WEIGHTED OVERLAY ANALYSIS FOR DELINEATION OF GROUND WATER POTENTIAL ZONE: A CASE STUDY OF PIRANGUT RIVER BASIN

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Abstract

Groundwater is the major natural resource of drinking water in both urban and rural India. Besides, it is an important source of water for the agricultural and the industrial sector. The aim of the present study is to delineate ground water potential zone and identifying land suitability for improving agricultural productivity over the area of Pirangut river basin catchments using remote sensing and GIS technology. GIS technology is helpful to prepare a various base layer and maps viz. such as, geology, geomorphology, Land Use Land Cover, slope, digital elevation model(DEM), worthy - non worthy, drainage line density, rainfall runoff, soil cover depth, drainage stream order, well density, ground water fluctuation, village proximity. GIS techniques were used for Weighted overlay analysis and integrated with multi-criteria analysis. This all layers are generated using a Light Imaging Self Scanner (LISS IV) sensor satellite image with 5.6m resolution and Survey of India (SOI) topographical maps with 1:50000 scale. Morphometry technique is performing to access the geo hydrological qualitative and quantitative characteristics of drainage basin. Hydro geological technique used to determine ground water fluctuation or flow of ground water conducting well location on field with well inventory analysis. The final groundwater potential map was prepared by assigning appropriate weightage to different thematic maps and superimposed by weighted overlay method.

Keywords: Remote Sensing, GIS, AHP, Multi criteria analysis

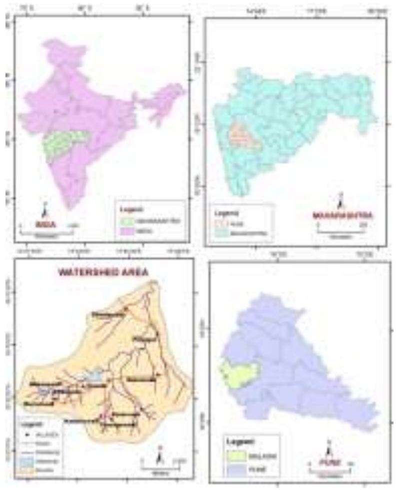
Introduction

Groundwater is the largest fresh water natural resource on the Earth, which makes it an important source for human consumption and the process of planning and development of country. Recently, mapping of groundwater potential zone is essential to demarcate location of new abstraction well to meet the increasing demand of water. In places where the surface water is not available for irrigation, ground water is used as alternative resource. Remote sensing and GIS techniques are rapidly used in hydrology and hydro geological studies, it provides high resolution of satellite imageries are used in groundwater studies due to its high spectral and spatial resolution. It is devoted specially to collect, store, retrieve and analyze spatially-referenced data. Researchers around the world, and it were found that the involved factors in determining the groundwater potential zones were different, and hence the results vary accordingly. (N.S.Magesh., 2012; N. Chandrasekhar., 2012)

Aims and Objective

- Delineation of the groundwater potential zones and identification of the suitability sites for groundwater development using weighted overlay analysis technique in GIS.
- Preparation of physical thematic layers required for multicriteria overlay analysis viz. contour, drainage, Land use Land Cover, village location map, geology for identification area of regolith and rocks, geomorphology to determine types of landforms, rainfall runoff, soil cover depth to determine thickness of soil pattern, slope and aspect, DEM for obtaining lowest to highest elevation of study area
- Perform Morphometry analysis to obtain geo hydrological parameter such as drainage stream order density and line density of watershed
- Perform hydrogeology analysis in well inventory method to delineating fluctuation of ground water level
- Perform weighted overlay analysis technique in GIS to determine most suitable site for ground water potential zone in Pirangut watershed basin.

Study Area



The study area is included in the Survey of India toposheet nos. 47 F/10 and 47 F/11. It lies between 18o 27’ 05” and 18o 34’ 00” North latitudes and between 73o 42’ 00” and 73o 49’ 15” East longitudes. The area is approachable by National Highway No. 4 and well connected with a network of metalled roads. It has undergone rapid urbanization in the last two decades, particularly around Pirangut, Uraode and Kasar Amboli villages. Few surface water tanks are also located in the study area. These include Uraode minor irrigation tank and Bhilarwadi tank. The areal extent of Pirangut watershed is 43.619 sq km and has an elevation ranging from 560 m to 1120 m above mean sea level.

