

## Identification of suitable sites for artificial recharge in Mewat District, Haryana

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### Abstract

*Aquifer replenishment through artificial recharge has become necessary to sustain groundwater resources in arid and semi-arid regions to alleviate the problem of continuous declining of water table. In this context, present study deals with the delineation of artificial recharge zones as well as the identification of favorable recharge sites using remote sensing, geographic information system and multi-criteria decision making technique for augmenting the groundwater resources in Mewat district of Haryana, India. For the purpose, thematic layers are prepared : These layers are prepared using Landsat ETM satellite imagery, Survey of India's toposheets, district resource maps by Geological Survey of India and other collateral data collected from different agencies and departments. Thematic layers and their corresponding features have been assigned weight on a scale of 1 to 9 respectively based on their relative contribution to groundwater recharge. Normalized weights are computed using pair-wise comparison matrix of Satty's analytical hierarchy process. All thematic layers are then integrated in the GIS environment using raster calculator tool to prepare a composite map representing artificial recharge zones in the study area. On the basis of the resulted map, study area is classified into three potential recharge zones namely; highly favorable, moderately favorable and least favorable. Intersection points of lineaments with streams of second and third order are considered as possible recharge sites. Results of this study could be very effective in the formulation of sustainable and efficient groundwater management plan of Mewat district.*

**Key Words:** ground water; aquifer replenishment, lineament, drainage density

### Introduction

The phenomenal human population growth has intensified pressure on each and every natural resource to produce adequate food and raw materials in order to meet the proportional demand. In many parts of India, especially in the arid and semi-arid regions, due to vagaries of monsoon and scarcity of surface water, dependence on groundwater

has increased tremendously. Consequently, pressure on groundwater in terms of both, quality and quantity has increased to a great extent and not only drinking water resources but also sensitive ecosystem is also threatened by contamination through human exploitation. Artificial groundwater recharge and rainwater harvesting have emerged as two basic measures for the

sustainable management of vital freshwater resources; both groundwater and surface water (Chowdhury et al 2009). Replenishing the groundwater through artificial recharge has been carried out in various parts of the world for the last six decades (Babcock and Cusing 1942; Todd 1959; Asano 1985). Literature review suggests that in identification of potential zones for artificial recharge Indian scholars like Saraf and Choudhury 1998; Ghavoumian et al 2005; Anbazhagan et al 2005; Ravi Shankar and Mohan 2005; Chowdhury et al 2009; Sukumar and Sankar 2010; Kadam et al 2012, considered a varying number of thematic layers. A few of them also attempted to select suitable sites for artificial recharge as well as to suggest salient recharge structures (Saraf and Choudhury 1998; Ravi Shankar and Mohan 2005; Chowdhury et al 2009).

The southern part of Haryana being mostly arid and semi-arid is in a disadvantageous position with regard to the quantity of water. Every year in summer, all surface water sources dry up, causing a serious water scarcity. Therefore, a majority of the cultivated area is irrigated using groundwater. However, the unrestricted excessive pumping of groundwater has resulted in the lowering of groundwater levels, which poses questions on groundwater sustainability. Thus for the sake of sustainability of water resources, there is a need for planning of these resources at regional as well as local levels. Therefore, aquifer replenishment through artificial recharge is necessary to sustain groundwater resources of the area on a long-term basis. In the light of the above said facts, present study of Mewat district, deals with the delineation of potential zones

for artificial recharge and identification of suitable recharge sites for the construction of recharge structures in order to alleviate the groundwater depletion problem by artificially augmenting the sub surface aquifers.

## **Study Area**

Mewat district lies between 27° 39' to 28° 20' N latitude and 76° 31' to 77° 20' E longitude; covering an area of 1484 km<sup>2</sup>. Climate of the district may be classified as tropical steppe, semi-arid and hot which is characterized by extreme dryness of air. Normal annual rainfall of the district is 594 mm which is spread over only 31 days. The depth of water level in the study area ranges from 1 to 34 meter below ground level (mbgl). The shallowest water table is recorded to be 1.15 mbgl. According to assessment made by Central Groundwater Board in 2009 net groundwater available in the district is 22364 hectare meter (ha-m) out of which 18776 ha-m is the gross yearly draft. District Mewat is in semi-critical stage of groundwater development. Most of the villages and town in the district have piped water supply based on tube wells which are also the major source of irrigation.

