Regional Groundwater Prospect Assessment: Role of Hydrogeomorphological and Lithological Indicators using Geoinformation

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Abstract:

Systematic assessment of availability of groundwater resources are the main options for the sustainable exploration and management of water resources particularly hard rock and semi-arid regions. In the present paper an attempts made to assess the regional groundwater status of the Gwalior area which is facing acute water crisis for drinking as well for Irrigation purpose. The present paper discusses the utility of remote sensing and GIS techniques for regional level groundwater prospect of the area by analyzing the hydro-geomorphic and lithological diversity.

For the evaluation of hydrogeomorphic and lithological units an integrated GIS based modeling approach has been used for the assessment of groundwater prospect of the area.

The results obtained by this work can be the primary level survey for water resource evaluation and management for proper planning and management of groundwater resources in different hydrogeological environment.

Key words: Hydrogeomorphology, Geological mapping, Remote Sensing and GIS.

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Introduction

Rapidly increasing industrial development, urbanisation, and agricultural production result in storage of water in many parts of India. Continuous extraction of water from the ground has thus decreased the water level beneath the earth surface. Hydrogeological mapping and drainage analysis forms an important part for the ground water development. Drainage assessment and analysis on the basis of relative parameters for the Gwalior district shows the relative requirement of water resource management in the area. In the recent past many of the researchers have used remote sensing data and GIS for groundwater prospects, investigating and monitoring which shows greater ability generating information in spatial and temporal domain, resulting in crucial but successful analysis validation and prediction (Raghuvanshi et al, 2008; Prasad et al, 2008; Jaiswal et al, 2003; Leblanc et al, 2007). GIS has been implemented for the delineation of morphometric characteristics of the basin (Singh and Thakur, 2012). The water demand is growing rapidly in places with increasing urbanisation and limited resources. This thrusts on the quality of water required for day-to-day life as well as running any kind of industry in the area (Sharma and Vairavamoorthy, 2009; Diwakar and Thakur, 2012). Gwalior district has many industries and the population is increasing at a fast pace. The urban sprawling and growth of population leads to relative stress on the water resources of the area. This includes all sorts of requirements like potable water, agriculture and industrial requirements (Singh and al, 2011a). Further, the untimely monsoons of low intensity create remarkable surface water supply shortages. This thrust has lead to turn to groundwater storages which in turn is explored at a tremendous rate and depleting. The result is decline of groundwater levels and drying up of aquifers due to over-exploitation. It is henceforth extremely essential to recharge groundwater almost at the same pace as it is being withdrawn. The water recharge programmes for the basins are needed to be increased (Ellis and Revitt, 2010; Rao, 2008; Eyquem, 2007). Morphometric techniques development is a major advance in the quantitative description of drainage basin geometry and its network characterizing many drainage networks thus examining effect of variables viz. rainfall, lithology and rock structure (Esper, 2008; Magesh et al, 2011; Bali et al, 2012). The drainage basin characteristics assessment via quantitative morphometric analysis provides information regarding hydrological nature of exposed rocks within the drainage basin. The drainage map provides reliable index of rock permeability and indication of yield of basin. The prevailing climate geology, tectonic framework and relief of a basin is expressed by a drainage network and also the interrelationship between drainage parameters (Thomas et al, 2012). The present work demonstrates capability of GIS applicability with satellite data for hydrogeomorphology for groundwater prospect assessment at regional level.

Study area

The study area lies between 77°40'E, 78°35'E and 25°50' N, 26°20'N and stands at a mean sea level elevation of 196m at an average. The climate of the area is moderately extremes with hot summers and cold winters. The area experiences south western monsoon rains between June to October. The annual rainfall is about <600mm. The climate is semi-arid in nature marked by extreme temperature and erratic rainfall pattern. The overall climate is dry with an exception of south-west monsoon period (June to October). The major sources of water supply are the bore wells for nearly all kinds of requirements viz. Agriculture, drinking, etc. Frequent drought like situations aggravate depleting groundwater levels; this being a common condition in all parts of the study area. Thus this water demand and thrust provokes a need for locating additional sources.