Pirangut stream is a tributary of river Mula. The longest stretch of Pirangut stream lies in the SW part of the watershed originating at Magalwadi, continues its travel through Botarwari, Uraode, Bhilarwadi, Ubhewadi, Kasar Amboli, shelarwadi, and finally meets river Mula near Rawatwadi. The NW part of Pune metropolis is endowed with a variety of ecosystems and also scenic landforms caused due to topographic highs and lows, and intervening streams of different orders. The small valleys in the area have provided niche for delicate eco-systems by way of thick forest. Such unique eco-systems that are on the threat of vanish due to rapid and haphazard development in the process of urbanization

Methodology

Indian Remote Sensing System Linear Imaging Self-scanning Sensor III (IRS-1D LISS IV) satellite imagery on 5.6m spatial resolution (geo-coded, with UTM projection, spheroid and datum WGS 84, Zone 44 North) was used to prepare the land use land cover maps and geomorphology. LISS 4 Resource Sat image is received from the NRSC Data Centre, Hyderabad. The climate data has been received from the Indian Meteorological Department (IMD), Pune.

The base map of Pirangut River Basin was prepared based on Survey of India topographic maps (47F/10, 47F/11) on a 1: 50,000 scale. Drainage network, geology, contour, village location, transportation for the study area was scanned from Survey of India (SOI) toposheet and digitized in ArcGIS 9.3 platform.

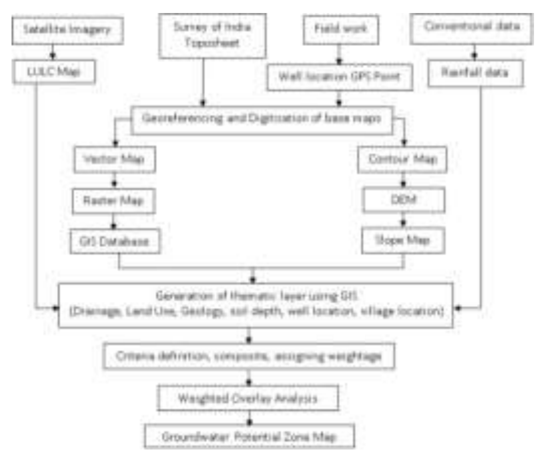
DEM was generated through 20m contour lines which were obtained from SOI topomaps (1:50,000). The slope map and worthy non worthy map was prepared from DEM data in ArcGIS Spatial Analyst module.

The drainage line density and drainage stream order density map were prepared using the line density analysis tool in the Arc GIS 9.3. Village proximity were prepare using Buffer analysis tool with each village location by population in ArcGIS 9.3.

Well location map was prepared from collecting GPS point on field work. The GCP coordinates of latitude(X), Longitude(Y) and elevation (Z) file (.csv) were prepared in table format using MS Excel 2007. Plot all well location within a catchment area by adding excel sheet file in Global Mapper 15.1.

Ground water fluctuation layer were prepared using flow tool by adding reading of well inventory analysis with measurement of ground water level of each well in winter and summer and coordinates of each well excel file in SURFER 8.

Flow diagram of methodology



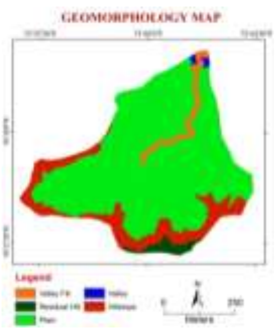
Rainfall runoff layer were prepared using Hypsometry Analysis tables prepared on the basis of total area of pixel in between two contour intervals and the data were then spatially interpolated using Inverse Distance Weighted (IDW) method in ERDAS Imagine 9.2 and ArcGIS9.3.

In GIS environment all thematic layer viz. geology, geomorphology, Land Use Land Cover, slope, digital elevation model(DEM), worthy - non worthy, drainage line density, rainfall runoff, soil cover depth, drainage stream order, well density, ground water fluctuation, village proximity were prepared in ArcGIS 9.3 all layers converted into raster format (20m resolution) and superimposed by weighted overlay analysis was adopted to combine all thematic layers by assigning rank according to the multi influencing factor (MIF) of that particular feature and weightage for each thematic layer. Weighted overlay analysis is a simple method to analyze multiclass maps based on the relative importance of each thematic layer and a layer's class. Finally, to the delineation of site suitability analysis was made by grouping the polygons into different prospect zones i.e. good, moderate to good, moderate, poor and not suitable.

