A review of integrated RS and GIS technique in groundwater potential zone mapping

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ABSTRACT

Groundwater is important and dependable source of water for various utilization in India. Productivity through groundwater is quite high as compared to surface water, but groundwater resources have not yet been properly exploited. Since the ground water is a hidden resource, a number of parameters like geology, lithology, geomorphology, soils, land use/cover, drainage pattern, lineaments which controls occurrence and movement of groundwater are to be considered and analyzed based on deductive techniques involving complex processes for groundwater potential zones mapping. Remote sensing (RS) and GIS based groundwater studies along with field investigations is found to be effective tool for complex groundwater studies. This review paper highlights RS and GIS technologies and their applications in groundwater potential zones mapping by comparing the work of other investigators in this field. The present study revealed that models used to calculate Ground Water Potential Index (GWPI) vary from one study to another. Also selection and weightages of thematic layers used are arbitrary and based on personal judgement. So it is necessary to develop standard model for this study, which will certainly enable us to develop and manage precious groundwater resource.

Keywords: Groundwater mapping, RS, GIS.

1. INTRODUCTION

Groundwater is important and dependable source of water for various utilization in India. It has emerged as the backbone of India's agriculture and drinking water security. According to Central Groundwater Board (CGWB), 2013, total annual replenishable groundwater resource of India is 447 bcm. Contribution of ground water is nearly 62% in irrigation, 85% in rural water supply and 45% in urban water supply (Ministry of Water Resources, River Development and Ganga Rejuvenation). Ground water is an annually replenishable resource but its availability is non-uniform in space and time.

Groundwater is a hidden resource and its occurrence at any place on the Earth is not a matter of chance but a consequence of the interaction of climatic, geologic, hydrologic, physiographic, and ecological factors. Factors like geology (lithology/structure), geomorphology, soils, land-use/land cover, etc., control the occurrence and movement of groundwater.

Remote sensing is defined as the process or technique of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device without being in contact with the object, area, or phenomenon being studied (Chandra and Ghosh 2002). Remotely sensed data with its advantages of spatial, spectral and temporal availability of data provides quick and baseline information on the factors controlling directly or indirectly the occurrence and movement of groundwater. A systematic study of these factors leads to better mapping of groundwater potential zones.

Geographic information system (GIS) is an information system that is designed to work with data referenced by spatial or geographic coordinates. It is an effective tool for efficiently handling large and complex spatial data and decision making in natural resources management.

Integrated RS and GIS technique has emerged as an effective tool for mapping of groundwater potential zones for hydrogeological reconnaissance areas of the world where the coverage of detailed geological maps and field data is insufficient. The important physical features of the landscape which can be derived from satellite imagery and used in GIS environment for assessing groundwater potential are summarized in Table 1.

Table 1: Salient physical features of the landscape used for assessing groundwater condition from RS data (Jha et al. 2007)

Sl.No	Surficial feature	Information obtained
1	Topography	The local and regional relief setting gives an idea about the general direction of groundwater flow and influence on groundwater recharge and discharge
	Low slope (0-5°)	Presence of high groundwater potential
	Medium slope (5-20°)	Presence of moderate to low groundwater potential
	High slope (>20°)	Presence of poor groundwater potential
2	Geologic landforms	
	Modern alluvial terraces, alluvial plains, floodplains and glacial moraines	Favorable sites for groundwater storage
	Sand dunes	Give an idea about the presence of underlying sandy glacio-fluvial sediments, which indicate the presence of groundwater
	Rock outcrops	Presence of potential aquifer
	Thick weathered rocks	Moderate groundwater existence
	Rocks with fractures/fissures	Very good or excellent potential of groundwater
	Rocks without fractures/fissures	Unfavorable sites for groundwater occurrences
	Hillocks, mounds and residual hills	Unfavorable sites for groundwater existence
3	Lakes and streams	
	Ox-bow lakes and old river channels	Favorable sites for groundwater extraction
	Perennial rivers and small perennial and intermittent lakes	High to moderate potential of groundwater
	Drainage density	High drainage density indicates unfavorable site for groundwater existence, moderate indicates moderate groundwater potential and less/no drainage density indicates high groundwater potential
	Drainage pattern	Gives an idea about the joints and faults in the bedrock which in turn indicates the presence or absence of groundwater
4	Lineaments	Give an idea about the underground faults and fractures and thereby indicate the occurrence of groundwater

2. FACTORS INFLUENCING GROUNDWATER POTENTIAL

The parameters mostly influencing the delineation groundwater potential zones are as discussed below.

