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

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Abstract
Groundwater is an essential and dependable source of water in India for various uses. Groundwater productivity is quite high when compared to surface water, but groundwater resources have yet to be fully utilized. Because groundwater is a hidden resource, a variety of parameters such as geology, lithology, geomorphology, soils, land use/cover, drainage pattern, and lineaments that control the occurrence and movement of groundwater must be considered and analyzed using deductive techniques involving complex processes for mapping groundwater potential zones. Remote sensing (RS) and GIS-based groundwater studies, in conjunction with field investigations, have been discovered to be effective tools for complex groundwater studies. This review paper compares the work of other researchers to highlight RS and GIS technologies and their applications in groundwater potential zone mapping. The current study discovered that the models used to calculate the Ground Water Potential Index (GWPI) differed from one study to the next. Thematic layer selection and weightages are also arbitrary and based on personal judgment. As a result, a standard model for this study is required, which will undoubtedly allow us to develop and manage precious groundwater resources.

Keywords: Groundwater mapping, RS, GIS

Introduction
Groundwater is an important and dependable source of water in India for a variety of uses. It has emerged as India's agricultural and drinking water security backbone. According to the Central Groundwater Board (CGWB), India's total annual replenishable groundwater resource is 447 billion cubic meters (BCM). Groundwater contributes nearly 62% to irrigation, 85% to rural water supply, and 45% to urban water supply (Ministry of Water Resources, River Development, and Ganga Rejuvenation). Groundwater is a renewable resource that replenishes itself on an annual basis, but its availability varies in space and time. Groundwater is a hidden resource, and its presence anywhere on the planet is the result of the interaction of climatic, geologic, hydrologic, physiographic, and ecological factors. Geology (lithology/structure), geomorphology, soils, land-use/land cover, and other factors influence the occurrence and movement of groundwater. 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 is defined as remote sensing (Chandra and Ghosh 2002) [2]. The integrated RS and GIS technique has emerged as an effective tool for mapping groundwater potential zones for hydrogeological reconnaissance areas around the world where detailed geological maps and field data coverage is insufficient. Table 1 summarizes the key physical landscape features that can be derived from satellite imagery and used in a GIS environment to assess groundwater potential.

Factors Influencing Groundwater Potential
The parameters mostly influencing the delineation groundwater potential zones are as discussed below.

Rainfall
Rainfall, the primary driving force in the hydrologic process, is the primary source of groundwater recharge. The amount of recharge is determined by a variety of hydro-meteorological and topographic factors, soil characteristics, and water table depth. Infiltration and thus groundwater storage are affected by spatial and temporal variations, intensity, and duration.

Table 1: Salient physical features of the landscape used for assessing groundwater condition from RS data (Jha *et al*. 2007) [3]

S. 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

Topography

The area's topographic slope is significant in controlling runoff, recharge, and groundwater movement. The slope regulates the infiltration of surface runoff. In general, flat and gently sloping areas encourage infiltration and groundwater recharge, whereas steeply sloping areas encourage runoff and little to no infiltration. The potential for groundwater is expected to be greater in the flat and gently sloping area. Flatter topography allows for greater groundwater accumulation.

Geomorphology

Geomorphology is the study of the physical characteristics of the earth's surface and its relationship to its geological structures. It regulates groundwater movement beneath the surface. Groundwater potential is high in geomorphic units such as alluvial plains, valley fill, and deeply weathered buried pediplains. An area's geomorphology depicts important geomorphic units, landforms, and underlying geology to provide an understanding of the processes, materials/lithology, structures, and geologic controls relating to groundwater occurrence and prospects.

Geology

Geology governs the flow and storage of water by determining the infiltration capabilities of soil and exposed rocks. The availability of groundwater is influenced by lithology, which is characterized by massive rock, as well as topography.