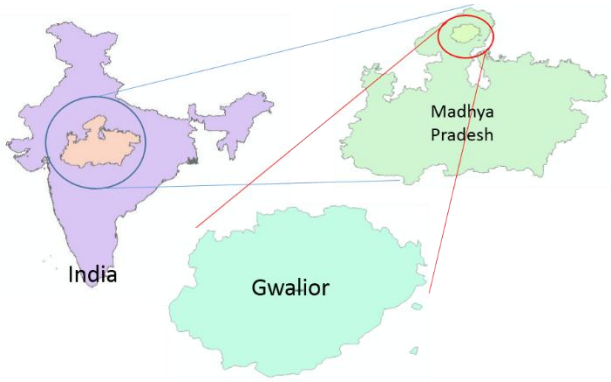

Fig 1: Location of the study area

Data Used

In the present study Landsat 8 satellite images have been used (which includes Operational Land Imager, OLI) and Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM). The data was reprojected and registered with the toposheets of the study area. Various thematic layers were generated viz. Geology, geomorphology, slope, aspect, drainage, stream order, etc. using the above data on Arc GIS 10.2 desktop version. The layers were generated using digital image processing techniques and GIS techniques. Further, Geographical Information System based processes have been used for digitization, editing, merging, integrating, and topology creation. Spatial Analysis tool was utlised for integration of thematic layers and delineation of groundwater potential zones.

Geological/Lithological Setting

The intra-cratonic Gwalior basin is present on the northwestern fringes of granitic Bundelkhand massif. The Gwalior litho-units group rest over Bundelkhand granite. These comprise of basal arenaceous Par formation overlain by volcano-sedimentary sequences of Morar formation consisting of ferruginous shale with bands of chert, jasper and limestone. The predominant rocks comprise of sandstone, shale, quartzite, doleritic dykes and alluvium (fig. 2). The weathered zones of shale, sandstone and alluvium deposits. These are an aggregation of medium-to-coarse-grained unconsolidated materials which form the principal groundwater reservoirs in the area. The thickness of this weathered zone is generally greater in the northern portion. In general, two to three water-bearing formations occur within a depth of 100 m. The Gwalior group of rocks is divided into two formations, viz, Morar formation and Par formation. The Gwalior Group of rocks overlie the Vindhyans group and are the youngest rocks in the region (Singh et al, 2011b). The water-yielding capacity of rocks largely depends on the extent of fracturing, openness, size of fracture, and nature of the interconnections between fractures. The area is covered by alluvium, sandstone and shales and the occurrence of groundwater in different formations varies with the rock type. The thickness of alluvium varies between 10 and 30 m. It is the most extensive aquifer in the area.

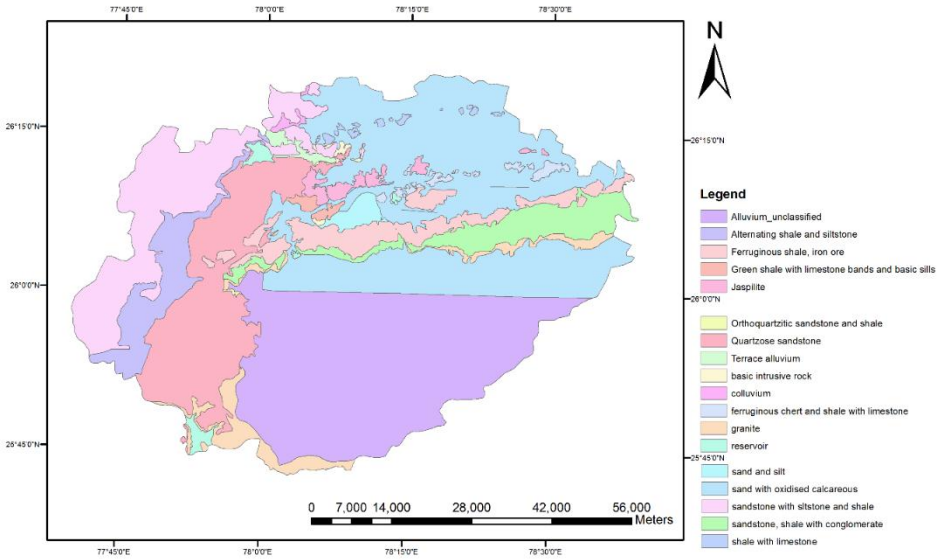

Fig 2: Geological / Lithological map of the study area

Geomorphology

Satellite images are used extensively in geomorphological studies. The Landsat data has been used in this study for the same purpose. Geomorphology relates to landform description, its classification, associations between landform and processes, process characterization. On the other hand, remote sensing is utilised for location, landform distribution, surface elevation and surface/sub-surface composition (Smith and Pain, 2009). Various geomorphic units have been identified from the satellite images and have been used for groundwater prospect mapping throughout India (Jha et al, 2010; Singh and Singh, 2009; Mukherjee, 2008; Lokesh and Narayana, 1996 and Rao, 2002). The various studies show result in promising groundwater prospects in valley fills and alluvial plains. Valley fills are related to thick alluvium and weathered materials. These provide high porosity and require permeability for occurrence and groundwater storage.