2.1 Rainfall

Rainfall the main driver of the hydrologic process, is the major source of groundwater recharge. The amount of recharge depend on various hydro-meteorological and topographic factors, soil characteristics and depth to water table. The spatial and temporal variations, intensity, duration affects the infiltration and thereby groundwater storage.

2.2 Topography

The topographic slope of the area has its own importance in controlling the runoff, recharge and movement of groundwater water. Slope controls the infiltration of surface runoff. Generally, flat and gently sloping areas promote infiltration and groundwater recharge, and steeply sloping grounds encourage run-off and little or no infiltration. Groundwater potentiality is expected to be greater in the flat and gently sloping area. Flatter topography then will give more chance for groundwater accumulation.

2.3 Geomorphology

Geomorphology is the study of the physical features of the surface of the earth and their relation to its geological structures. It controls the subsurface movement of groundwater. Geomorphic units like alluvial plains, valleys fill and deeply weathered buried pediplains have good groundwater potential. Geomorphology of an area depicts important geomorphic units, landforms and underlying geology so as to provide an understanding of the processes, materials/lithology, structures, and geologic controls relating to groundwater occurrence as well as to groundwater prospects.

2.4 Geology

Geology determines the soil and exposed rocks infiltration capabilities and govern the flow and storage of water. Lithology characterized by massive rock along with topography influences the groundwater availability.

2.5 Lineament

A lineament is a linear feature in a landscape which is an expression of an underlying geological structure such as a fault, fracture, and joint. They provide pathways for groundwater movement and have water holding capacity. The presence of lineaments in an area results in increased secondary porosity and therefore serves as groundwater potential zone. Fracture zones, shear zones and igneous intrusions such as dykes can also give rise to lineaments. Generally lineaments are underlain by zones of localized weathering and increased permeability and porosity. Therefore mapping of lineaments closely related to groundwater occurrence and yield is essential to groundwater surveys, development, and management. Lineament analysis for groundwater exploration in hard rock terrain has considerable importance as joints and fractures serve as conduits for movement of groundwater.

2.6 Soil Type

The transmission of surface water into an aquifer system is a function of soil type, texture, permeability and structure. The infiltration capacity of soil helps the rain water to enter into soil. Soils with high rate of infiltration act as good groundwater recharge medium. Sand or gravel allow maximum infiltration whereas in clay or fine grained soils infiltration is less which causes surface runoff.

2.7 Drainage Pattern and Drainage Density

Drainage pattern of any terrain reflects the characteristics of surface as well as subsurface formations. They are classified as dendritic, parallel, rectangular, radial and annular. Drainage density (expressed in terms of km/sq.km) indicates the total length of all streams and rivers in a drainage basin divided by the total area of the drainage basin. It indicates the permeability and porosity of the terrain and therefore is an important factor in groundwater evaluation. More the drainage density, higher would be runoff. Thus, the drainage density characterizes the runoff in the area or in other words, the quantum of rainwater that could have infiltrated. Hence lesser the drainage density, higher is the probability of recharge or potential groundwater zone.

2.8 Groundwater Recharge

Depth to groundwater level data of pre and post-monsoon season provide sufficient information about groundwater conditions. Seasonal fluctuation of the water table is directly related to groundwater recharge. Subtraction of the pre-monsoon water table from the post-monsoon water table image yields a water level fluctuation image.

2.9 Land Use/ Land Cover

Land use/ land cover plays a significant role in the development of groundwater resources. The nature of land surface and its pattern control infiltration and runoff. The regional relief setting along with land use/ land cover gives an idea about general direction of groundwater flow and its influence on groundwater recharge and discharge.