Lineament

A lineament is a landscape feature that is a linear expression of an underlying geological structure such as a fault, fracture, or joint. They have the ability to hold water and provide pathways for groundwater movement. The presence of lineaments in an area increases secondary porosity, which serves as a groundwater potential zone. Lineaments can also be formed by fracture zones, shear zones, and igneous intrusions such as dykes. Lineaments are typically underlain by areas of localized weathering and increased permeability and porosity. As a result, mapping lineaments that are closely related to groundwater occurrence and yield is critical for groundwater surveys, development, and management. Lineament analysis is critical for groundwater exploration in hard rock terrain because joints and fractures serve as conduits for groundwater movement.

Soil Type
Surface water transmission into an aquifer system is determined by soil type, texture, permeability, and structure. Soil infiltration capacity allows rainwater to enter the soil. Soils with a high rate of infiltration serve as an excellent groundwater recharge medium. Sand and gravel allow for maximum infiltration, whereas clay and fine-grained soils allow for less infiltration, resulting in surface runoff.

Drainage Pattern and Drainage Density
Any terrain's drainage pattern reflects the characteristics of both surface and subsurface formations. They can be dendritic, parallel, rectangular, radial, or annular. Drainage density (measured in kilometers per square kilometer) is the total length of all streams and rivers in a drainage basin divided by the drainage basin's total area. It indicates the terrain's permeability and porosity and is thus an important factor in groundwater evaluation. The greater the drainage density, the greater the runoff. Thus, drainage density characterizes runoff in the area or the amount of rainwater that could have infiltrated. As a result, the lower the drainage density, the greater the likelihood of recharge or potential groundwater zone.

Groundwater Recharge
Pre and post-monsoon season depth to groundwater level data provide sufficient information about groundwater conditions. Groundwater recharge is directly related to seasonal fluctuations in the water table. The water level fluctuation image is obtained by subtracting the pre-monsoon water table image from the post-monsoon water table image.

Land Use/ Land Cover
The development of groundwater resources is heavily influenced by land use and land cover. Infiltration and runoff are influenced by the nature and pattern of the land surface. The regional relief setting, together with land use/land cover, provides an idea of the general direction of groundwater flow and its influence on groundwater recharge and discharge.