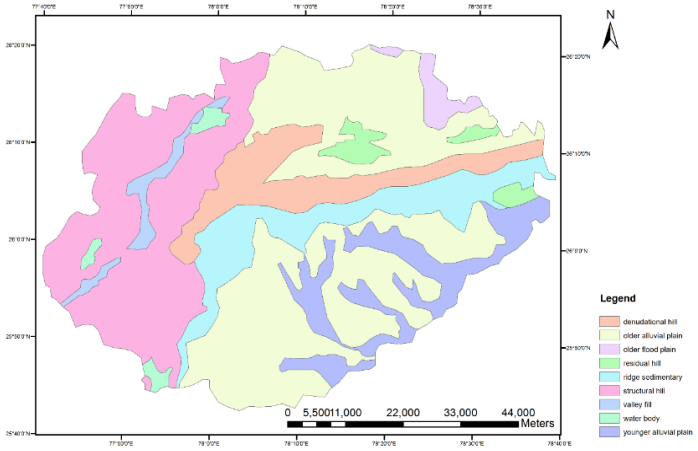

Fig 3: Hydrogeomorphological map of the study area

Aspect

The aspect basically refers to the direction to which a mountain slope faces. It is an important parameter to understand impact of sun on local climate of the area. West facing slope showing hottest time of day in the afternoon and in most cases a west-facing slope will be warmer than sheltered east-facing slope. The distribution of vegetation type within the area is affected by the aspect respectively. The aspect map derived from SRTM DEM represents the compass direction of the aspect. 0_ is true north; a 90_ aspect is to the east (Figure 4). The Gwalior basin showing east-facing slopes and therefore, these slopes have higher moisture content and higher vegetation compare to west facing slope.

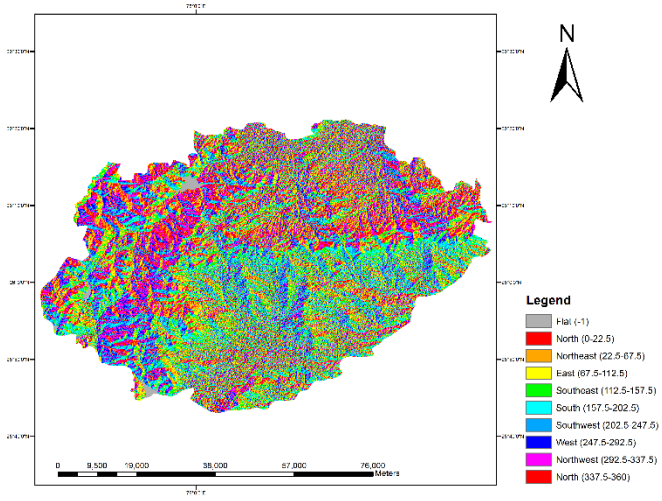

Fig 4: Aspect map of the study area

Slope

The slope is a critical parameter which directly controls runoff and infiltration of any terrain. Runoff in higher slope regions causes less infiltration. This factor significantly controls the development of aquifers. SRTM DEM was utilised to generate a topographic slope map using the spatial analysis tool in Arc GIS. The slope map of the study area has grouped into basic three categories viz. 1-3^0 (Gentle) , 3-5^0 (Moderate) , 5-10 ^{0} (Steep) , 10-35^0 (Very Steep) and > 35^0 (very Very Steep) (fig. 5) . In the extreme cases of very steep and steep slope, rapid runoff happens with increased erosion rate and less groundwater recharge potential. Most of the Gwalior basin area comes under gentle and moderate slope, indicating almost flat topography of the area. Gentle slopes were designated in the "excellent" category for groundwater management as the nearly flat terrain is the most favorable for infiltration. The moderate slopes has been categorised under good zone due to slightly undulating topography for partial runoff percolation to be maximum. The steep class, having high surface runoff with a negligible amount of infiltration and they are marked under good zone for construction of stop dams, etc.