## **Methodology**

### **Database Creation**

Present study focuses on the delineation of suitable artificial recharge zones and the selection of suitable sites for artificial recharge using remote Sensing (RS); Geographic Information System (GIS) and multi criteria decision making (MCDM) techniques. For the delineation of artificial recharge zones, a multi-parametric dataset comprising

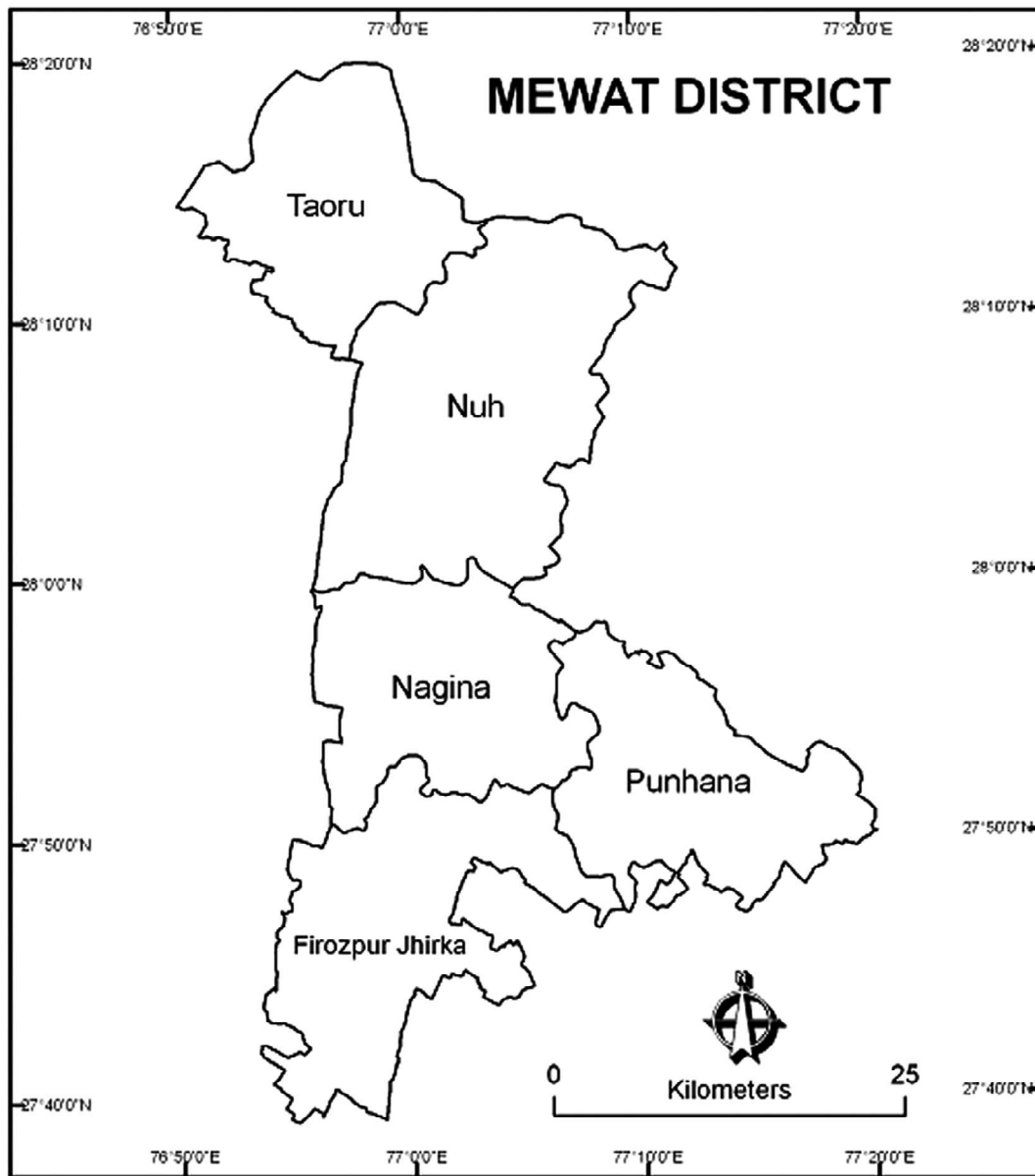


Fig. 1 : Location of Study Area

satellite data and other conventional maps including Survey of India toposheet, District Resource maps by Geological Survey of India are used. Seven thematic layers viz., geology, geomorphology, lineament density, drainage density, slope, soil type and land use land cover are considered. Geology