Review of Researchers
Thomas *et al*. (2009) [4] delineated potential groundwater zones in Kalikavu Panchayat of Malappuram district, Kerala, India, using Landsat ETM+ data, ERDAS Imagine, and ArcGIS software. They reclassified the composite output map scores into different zones using a decision rule. For the relative weights and rates for each theme and their feature, they followed the advice of field experts. They validated their findings by using the long-term average water level of the area's wells. They made the assumption that all of the parameters were unconditionally independent. This may not be accurate because the geomorphology map is a compilation of expert opinions that takes into account slope, land use, and various geomorphometric parameters. They have not conducted conditional independence test and uncertainty analysis on parameters.
Rao and Jugran (2003) [5] used IRS ID-LISS III and Landsat 5 TM data, along with Integrated Land and Water Information System (ILWIS) software, to delineate groundwater potential zones in hard rock terrain in the Chittoor area, which is located in the drought-prone Rayalaseema region of Andhra Pradesh, India. In each thematic map, they assigned a knowledge-based hierarchy of weights to different classes. Because of the inherent higher image resolution, they concluded that IRS ID image data were slightly more useful than Landsat 5 data for identifying dikes and hydrological features (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) [6] depicted village-wise groundwater prospect zones in the Gorna sub-basin, a part of the Son watershed in Madhya Pradesh, India, using IRS LISS III and PAN sensors with the ARC/INFO GIS software package. They used knowledge-based weighting to assign weight to each theme and its features. They ignored the effect of surface water bodies on groundwater recharge and gave it zero weight on the thematic map. They created a model to divide maximum and minimum values into different categories using relevant logical conditions and GIS, as well as to determine upper and lower values. Their research demonstrated the capabilities of an RS data and GIS technique for delineating groundwater prospects, particularly in typical hard rock terrain where groundwater occurrence is more complex and restricted.
Shahid and Nath (2000) [7] delineated the groundwater potential zone in a soft rock area of Midnapur District, West Bengal, India and using IRS-1B LISS-II data. To calculate the Ground Water Potential Index, they integrated and evaluated each feature of all thematic maps based on its relative importance (GWPI). They used the DRASTIC ratings of Aller *et al*. (1987) [8] to rank thematic maps of net recharge and slope, while the rest of thematic maps were weighted based on knowledge.
Saraf and Choudhury (1998) [9] extracted information on the hydro geomorphic features of a hard rock terrain in the Sironj area of Madhya Pradesh's Vidisha district using IRS-LISS II data and other data sets. They collected IRS-LISS-II digital data on February 27, 1995, because it is the peak of winter crop growth (Rabi) and dry season vegetation is an indicator of groundwater. It also aided them in distinguishing lithologic characteristics from postmonsoon data. They discovered that stretching the contrast of individual bands improves the interpretability of various features. They determined the best suitable condition by assigning weights to different information layers based on their relative importance. They concluded that information on seasonal water level fluctuations and groundwater recharge is required for assessing groundwater conditions in a given area.
Jasrotia *et al*. (2011) [10] used IRS-ID and LISS-III data to explore groundwater in the Western Doon valley. They assigned weights to various themes ranging from 1 to 10, with the highest weight assigned to the class, which is excellent for groundwater potential. They discovered that high groundwater potential zones are associated with the lower piedmont unit, which is characterised by a shallow water table, higher aquifer thickness, low drainage density, and very low slopes, whereas very low potential zones are associated with residual hills, denudational hills, and structural hills with high slope as runoff zone in the study area.
Mohanty and Behera (2009) [11] used Landsat TM data and Integrated Land and Water Information (ILWIS) to delineate groundwater potential units in the Khallikote block of Ganjam district, Orissa. They used the SMCE (Spatial Multi-Criteria Evaluation) module to aid in the decision-making process for

evaluating the ground water potential zones in the area. They discovered that excellent to very high categories are scattered throughout the study area in pockets, mostly in valley fill areas and along the courses of major and minor rivers. Poor ground water prospect zones are structural and residual hills with a steep slope and where surface runoff is higher and infiltration is lower. Valley fills, deeply buried pediments, and lineaments are ideal locations for ground water development.
Machiwal *et al*. (2010) [12] used a case study in the Udaipur district of Rajasthan, western India, to propose standard methodology for delineating groundwater potential zones using RS, GIS, and multi-criteria decision making (MCDM) techniques. They used principal component analysis to select influential layers for groundwater prospecting, and their features were assigned appropriate weights on the Saaty's (1980) scale based on their relative importance. They used the AHP (analytic hierarchy process), MCDM technique, and eigenvector method to normalize the assigned weights of the thematic layers and their features.
Themes and methodologies used to calculate GWPI by all the above researchers are summarized in table 2.

Table 2: Themes and GWPI calculation methodologies

S. 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) [4]
2.	Weighted aggregation method	Slope, geology, lineament distance, hydro geomorphology, depth to water table, drainage channel distance, well yield	Rao and Jugran (2003) [5]
3.	Weighted aggregation method	Lithology, landform, soil, land use/land cover, lineament, surface water bodies, slope, drainage density	Jaiswal *et al*. (2003) [6]
4.	Normalized aggregation method	Lithology, geomorphology, soil, drainage density, slope, net recharge, surface water bodies	Shahid And Nath (2000) [7]
5	Weighted aggregation method	Soil, slope, geology, geomorphology, lineament	Saraf and Choudhury (1998) [9]
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) [10]
7.	Spatial Multi- Criteria Evaluation (SMCE) and overlay analysis	7 Geology, geomorphology, land use/land cover, drainage density, lineament density, slope	Mohanty and Behera (2009) [11]
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) [12]

Methodology

Preparation of thematic maps

To assess the groundwater potential of the study area, thematic maps of various parameters influencing groundwater potential are generated using RS and GIS software. Table 3 summarises the different thematic layers required for mapping groundwater potential zones, as well as their data collection sources in India.