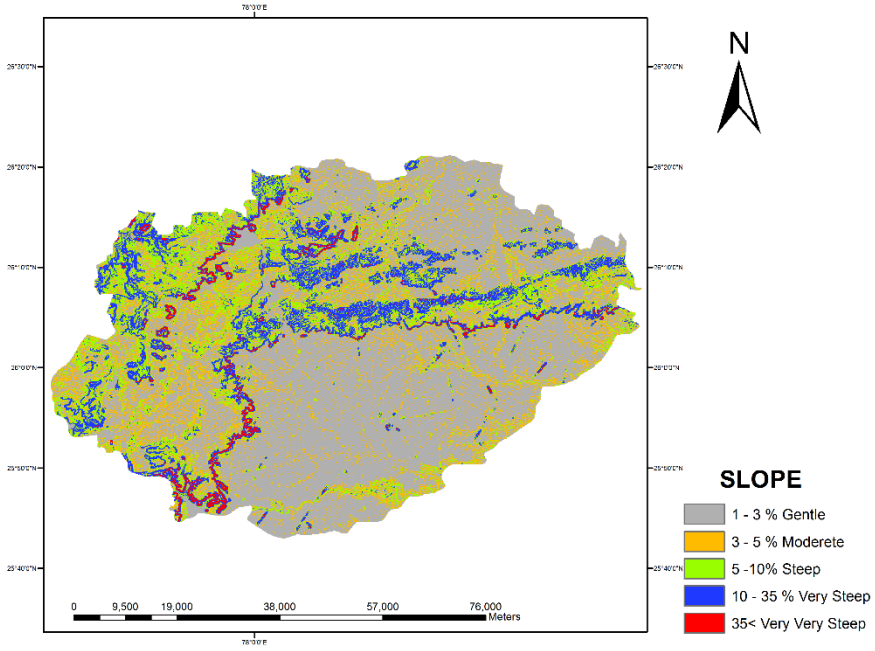

Fig 5: Slope map of the study area

Drainage Pattern of the Study area

A drainage system is a pattern formed by streams, rivers and lakes within a particular basin, governed by certain factors like topography of the land, rock type (which can be hard or soft in nature) and the gradient of the land. These drainage basins form the basis for the watersheds of a region. A drainage basin is a kind of topographic region wherefrom a stream receives its run-off and groundwater flow. The drainage pattern of the study area is dendritic in nature. These are the most commonly found drainage patterns found in India and the present study area is chiefly composed of dendritic pattern itself. In such a pattern there are many contributing streams which join in due course to form tributaries of a river. Such channel develops from the slope towards the terrain. The tributaries meet at low angles and are randomly branched in a tree-like pattern. A major characteristic feature of a dendritic pattern of drainage is that they form and develop in areas where there is a considerable or vast presence of impervious and non-porous rock. The area has a vast distribution of channels but most of them remain dry for most pert of the year. The figure (fig 6) shows drainage distribution of the area in different stream orders. Drainage up to 5th stream order has been determined using spatial analysis tool of Arc GIS.