Analysis

Geomorphology

The **physical setup** of study area covered by horizontally disposed basaltic flows which extend for a considerable distance and show features such as spheroidal weathering, columnar and sheet jointing, and red bole horizons. The flows on the hill slopes are covered by a thin veneer of residual soils (up to 0.4 m) underlain by poor to moderately weathered/jointed basalt; foothills by colluviums (up to 1.5 m) again underlain by weathered or jointed basalt whereas gently rolling terrain extending up to the banks of third order streams and the river Pirangut is underlain by alluvium/weathered basalt (up to 2 m). Outcrops of fresh basalt are intermittently seen all over the area.

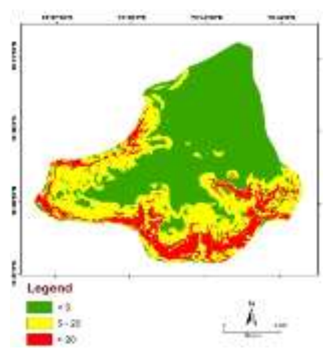


The **landforms** of study area were classified into three major categories i.e. structural, denudational, fluvial units. Geomorphologicallly analysis, Highly Dissected Plateau found in the southern part, massive type residual hills found in the south-western part of the study area. Near plain to undulating topography with units like denudational hills and slopes in the Western, Eastern and South-Central portion and Unit of fluvial origin viz. the valley fills and the alluvial plains occurring along the river Mula (Near Ravatwadi) and it's tributary with moderate soil cover.

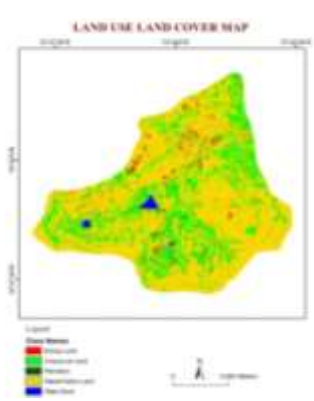
Drainage pattern of watershed is defined as the spatial relationship between individual stream courses in an area. The drainage of study area is drained by mula river tributaries near Pirangut that is fifth order stream. Mostly dendritic types of lower order stream network were found in Pirangut river basin. In the Middle Reaches of the basin identify Parallel to Sub-Parallel drainage. Rectilinear Type of drainage indicative of the structural control observes towards the north east part of the watershed.

Disposition of contours within watershed represent the distance between consecutive contours gives an idea about the gradient of drainage basin. Closely spaced contours are indicative of a steep gradient. In study area watershed a closely spaced contours have been observed in the southern part of the watershed and the distance between two consecutive contours increases towards the north.

The study area is characterized by monsoon climate, which begins in early June and lasts until the middle of October. The average annual rainfall of the study area is 1688 mm. Based on Mulshi weather station data, the maximum average temperature in summer is 42˚C whereas minimum average temperature in winter upto 10˚C. The average annual relative humidity is 48.54%. The maximum annual average monthly evaporation is 276 mm in May, while the minimum is 97.2 mm in August. The average annual wind speed is 1.62 m/s. The average monthly maximum sunshine is 9.57 h/day. The mean annual sunshine duration is 8.1 hours/ day for period 1998-2008.

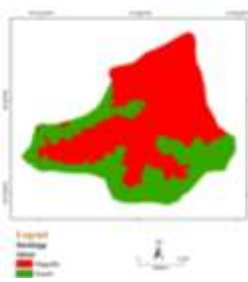


Watershed characteristics may be determined in terms of size, shape, slope, deposition of contours, and drainage pattern and land use land cover of watershed. The total Size of watershed area is 43.619 sq. km and the stream length is 9.810 km. The shape of watershed is pear shape / elongated pear shape. The land slope of the



watershed controls the rainfall distribution and movement, land utilization, watershed behavior and speed and extent of runoff i.e. depend on slope of the land. The degree of slope affects the velocity of overland flow and runoff, infiltration rate, and thus soil transportation. The slope map of study area watershed classified into three categories i.e. gentle (<5), moderate (5-20) and steep (>20) where 23.22 sq. km area falls under the slope less than 5˚, 32.99 sq. km between the slope 5˚ and 20˚, and 13.48 sq. km area represents the slope more than 20˚.The land use land cover classification of watershed may be depicted in five classes i.e. built up land, crop land, plantation, waste land and water body. Out of total watershed area the built up land is 2% and the land under crop / vegetation is 25%.