3. REVIEW OF RESEARCHERS

Thomas *et al.* (2009) used Landsat ETM+ data along with ERDAS Imagine and ArcGIS software for the data processing to delineate potential groundwater zones in Kalikavu Panchayat of Malappuram district, Kerala, India. They used a decision rule to reclassify the composite output map scores into different zones. They followed advice of field experts for the relative weights and rates for each theme and their feature. They validated results using the long term average water level of the wells in the area. They assumed that all the parameters used are unconditionally independent. This may not be reflecting the reality as the geomorphology map is in itself a combination of expert judgement that takes into account the slope, land use and various geo-morphometric parameters. They have not conducted conditional independence test and uncertainty analysis on parameters.

Rao and Jugran (2003) used IRS ID-LISS III and Landsat 5 TM data along with Integrated Land and Water Information System (ILWIS) software as efficient and effective result oriented method for delineation of groundwater potential zones in hard rock terrain, Chittoor area, located in the drought-prone Rayalaseema region of Andhra Pradesh, India. They assigned a knowledge-based hierarchy of weights for Different classes in each thematic map. They concluded that IRS ID image data were somewhat more useful than the Landsat 5 data for identification of dikes and hydrological features, due to the inherent higher image resolution (23.5 m *vs* 30 m). They found that comprehensive use of GIS resulted in the development of an efficient and effective methodology of spatial data management and manipulation.

Jaiswal *et al.* (2003) used IRS LISS III and PAN sensor with ARC/INFO GIS software package to depict village-wise groundwater prospect zones in Gorna sub-basin, a part of the Son watershed, Madhya Pradesh, India. They used Knowledge-based weight assignment for each theme and their features. They neglected the effect of surface waterbodies on groundwater recharge and assigned zero weight for thematic map of it. They developed a model for dividing the maximum and minimum values into different categories using relevant logical conditions through GIS and also to find out the upper and lower values. Their study demonstrated the capabilities of a RS data and GIS technique for demarcation of groundwater prospects, especially in typical hard rock terrain where the occurrence of groundwater is more complex and restricted.

Shahid and Nath (2000) used IRS-1B LISS-II data to demarcate the groundwater potential zone in a soft rock area of Midnapur District, West Bengal, India. They integrated and evaluated each feature of all the thematic maps according to its relative importance to calculate the Ground Water Potential Index (GWPI). They followed DRASTIC ratings of Aller *et al*. (1987) to rank thematic maps of net recharge and slope, while knowledge based weightage was given to rest of thematic maps.

Saraf and Choudhury (1998) used IRS-LISS II data along with other data sets to extract information on the hydrogeomorphic features of a hard rock terrain in the Sironj area of Vidisha district of Madhya Pradesh, India. They collected IRS-LISS-II digital data on 27 February 1995 because it is the peak time of growth of winter crops (Rabi) and dry season vegetation is an indicator of groundwater. It also facilitated them discrimination of lithologic characters than post-monsoon data. They found that Contrast stretching of individual bands is effective in improving interpretability of different features. On the basis of relative importance they decided set of weights for different information layers and derived the best suitable condition. They concluded that evaluation of groundwater conditions in an area needs information on seasonal water level fluctuations and groundwater recharge.

Jasrotia *et al.* (2011) carried out groundwater exploration in the Western Doon valley with the help of IRS-ID, LISS-III data. For groundwater exploration they assigned weights to various themes ranged from 1 to 10 like the highest weight assigned to the class which is excellent for groundwater potential. They found that high groundwater potential zones are associated with the part of older terrace (alluvium) and lower piedmont unit which is characterized by shallow water table, higher aquifer thickness, low drainage density and very low slopes, whereas very low potential zones in residual hills, denudational hills, and structural hills with high slope as runoff zone in the study area.

Mohanty and Behera (2009) delineated groundwater potential units using Landsat TM data and Integrated Land and Water Information (ILWIS) in Khallikote block of Ganjam disrict, Orissa. They used the SMCE (Spatial Multi- Criteria Evaluation) module to support the decision-making process for evaluating the ground water potential zones in the area. They found that excellent to very high categories are scattered throughout the study area in pockets mostly in the valley fill areas and along the courses of major and minor rivers. The structural and residual hills having a steep slope and where the surface runoff is more and infiltration is less is poor ground water prospect zones. Valley fills, deep buried pediments, and lineaments are the suitable locales for ground water development.