layer is prepared from existing District Resource Map by Geological Survey of India. Geomorphology and land use land cover layers are prepared using Landsat 7 ETM data downloaded from global land cover facility (glcf) server. Sub categories of these layers are visually interpreted from

the satellite data and then digitized in Arc GIS software. Survey of India toposheets on 1:25,000 scale are used for the digitization of drainage and contour lines of the study area. To finalize the drainage order Strahler's system of stream ordering (Strahler 1957) is used and digitized drainages are updated from the satellite data. Digital Elevation Model of the study area is prepared from contour lines on 10 meter interval digitized from the SOI toposheet and subsequently slope of the study area is calculated. Lineament layer is prepared from the existing map procured from Haryana Space Application Center, Hisar (HARSAC). Using line density tool in Arc GIS software, density of drainage and lineament layers is calculated. Soil type layer of the study area is prepared on the basis of soil map prepared by National Bureau of Soil Survey and Land Use Planning, Nagpur (ICAR) in cooperation with Department of Agriculture, Haryana. Data of depth to groundwater level (mbgl) for pre and post monsoon season is collected from the Groundwater Cell, Gurgaon for monitoring wells for the year 2010.

### **Weight Assignment and Delineation of Potential Recharge Zones**

Groundwater management is interdisciplinary in nature and multiple data sets are used in this process. MCDM approach is found best when dealing with more than one criterion in supporting the decision process (Chowdhury et al 2009). To serve the purpose of the study, thematic layers have been assigned weights on a scale of 1 to 9 based on their influence on the groundwater recharge process. Different features of each theme have also

been assigned weights on a scale of 1 to 9 considering their relative importance for groundwater recharge. Suitable weights for seven themes and their individual features are finalized by taking into account their hydrogeologic importance based on local experience and literature survey. Normalized weights of individual themes and their different features are calculated using Satty's Analytical Hierarchy Process (AHP). It is well known that AHP is the technique that allows users to assess the relative weight of multiple criteria using pair-wise comparison matrix of  $n$  parameters (Satty 1980). After calculating weights for all thematic layers and their corresponding categories, 'Raster Calculator' tool of spatial analyst extension in Arc GIS 9.3 is used to prepare the integrated final artificial recharge zone map of the study area. Resulted map is further classified as 'Highly favorable', 'Moderately favorable' and 'Least favorable' zones.

### **Selection of Recharge Sites**

Selection of parameters in the identification of favorable sites for artificial recharge plays an important role in sustainable development and management of recharge structures to be created. In the present study second and third order streams and lineament layers are superimposed on the artificial recharge zone map. The location where drainage line intersects with lineament lines is considered as favorable sites for artificial recharge (Chowdhury et al 2009). In the hard rock areas due to the absence of primary porosity role of lineaments become inevitable as the percolation of stored water in a recharge structure depends on their presence.

## Result and Discussion

### Geology

Geology of the study area is dominated by Quaternary deposits of unconsolidated sediments and Delhi supergroup of rock formations. Quaternary sediments include alluvium and Aeolian deposits. Alluvium deposits are composed of a sequence of sand, silt and clay with occasional kankar. In case of Aeolian deposits coarse to fine Aeolian sand is reported by GSI. These two classes are largely distributed over 1135.27 km<sup>2</sup> and 166.69 km<sup>2</sup> area, respectively. Delhi supergroup of rock formation occupies 182.04 km<sup>2</sup> area. South-eastern part is dominated by quartzite, phyllite and slate while quartzite and schist dominates western edges of the study area.

### Geomorphology

Geomorphological mapping deals with the identification and characterization of various landforms and structural features. Major units found in the study area are residual hills, structural hills, linear ridges, piedmont alluvium, paleo-channels, alluvial plain and Aeolian plain (sitender and Rajeshwari, 2011). Residual hills (8.01 km<sup>2</sup>) in the absence of unfractured rock material have low infiltration and behave largely as runoff zone. Structural hills (97.09 km<sup>2</sup>) exhibit definite trend lines and presence of lineaments and high drainage density make them suitable for artificial recharge. Linear ridges (19.64 km<sup>2</sup>) are

characterized by massive structure and high resistance to erosion. Piedmont alluvium (56.61 km<sup>2</sup>) has low relief due to which surface water remains for considerable time before meeting major rivers. It provides good scope for infiltration and recharge of groundwater. Paleo-channels (1.58 km<sup>2</sup>) also show excellent potential for groundwater recharge. Aeolian plain (247.93 km<sup>2</sup>) is covered by sand of Aeolian origin with the presence of scattered sand dunes. Lithologically they are composed of porous and permeable medium to fine sand with