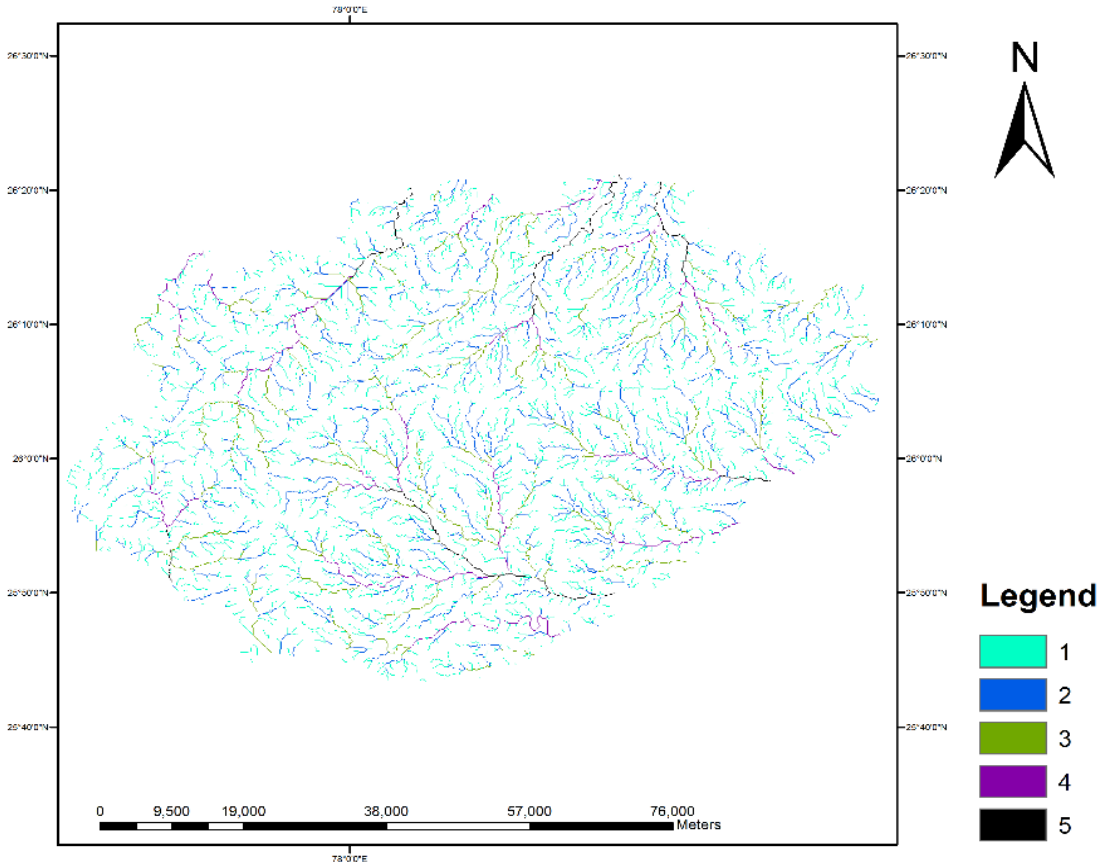

Fig 6: Drainage map of the study area with stream orders

Groundwater Prospect of the Study Area

The rock formations of the study area are ranging in age from Archaean to recent. Lithologically, the area consists of sandstone, shale and alluvium. Different lithological units of the study area were delineated from the satellite data by their distinct image characteristics and also by applying various image enhancement techniques. Sandstone intermixed with shale is more permeable than sandstone intermixed with clay.

Hence, sandstone intermixed with shale is categorized as good. Alluvium deposits mostly consisting of sand, silt and kankar of varying thickness are the excellent zones of the study area**.** Hydrgeomorphologically, the area consists of denudational hills, structural hills, residual hills, pediments, pediplain, pediplain, valley fills and alluvial plains. Each geomorphic unit with its groundwater potential. Hydrogeomorphological, geological, slope and drainage maps were discuss and their groundwater prospect are presented in table 2.

Table 1
Groundwater prospect of individual Themes

Sl. No.	Themes	Influence on groundwater occurance	Class	Groundwater Potential
1.	Geomorphology	The geomorphological characteristics largely affect its response with its suroundings which on co-relating with hydrological characteristics can provide better way to understand the groundwater characteristics and behaviour.	Denudational hill Residual hill Structural hill Older alluvial plain Younger alluvial plain Valley fill ridges	Very poor Moderate Moderate to good Very good Very good Moderate to good poor
2.	Geology	The porosity of the rock determines the storage capacity of groundwater. The variation of hydraulic gradients force the water to move from recharge area to discharge area which further depends on the hydraulic conductivity /permeability.	Alluvium Shale Sandstone Granite Sand and silt limestone	Very good to good Moderate Moderate to poor Poor Very good to good good
3.	Slope	Another indicator for groundwater prospect suitability is the slope which controls the infiltration of water. A steeper slope will have higher run-off and less infiltration showing poor groundwater prospect as compared to gentle slopes.	Very very steep Very steep Steep Moderate Gentle	Very very poor Very poor Poor Moderate to good Good to very good
4.	Drainage Pattern	Density of drainage are one of the important hydrological parameters to inference the hydrogeological conditions of subsurface strata.	Low Medium High	Drainage pattern of the area is mainly dendritic type. Low and medium drainage density area can be the good zone for groundwater exploration and management.

Conclusion

The presented study demonstrate that the integrated use of Remote Sensing, GIS and associated data sets are the potential tools for primary level hydrological investigation of the hard rock terrain . In the present paper, important hydrological parameters such as hydrgeomorphology, geology / lithology, Drainage pattern and slope for groundwater responsible for groundwater storage and movement of the prospective area were evaluated. The results observed from the present study are very useful for groundwater exploration and management. It is also recommended that area needs the micro level groundwater management program by adapting watershed development activities and use of advance groundwater investigation techniques such as geophysical investigation for proper aquifer characterization and their management.

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