Machiwal *et al.* (2010) proposed standard methodology for delineating groundwater potential zones using RS, GIS and multi-criteria decision making (MCDM) techniques by a case study in Udaipur district of Rajasthan, western India. They performed principal component analysis to select influential layers for groundwater prospecting and selected thematic layers and their features were assigned suitable weights on the Saaty's (1980) scale according to their relative importance. They normalized assigned weights of the thematic layers and their features by using AHP (analytic hierarchy process) MCDM technique and eigenvector method.

Themes and methodologies used to calculate GWPI by all the above researchers are summarized in table 2.

Table 2: Themes and GWPI calculation methodologies

Sl.No	Method of calculation of GWPI	Themes used	Researcher
1	Heuristic method	Land use/land cover, geomorphology, slope, soil, drainage type, geology	Thomas *et al.* (2009)
2	Weighted aggregation method	Slope, geology, lineament distance, hydro-geomorphology, depth to water table, drainage channel distance, well yield	Rao and Jugran (2003)
3	Weighted aggregation method	Lithology, landform, soil, land use/land cover, lineament, surface water bodies, slope, drainage density	Jaiswal *et al.* (2003)
4	Normalized aggregation method	Lithology, geomorphology, soil, drainage density, slope, net recharge, surface water bodies	Shahid And Nath (2000)
5	Weighted aggregation method	Soil, slope, geology, geomorphology, lineament	Saraf and Choudhury (1998)
6	Index overlay	Hydro-geomorphology, land use/land cover, slope, soil, drainage density, pre and post monsoon water table, static water level	Jasrotia *et al.* (2011)
7	Spatial Multi- Criteria Evaluation (SMCE) and overlay analysis	Geology, geomorphology, land use/land cover, drainage density, lineament density, slope	Mohanty and Behera (2009)
8	Multi-criteria decision making(MCDM) and Weighted linear combination	Slope, geomorphology, elevation, rainfall, surface water bodies, geology, soil, pre and post monsoon water table, net recharge	Machiwal *et al.* (2010)

4. METHODOLOGY

4.1 Preparation of thematic maps

In order to assess groundwater potential of study area thematic maps of different parameters influencing groundwater potential are generated with the help of RS and GIS software. Different thematic layers required for groundwater potential zones mapping along with their source of data collection in India are summarized in table 3.

Table 3: Thematic layers and their source of collection in India

Sl.no	Thematic map	Source of data
1	Rainfall map	India Meteorological Department (IMD) / National Informatics Centre
2	Topographic map	Survey of India (SOI) topo sheets / SRTM data
3	Geomorphological map	National Remote Sensing Centre (NRSC) / Satellite imageries
4	Geological map	Geological Survey of India (GSI)
5	Lineament map	Geological Survey of India (GSI)
6	Soil map	National Bureau of Soil Survey and Land Use Planning (NBSS and LUP)
7	Drainage map	Survey of India (SOI) topo sheets
8	Groundwater recharge	Central Ground Water Board / Groundwater Surveys Development Agency
9	Land use/ land cover	National Remote Sensing Centre (NRSC) / Satellite imageries

4.2 Selection of thematic maps

Selection of various thematic maps for groundwater potential zones mapping is based on their significant influence on occurrence of groundwater.

4.3 Assignment of weight

Each thematic layer and its features have relative importance on groundwater occurrence. So based on past study and experts (geologists and hydrogeologists) opinions about the relative importance of the themes and their features weights are assigned to different thematic maps and their individual features. Finally all the selected thematic maps are integrated in GIS software to generate GWPI. The GWPI is computed by using the weighted linear combination method (Malczewski 1999) as given in Eq. 1

$$GWPI = \sum_{w=1}^{m}\sum_{i=1}^{n}(w_j \times x_i) \quad (1)$$

Where, GWPI = groundwater potential index, x_i = normalized weight of the ith class/feature of theme and w_j = normalized weight of the jth theme, m= total number of themes, and n = total number of classes in a theme.

Based on this GWPI groundwater potential zones are delineated.