Geological structure of study area may found in compact structure regolith and dominantly constituted of basaltic rocks it falls in the Bushe formation of the Lonavala sub-group belonging to Deccan Basalt Group. Basalt at the fringe area and regolith cover towards the closure of the watershed. Basalts occur in the form of horizontal flows having variation in the thickness. The alluvium soil structure seen to be developed along the banks of Pirangut river basin.



No.	Parameter	Formulae
1	Bifurcation Ratio	Number Of Stream A Given Order / Number Stream of The Next Higher Order
2	Stream Length	Length of the stream
3	Stream Length Ratio	Mean stream length of a given order / Mean stream length of next lower order
4	Stream Frequency	Total Number of Streams/ Total Drainage Area
5	Mean Stream Length	Total stream length of order/ Total no. of stream segments of order
6	Drainage Density	Total stream length of all orders/ Area of the basin
7	Length of overland flow	1/2Drainage Density
8	Constant channel maintenance	1/Drainage Density
9	Drainage Density	Stream Frequency Drainage Density

Morphometry

Morphometry is a measurement and mathematical analysis of qualitative and quantitative parameter of landform that may applied to particular kind of drainage basin. The morphometric analysis of the drainage basin and channel network play an important role in understanding the geo-hydrological behavior of drainage basin.

Morphometric analysis of a watershed provides a quantitative description of the drainage system, which is an important input for the characterization of watershed. Remote Sensing and Geographical Information System (RS-GIS) techniques are in vogue for assessing various quantitative morphometric parameters of the drainage basins / watersheds, as they provide a user friendly environment and a powerful tool for the manipulation and analysis of spatial information.

Stream Order	1		2		3		4		5
No. of Streams	165		50		11		3		1
Bifurcation ratio		3.3		4.54		3.66		5	
Stream length	88.17		35.11		12.13		7.68		7.29
Stream length ratio		2.52				1.57		1.05	
Stream frequency	1.83		1.15		0.25		0.06		0.03
Mean stream length	0.34		0.71		1.11		2.56		7.29
Drainage density	0.03		0.81		0.27		0.17		0.16
Length of overland flow	1.02		0.41		0.14		0.08		0.08
Constant channel maintenance	0.49		1.25		3.59		5.67		5.97
Drainage intensity	1.89		1.43		0.91		0.38		0.14

Hydrogeology

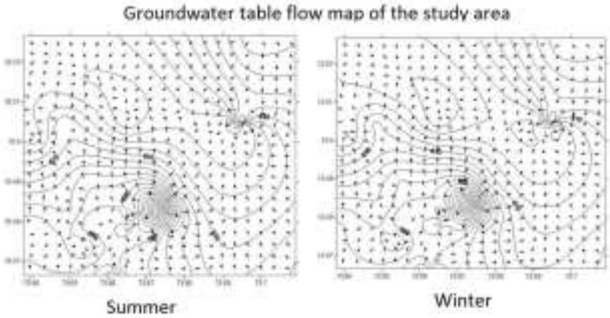
Hydrogeology include the frequency and extent of jointing, fracturing, flow contacts and weathering types of significant parameters imparting permeability and porosity for forming suitable site for groundwater reservoirs in the Deccan basalt terrain. The Deccan basaltic area of Maharashtra, groundwater forms an important source of water supply. The groundwater occurs in these Deccan basalts under the shallow unconfined conditions as well as under deeper confined conditions. It is observed that the groundwater occurs in unconfined aquifer conditions in the study area. In unconfined aquifer there is no impermeable layer above or on the top. Recharge to the aquifer can be from downward seepage through the vadose zone.

Sr. no.	Parameter	Calculated Value
1	Main stream length	9.707 km.
2	Basin Perimeter	29.309 km
3	Length of the basin	9.506 km
4	Form factor	0.4827
5	Lemniscates factor	0.51792
6	Elongation ratio	0.784.
7	Circularity ratio	18.6924
8	Drainage texture	7.84742
9	Fitness ratio	0.3312
10	Compactness coefficient	1.48825
11	Relief difference	630 m

Study area of Hydrogeology analysis is divided into three parts, i.e.