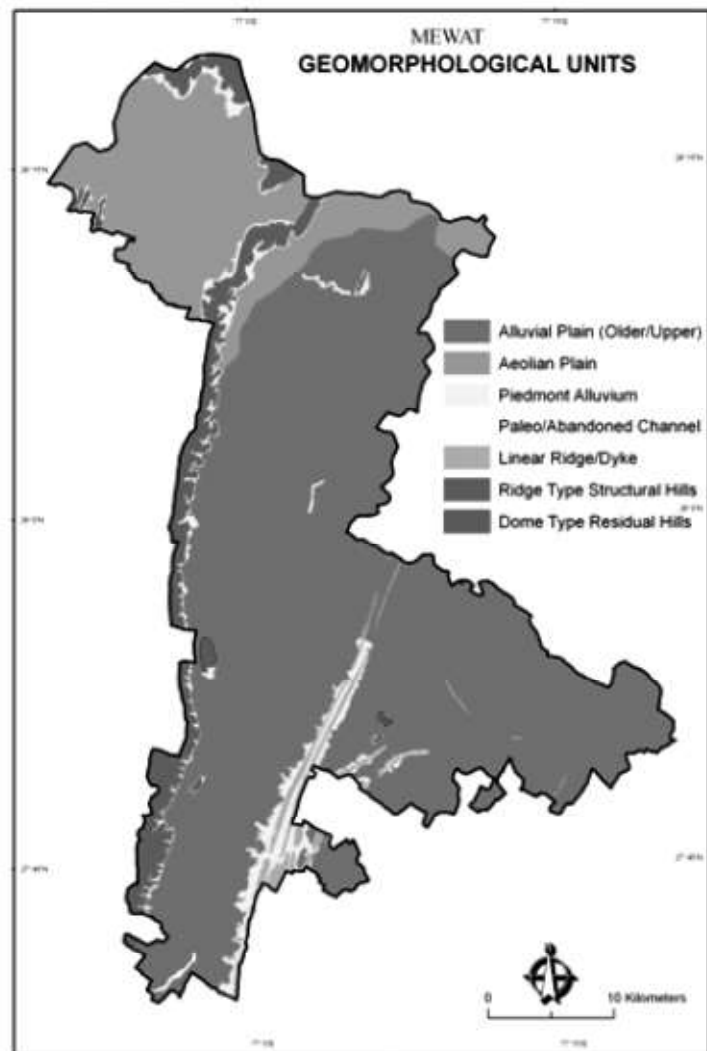


Fig. 2 : Geomorphological Features of Study Area



little clay which makes it potential area from recharge point of view. Alluvial plain (1053.19 km<sup>2</sup>) comprises a sequence of sand, silt and clay with kankars (fig.2). Fine to coarse sand layers form potential aquifers and yield copious water as well as provides a good scope for artificial recharge to groundwater.

### **Lineament density**

Lineament density map is a measure of quantitative length of linear feature expressed in a grid. Presence of lineaments may act as a conduit for groundwater movement which results in increased secondary porosity and therefore, can serve as groundwater potential zone (Obi Reddy et al 2000). Lineament density of an area indirectly reveals the potentiality of the area for artificial recharge sites because the presence of lineaments makes the hard rock area permeable for groundwater infiltration. In most of the study area lineament density are less than 1.09 km/km<sup>2</sup> while in the rest of the area it varies from 1.09 to 3.28 km/km<sup>2</sup> which is confined to the hard rock region on the western and south eastern edges of the study area.

### **Percent slope**

Slope of any area plays a very important role in the infiltration of water into subsurface area. In the gentle slope area, due to slow surface runoff, rainwater gets more time to percolate. On the other hand, steep slope area supports high runoff which provide less residence time for rainwater resulting in less infiltration. Therefore, from the contour lines digitized from SOI toposheet (at 10 meter interval) DEM was generated

and percent slope is derived. Most of the area (1176.59 km<sup>2</sup>) is covered by less than 1% slope (Nearly level), 177.55 km<sup>2</sup> area has 1-5% slope (Very gentle), 29.24 km<sup>2</sup> area has 5-10% slope (Gentle), 29.77 km<sup>2</sup> area has 10-20% slope (Moderately gentle), 47.88 km<sup>2</sup> area has 20-50% slope (Steep) and 22.97 km<sup>2</sup> area has more than 50% slope (Very steep).

