worldwide standard groundwater flow model. It is used to simulate systems for water supply, containment remediation and mine dewatering. When properly applied, MODFLOW is the recognized standard model.

Samuelson and Alan C, (2004) their study was undertaken to improve understanding of the geologic and hydro geologic framework of Delaware County, Indiana. Arc View GIS 3-D and Spatial Analysts along with VISUAL MODFLOW were used to study ground water flow patterns by developing a 3-D model of major aquifers. Areas of upward and downward gradients implied from differences in static water levels in shallow versus deeper wells are compared with areas of higher versus lower recharge in different soil associations and with flow paths in the model.

STUDY AREA AND METHODOLOGY

The study area chosen is the Thirukkazhukundram Taluk of Kanchipuram District in Tamilnadu, one of the most groundwater exploited taluks in Tamilnadu. According to GEC recommendations groundwater should be assessed normally based on watershed approach. Further if the area to be assessed is alluvial area, then groundwater assessment may be done on block/taluk basis. As this study area is around 70% alluvial, groundwater potential is assessed on block basis. GEC norms were used to estimate the groundwater potential of the study area.

Following thematic maps were prepared using remotely sensed data viz., Land use map, Geology map, Geomorphology map, Rainfall, Soil map, Slope map. Thematic maps were prepared using base map of the study area. As the first step SOI topo sheet in which the study area lies was collected from the respective department. For giving input to GIS software the prepared thematic maps are to be digitized.

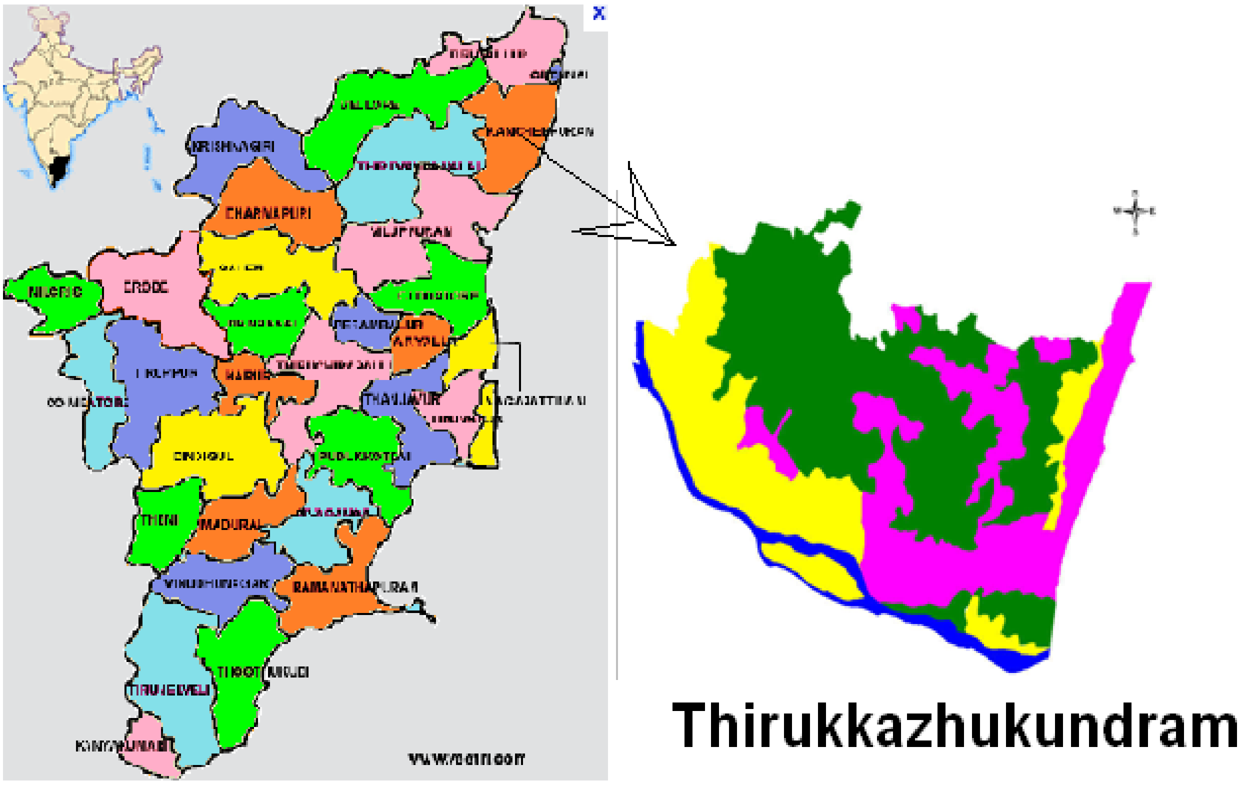

Figure 2: Key Plan of Study Area

The digitization is done on screen using MapInfo software and the attributes for the corresponding features are added in the table. Weights were assigned to each theme as per the experts opinion as given below in Table.1.