1. The collection of data of existing wells in terms of dimension, depth of the water table, aquifer type etc. this data is useful to perform well inventory analysis and to determine groundwater flow map.
2. The pumping tests conducted on representative wells selected on the basis of landforms and aquifer type.
3. Setting of aquifer boundary conditions and construction of groundwater flow map

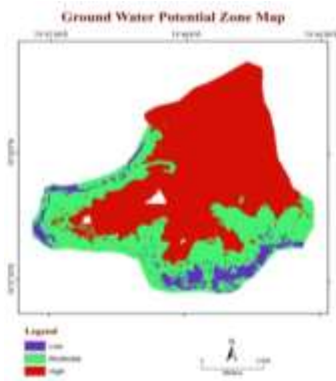
Groundwater table flow map of the study area

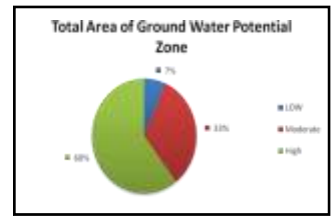


Result and Discussion

To delineation of ground water potential zone of study area all thematic layers were converted into grid (raster) format and overlaying to each another using weighted overlay method using spatial analysis tool in ArcGIS 9.3. In this technique each class of the main thirteen thematic layers are qualitatively placed into one of the following categories viz., i. low, ii. Moderate, iii. High. During weighted overlay analysis the ranking assigning from 1 to 4 for each individual parameter of each thematic map on the basis of their significance with reference to their site selection and weight is assign for the influence of different parameter for installing groundwater potential zone area. In ranking method, larger number value is given to the feature with highest groundwater potentiality and the smaller number is given to the lowest groundwater potentially area. The final score of a theme is equal to the product of the rank and weightage. For example, in slope map a highest rank is assign for gentle slope and lowest rank is assign for steep slope.

Ground water potential zone map diagram





Sr. No.	Criteria	Classes	Rank	Weights (%)
1	Slope (%)	0 - 10	4	18
		10-15	3	
		15-20	2	
		<20	1	
2	DEM	560-640	4	15
		640-700	3	
		700-760	2	
		<760	1	
3	Drainage Line Density	Low	3	6
		Moderate	2	
		High	1	
4	Rainfall Runoff	<5	3	7
		5-20	2	
		>20	1	
5	Land Use Land Cover	Crop	3	5
		Built up	1	
		Water body	0	
		Shrub	3	
		Fallow/wasteland	4	
6	Geology	Regolith	2	12
		Basalt	1	
7	Soil Cover Depth	1.2 – 2 m	4	5
		8 cm – 1.2m	3	
		3 – 8 cm	2	
		1 – 3 cm	1	

8	Worthy – Non Worthy	Worthy	2	5
		Non Worthy	1	
9	Geomorphology	Valley Fill	4	8
		Residual Hill	1	
		Plain	3	
		Valley	4	
		Hill slope	2	
10	Fluctuation	560 - 605	1	6
		605 - 644	2	
		644- 760	3	
11	Drainage Stream Order	1st – 2nd Order	1	6
		2nd– 3rd Order	2	
		4th – 5th Order	3	
12	Well Density	Low	3	5
		Moderate	2	
		High	1	
13	Village proximity	0 – 500	1	2
		500 - 700	2	
		< 700	3	

Conclusion

Remote sensing and GIS technology is efficient tool for delineating groundwater potential zone in Pirangut watershed of Mula River in Pune district. Satellite imagery, topographical maps and conventional data are used to prepare for all thematic layers while the weighted overlay method is very useful to integration of thematic layer and mapping of ground water potential zone. According, to the resultant ground water potential zone map, Pirangut watershed is classified into three ground water potential zone categories i.e. “highly suitable area”, “moderately suitable area” and “low suitable area”. Out of the total 43.619 sqkm study area, 25.9 km² areas false in highly suitable categories, 14.3 km² areas false under moderately suitable categories and 2.8 km² depicts low suitability for groundwater potential zone map. Highly suitable area can helpful for ground water development and management. For example, surface water harvesting structure can be design in this area to recharge the aquifer and make the sustainable water source. Moderately suitable area shows moderate regolith cover and 5 to 6 meter depth of weathering. As a result, it is best site for ground water, recharge technique implementation.

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