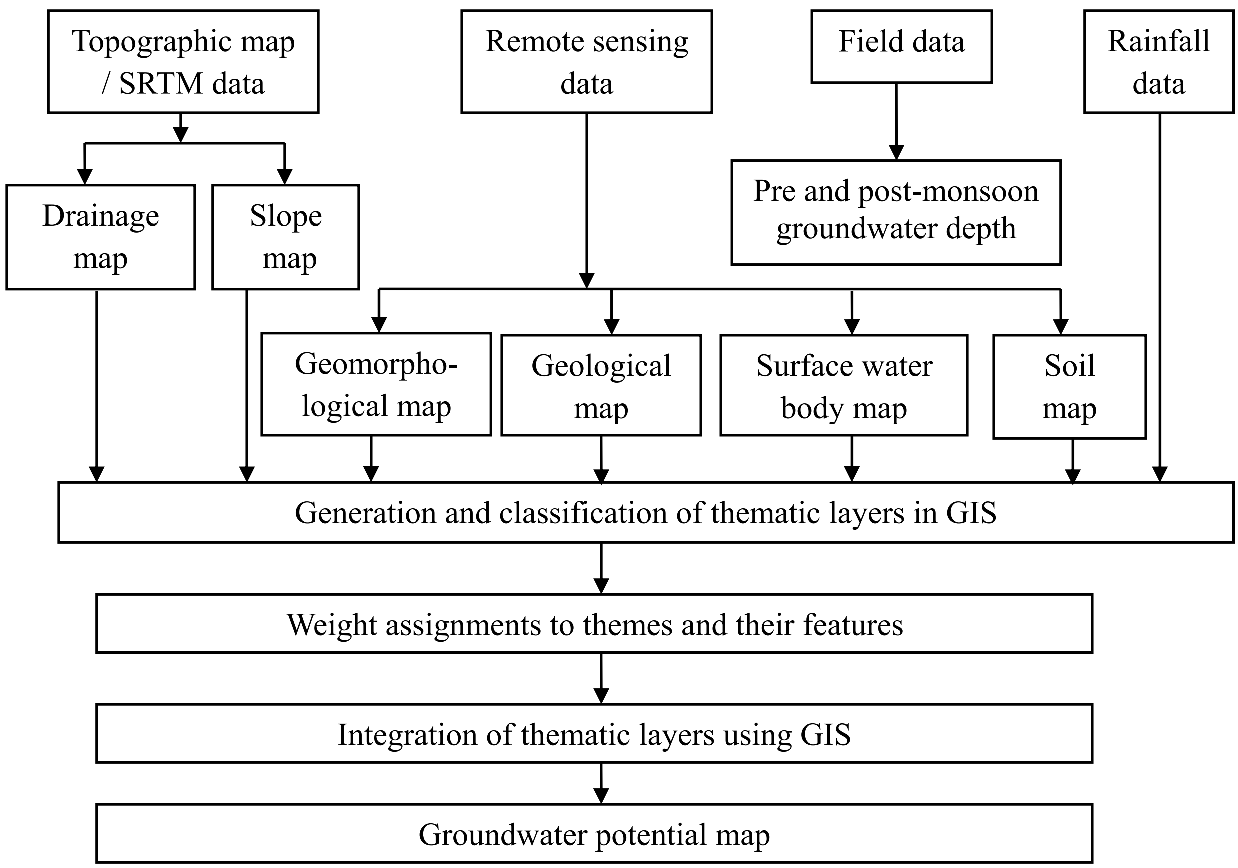

Figure1: Flow chart for mapping of groundwater potential zones using RS and GIS

5. CONCLUSION

The detailed reviews presented in this paper highlights the application of integrated RS and GIS technologies in groundwater exploration and assessment. The present study put emphasis on following points:

(i) RS and GIS techniques are powerful tools for evaluating groundwater potential which can help prepare a suitable and cost-effective groundwater exploration plan for any area.

(ii) The methodology is economical as well as more suitable for developing and low-income countries where adequate and good quality hydro-geologic data are often lacking for groundwater evaluation by data-intensive techniques.

(iii) Type and number of thematic layers used by researchers vary from one study to another and their selection is also arbitrary.

(iv) In majority of the studies personal judgment has been used to assign weights to various thematic layers and their features.

(v) Field investigation is also vital parameter to effectively exploit the potential of RS and GIS technology.

(vi) Standard methodology for groundwater potential mapping with integrated RS and GIS is generally lacking. A standard model for this study will certainly enable us to develop and manage precious groundwater resource.

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