### **Drainage density**

Drainage density of an area is defined in terms of length of channels per unit area (km/km<sup>2</sup>) which indicates the closeness of spacing of channels. Drainage density indirectly indicates the permeability and porosity of the area due to its relationship with surface runoff (Krishnamurthy et al 2000). To visualize the density of drainage, the zones of different drainage density viz. very high (>6km km/km<sup>2</sup>), high (4-6 km/km<sup>2</sup>), moderate (2-4 km/km<sup>2</sup>), low (1-2 km/km<sup>2</sup>) and very low (<1 km/km<sup>2</sup>) are derived based on spatial density analysis of drainage network which comprises 6.04 km<sup>2</sup>, 62.75 km<sup>2</sup>, 120.52 km<sup>2</sup>, 1293.25 km<sup>2</sup> and 1.44 km<sup>2</sup> of the area, respectively.

### **Land use land cover**

Land use land cover of an area plays an important role for the selection of suitable sites for artificial recharge. In the study area six types of land cover has been detected and mapped from the satellite data (fig.3). It is observed that majority of the area is comprised of agricultural land (1208.26 km<sup>2</sup>), vegetation cover (167.24 km<sup>2</sup>) and settlement (76.09 km<sup>2</sup>) followed by water bodies (20.02 km<sup>2</sup>), scrub land (9.23 km<sup>2</sup>) and barren rocky waste (3.16 km<sup>2</sup>).

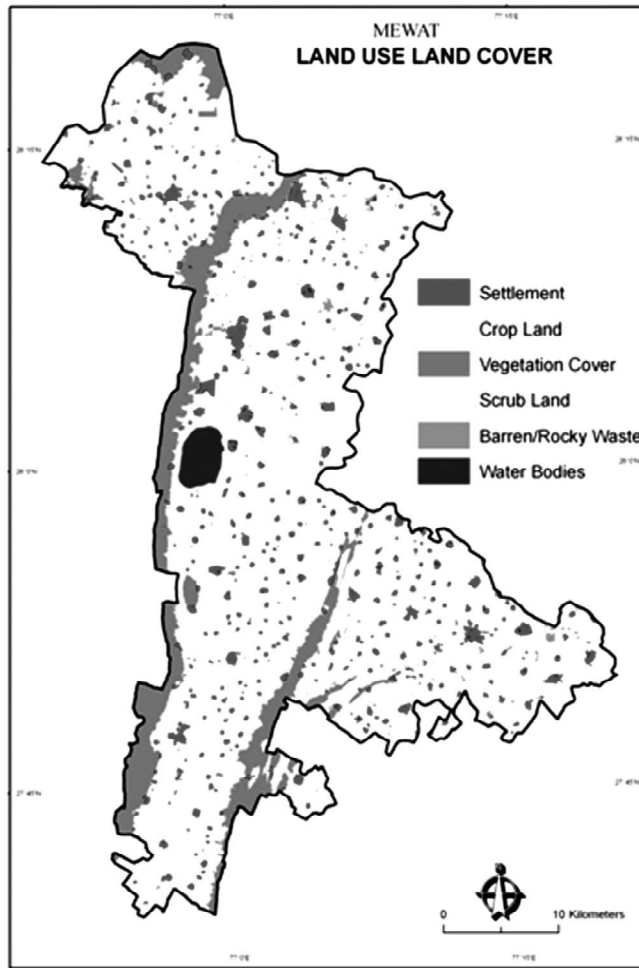


Fig. 3 : Land use Land cover Map of Study Area

### Soil type

Soil infiltration rate and its texture determine the structure to be located for its runoff potential (Jasrotia et al 2009). The soil map of Haryana prepared by National Bureau of Soil Science and Land Use Planning, Nagpur is used to delineate the soil classes of study area. Classification of soil is based on the classification system adopted by United State Department of Agriculture (USDA). Three sub-order of soil have been interpreted from the map in which Typic Ustochrepts (1093.36 km<sup>2</sup>) is dominant followed by Typic Ustorthents (239.38 km<sup>2</sup>), Typic Ustifluvents (0.95 km<sup>2</sup>) while rocks and hills outcrops (150.31 km<sup>2</sup>). In the study area, Typic Ustochrepts type of soils are dominated by coarse to fine loamy and somewhere clayey textures which carries moderate permeability. Typic Ustorthents soils are comprised of coarse loamy textures with