Table 1: Weights to Each Theme

S.No	Theme	Weights
1	Geology	27
2	Soil	20
3	Geomorphology	20
4	Rainfall	15
5	Land use	10
6	Slope	10

Using the GIS software Arc View all these thematic maps are overlaid and the final overlaid map which shows the ground water potential zones is obtained. Collateral data like, Rainfall and agricultural data, Temperature data, Well data, Aquifer details, Tank details, population data etc were also obtained. The following figure 3 explains the flow diagram of the methodology adopted.

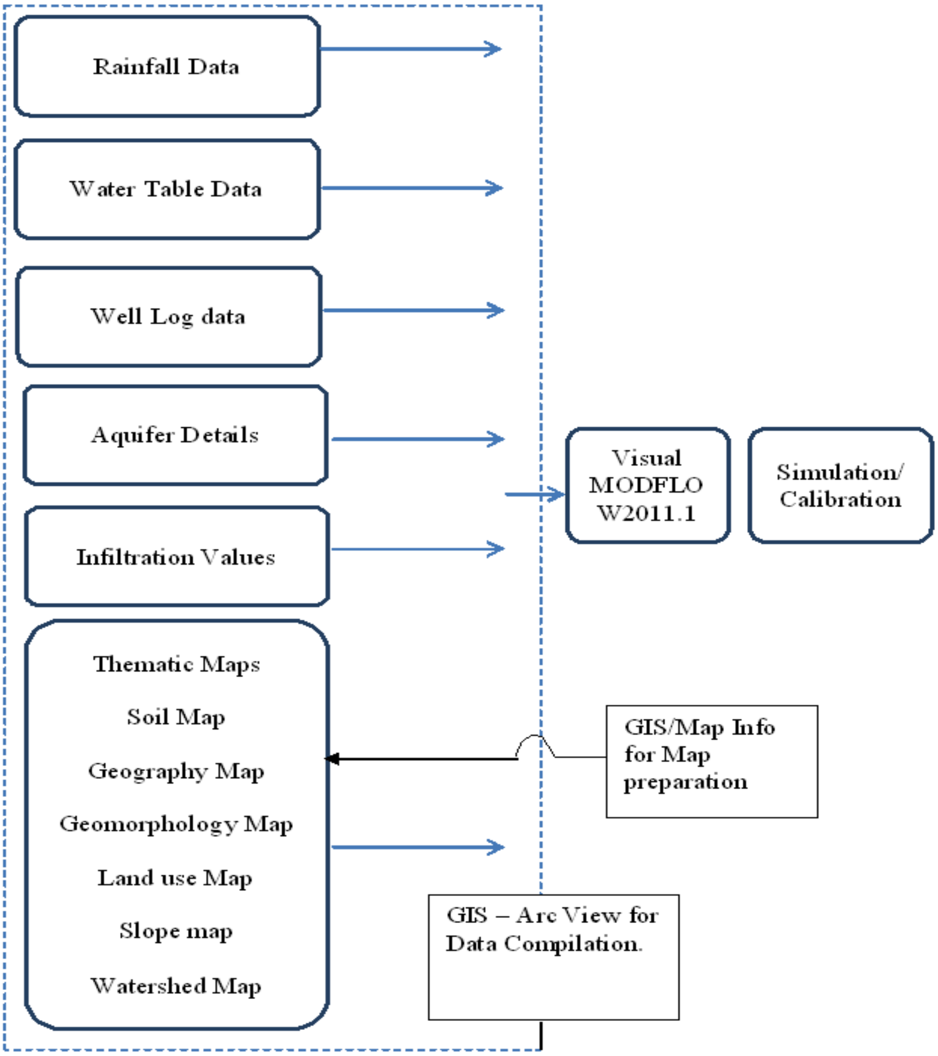

Figure 3: Flow Diagram of the Methodology

GROUNDWATER FLOW MODEL

The use of groundwater models is prevalent in the field of Water Resource Engineering. Models have been applied to investigate a wide variety of hydro- geologic conditions. In general, models are conceptual descriptions or approximations that describe physical systems using mathematical equations; they are not exact descriptions of physical systems or processes. By mathematically representing a simplified version of a hydro geological system, reasonable alternative scenarios can be predicted, tested, and compared. Groundwater models describe the groundwater flow processes using mathematical equations based on certain simplified assumptions. These assumptions typically involve the direction of flow, geometry of the aquifer, the heterogeneity or anisotropy of sediments or bedrock.