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

S. 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

Selection of thematic maps

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

Assignment of weight

Each thematic layer and its features play a different role in groundwater occurrence. Weights are assigned to different thematic maps and their individual features based on previous research and expert (geologists and hydro geologists) opinions about the relative importance of the themes and their features. Finally, all of the chosen thematic maps are imported into GIS software to generate GWPI. The weighted linear combination method (Malczewski 1999) [18] is used to compute the GWPI, as shown in Eq. 1.

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

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.

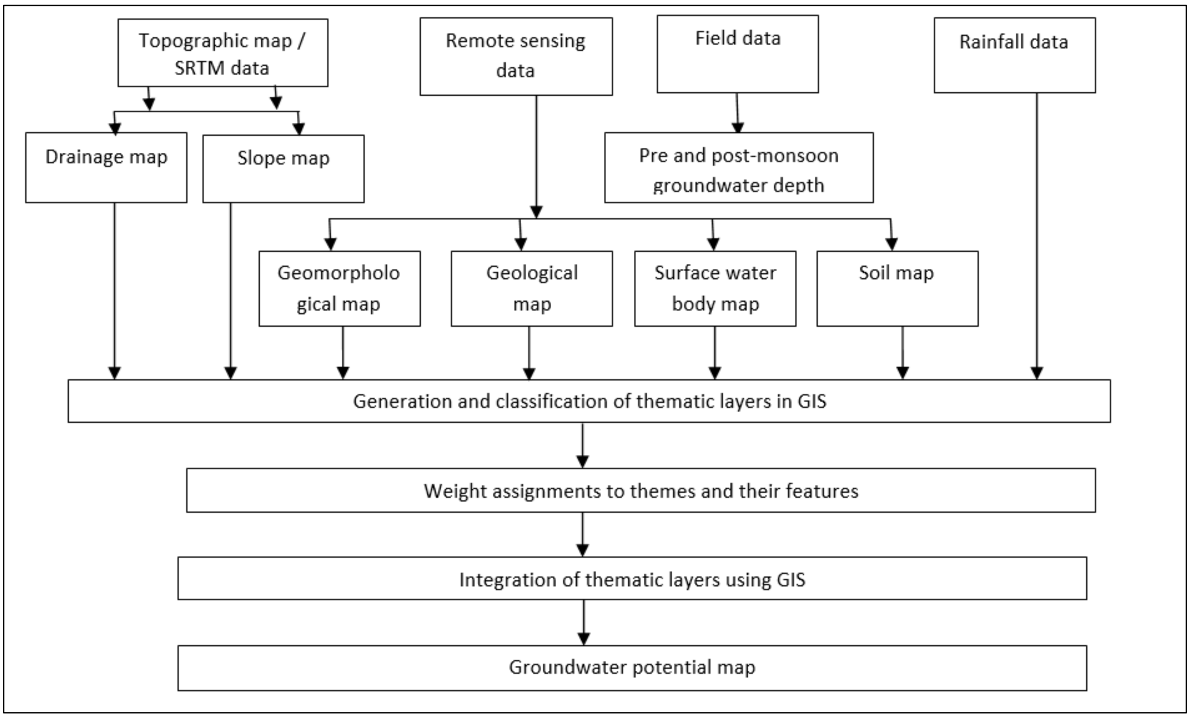

Fig 1: Flow chart for mapping of groundwater potential zones using RS and GIS

Conclusion

This paper's detailed reviews highlight the use of integrated RS and GIS technologies in groundwater exploration and assessment. The following points were highlighted in the current study:

1. 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.
2. 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.
3. Type and number of thematic layers used by researchers vary from one study to another and their selection is also arbitrary.
4. In majority of the studies personal judgment has been used to assign weights to various thematic layers and their features.
5. Field investigation is also vital parameter to effectively exploit the potential of RS and GIS technology.
6. 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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