Table 1: Pair wise Comparison Matrix and Calculation of Normalized Weights

	Soil	Geom.	Geol	LULC	DD	Slope	LD	GM	NW
Soil	9/9	9/8	9/7	9/6	9/5	9/4	9/3	1.59	0.22
Geom.	8/9	8/8	8/7	8/6	8/5	8/4	8/3	1.46	0.19
Geol	7/9	7/8	7/7	7/6	7/5	7/4	7/3	1.24	0.17
LD	6/9	6/8	6/7	6/6	6/5	6/4	6/3	1.06	0.14
DD	5/9	5/8	5/7	5/6	5/5	5/4	5/3	0.88	0.12
Slope	4/9	4/8	4/7	4/6	4/5	4/4	4/3	0.71	0.09
LULC	3/9	3/8	3/7	3/6	3/5	3/4	3/3	0.53	0.07
Total								7.47	1.00

Soil = Soil Texture

LC = Land cover

LD = Lineament Density

Geom. = Geomorphology

DD = Drainage Density

GM = Geometric Mean

Geol. = Geology

Slope = Slope Percent

NW = Normalized Weight

Table 2 Assigned and Calculated Normalized Weights of Each Theme and its Categories

<b>Geology</b>	<b>0.17</b>		<b>Soil Type</b>	<b>0.22</b>	
Sub Category	Assigned weight	Normalized weight	Sub Category	Assigned weight	Normalized weight
Newer Alluvium	9	0.38	Hills and Rock Outcrops	2	0.09
Ambala Older Alluvium	7	0.29	Typic Ustifluvents	8	0.38
Aeolian Deposit	5	0.21	Typic Ustochrepts	4	0.19
Delhi Supergroup	3	0.12	Typic Ustorthents	7	0.34
<b>Geomorphology</b>	<b>0.19</b>		<b>Land Cover</b>	<b>0.04</b>	
Sub Category	Assigned weight	Normalized weight	Sub Category	Assigned weight	Normalized weight
Deep Alluvial Plain	9	0.29	Settlement	1	0.03
Aeolian Plain	6	0.19	Crop Land	9	0.30
Piedmont Alluvium	7	0.22	Vegetation Cover	8	0.27
Paleo Channel	4	0.12	Scrub Land	6	0.20
Residual Hills	1	0.03	Barren Rocky Waste	4	0.13
Linear Ridges	2	0.06	Water Bodies	2	0.07
Structural Hills	3	0.09			
<b>Slope</b>	<b>0.09</b>		<b>Drainage Density</b>	<b>0.12</b>	
Sub Category	Assigned weight	Normalized weight	Sub Category	Assigned weight	Normalized weight
Less than 1	9	0.30	0 – 1	9	0.30
1 – 5	8	0.27	1 – 2	8	0.27
5 – 10	6	0.20	2 – 4	7	0.23
10 – 20	4	0.13	4 – 6	4	0.13
20 – 50	2	0.07	4 – 6	2	0.07
More than 50	1	0.03			
<b>Lineament Density</b>	<b>0.07</b>				
Sub Category	Assigned weight	Normalized weight			
0.00 – 0.54	1	0.03			
0.54 – 1.09	3	0.09			
1.09 – 1.64	5	0.15			
1.64 – 2.18	7	0.21			
2.18 – 2.73	8	0.25			
2.73 – 3.28	9	0.27			



good permeability rate and Typic Ustifluvents soils have sandy loam textures which is highly permeable (Bouwer 2002). Typical hydraulic conductivity values of various soils are considered based upon their texture suggested by Herman Bouwer (2002) and United State Department of Agriculture (USDA) and their weights are assigned accordingly.