With the development of the computing science and computers, groundwater numerical simulation technology is developed rapidly, which can not only solve the problems of quantitative assessment on groundwater flow and quantity, but also can be used to solve the problems of solute transport and thermal transport of groundwater and land sedimentation. The development trend of groundwater numerical simulation model reflects the following characteristics: (1) a friendly interactive interface; (2) generalization: a lot of groundwater models are able to solve a variety of types of problems of groundwater software simulation, for example, they are able to solve the one-dimensional, two-dimensional and three-dimensional problems, and they are also able to solve the problems of flow, solute transport and thermal transport of groundwater; (3) intelligence of pre-handling and post processing, such as the automatic partition of calculation region, discrete points interpolation, the automatic detection of errors, balanced calculation and visual expression and etc. (4) based on GIS technology base. At present, there are more advanced foreign models of groundwater software, such as Visual Modflow, GMS, FEFLOW, and PMW in and so on.

Visual MODFLOW was used as modeling software for the simulation. As a first step of groundwater flow model generation the data base which includes the details like bore hole details of wells physical parameters like, hydraulic conductivity, storage coefficient, soil type, geology types, lithology details, time series data on rainfall etc were obtained. For the flow in aquifer of large horizontal extent, compared to their thickness, it may be assumed that the variations of Groundwater head in vertical direction are so small that it can be neglected. This leads to a two-dimensional model in the horizontal plane. In the present analysis unconfined aquifer alone is considered. Figure 4 Shows the groundwater model flow for the same using Visual MODFLOW.

The Following data are given as input to the Visual MODFLOW package to calibrate and simulate the real field aquifer.

- Model Grid
- Type of layer
- Boundary condition
- Initial Hydraulic head
- Horizontal Hydraulic conductivity
- Specific yield.

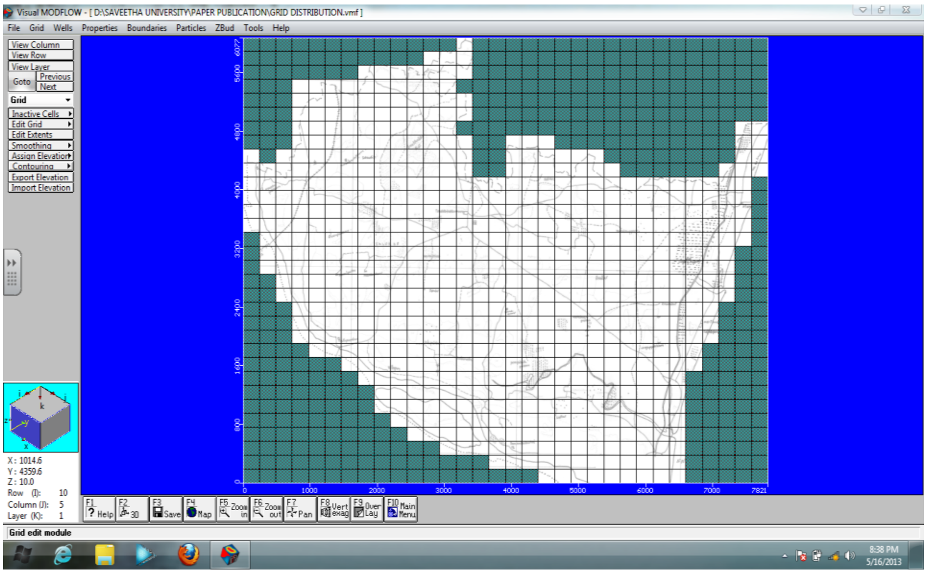

Figure 4: Groundwater Flow Model

RESULTS AND DISCUSSIONS

GIS is a very effective tool for the data compilation and assessment. GIS could be used very effectively for this study along with Visual MODFLOW which gave a very good satisfactory simulation results. Long term water table trend and water table trend for individual wells for pre & post monsoon were drawn using 20 years (1991 – 2011) water level data. Comparing the long term water table trend and stage of development the study area was categorized as critical one. Visual MODFLOW was used to simulate water levels in the observation wells. The time period from January 2000 to

December 2011 was used for the calibration of the model and data of two years (2008-2010) were used for simulation. Simulated Water levels show satisfactory correlation with the observed ones. Calibration of the developed groundwater model is showing satisfactory correlation with the observed data. Better results could have been achieved if there were more spatially distributed wells available for study. As pointed out earlier the effectiveness of a model especially water related model mainly depends upon the availability and accuracy of the vast number of collateral data. The things could have been assessed in a better way if more distributed data were available for reference. However with the available limited data the simulation model shows better results.

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