### Artificial recharge zone map

Normalized weights of individual themes and their associated features are calculated by AHP technique using the pairs of criteria  $C_i$  (in row) and  $C_j$  (in column). Table 1 shows how cell values in a square matrix are generated. In this table cell values for the factor of equal importance at intersection of row  $i$  and column  $j$  is 1; if  $C_j$  is more important than  $C_i$ , then  $a_{ij}$  is set equal to the importance of score and its value is more than 1 and if  $C_i$  is more important than  $C_j$ , then  $a_{ij}$  is set equal to the reciprocal of the importance score and its value is less than 1. Thereafter, the geometric mean of each row of matrix is calculated and then the normalized weight of each theme is obtained by dividing the individual geometric means with the sum of the geometric means (Chowdhury et al 2009). In the same way, normalized weights for different features of each thematic layer are also calculated as summarized in Table 2. On the basis of normalized weights for individual themes and their corresponding categories, all the seven thematic layers are integrated using 'Raster calculator' tool of Arc GIS software to demarcate potential

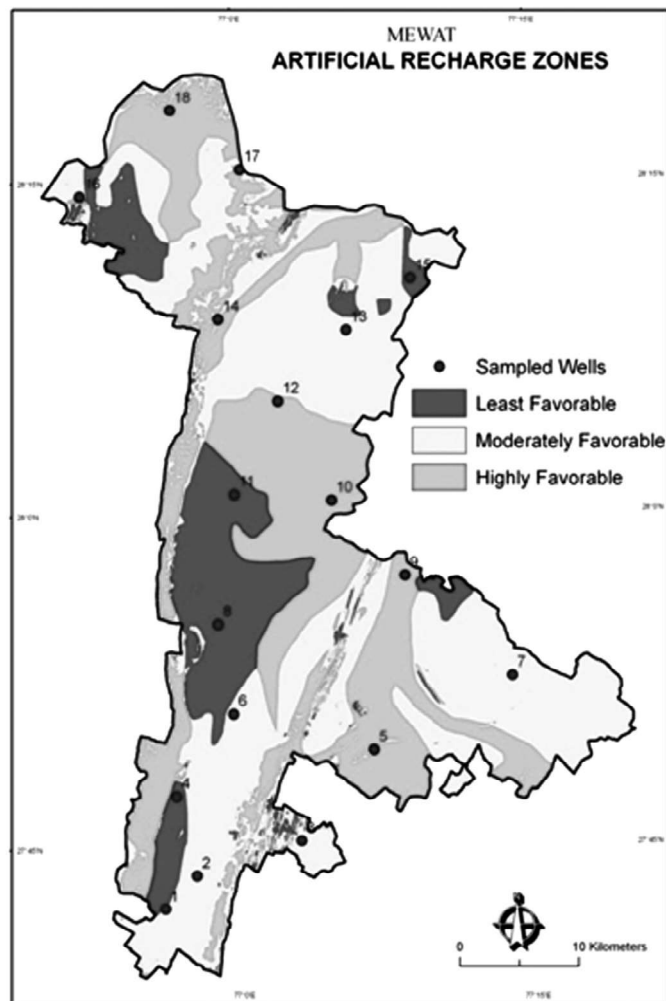


Fig. 4 : Artificial Recharge Zones Map with Sampled Wells

zones for artificial recharge. Resulted map indicates the potentiality for groundwater recharge in the study area which is then classified into three categories based on the mean and standard deviation values namely highly favorable, moderately favorable and least favorable. The level of suitability for artificial recharge is found in agreement with the geology, geomorphology, drainage and lineament density, slope and soil type of the study area. Of the study area, 535.05 km<sup>2</sup>

Table 3 Depth to Water Table (mbgl) Data of Sampled Wells

Sr. No.	Monitoring Well	Pre Monsoon	Post Monsoon	Recharge Zone
1	Raoli	12.65	12.70	Moderately Favorable
2	Agaun	14.10	14.05	Moderately Favorable
3	Biwan	14.85	14.90	Moderately Favorable
4	Firozpur Jhirka	13.20	13.30	Least Favorable
5	Ainchwari	13.50	13.00	Least Favorable
6	Sakras	10.65	10.05	Moderately Favorable
7	Ghira	15.80	15.35	Moderately Favorable
8	Nagina	4.45	4.45	Least Favorable
9	Sikrawa	4.80	4.60	Highly Favorable
10	Sangel	2.90	3.10	Highly Favorable
11	Akaira	1.80	1.90	Least Favorable
12	Adbar	30.65	30.55	Highly Favorable
13	Chhapera	5.10	5.15	Moderately Favorable
14	Tapkan	1.00	1.00	Least Favorable
15	Hasanpur Sohna	6.10	6.00	Least Favorable
16	Rathiwas	23.00	23.50	Highly Favorable
17	Chahalka	35.00	34.50	Highly Favorable
18	Biswar Akbarpur	30.50	30.50	Highly Favorable

Source: Hydrologist, Groundwater Cell, Gurgaon, Haryana

(36.06%) area is highly suitable, 712.44 km<sup>2</sup> (48%) is moderately suitable and 236.61 km<sup>2</sup> (15.94%) area is least suitable for artificial recharge (fig.4).

To validate the artificial recharge zone map, 18 monitoring wells (fig.4) are randomly selected with 6 wells from each recharge zone (table 3). High groundwater depth of an

area suggests dynamic underground storage during non monsoon period and, hence, favorable for the construction of structures for artificial recharge. When compared with the sampled wells data and depth to water level map for pre and post monsoon period, it is found that area demarcated as 'Highly favorable' has sufficiently deep groundwater

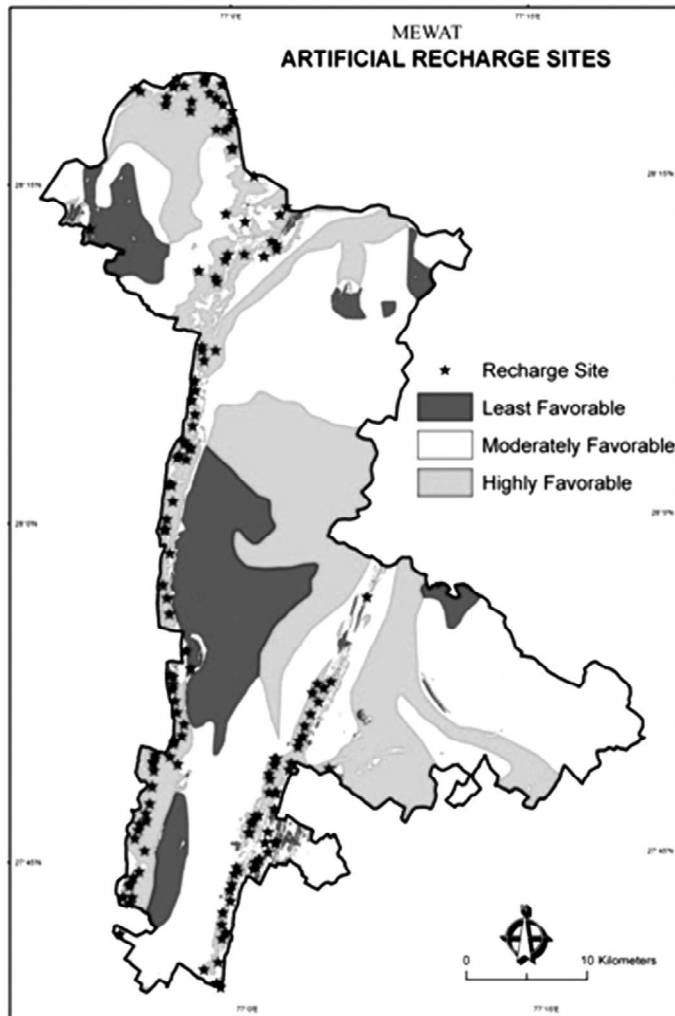


Fig. 5 Location of Artificial Recharge Sites

and on an average groundwater is more than 20 meter deep. In 'Moderately favorable' zone; out of six sampled wells, five has groundwater more than 10 meter deep whereas in 'Least favorable' zone only two wells has groundwater deeper than 10 meter otherwise it is less than 6 meter.

#### Artificial recharge sites

In the study area, a total of 155 artificial recharge sites are identified after intersecting

the lineament lines with 2nd and 3rd order streams. Out of which 103 sites lies in the highly favorable zone, 45 sites in moderately favorable zone and only 7 sites lies in the least favorable zone (fig.5).

As far as the artificial recharge structures are concerned check dams could be constructed at the identified sites. As these are small scale structures and are suitable to enhance infiltration of rain water during monsoon season. Other recharge structures like percolation tanks, on-farm reservoirs, stock ponds etc. can also be built wherever feasible. But it is recommended that before applying the practices for construction of recharge structures, a detailed study of the particular site should be carried out. In this process this study helps to find out the geology, soil type, permeability, slope, stream order and land use of a particular site in finalizing the specific recharge structure.

#### Conclusion

MCDM technique supported by remote sensing data and geographic information system is very effective for groundwater resources management by storing and manipulating a vast array of data. Methodology using weighted aggregation method in a GIS based multi criteria analysis is applied for demarcating potential recharge zones and selection of suitable sites for artificial recharge to improve the status of groundwater resources of Mewat district.

Thematic layers considered in this study are very important to understand the recharge process of any area like geomorphology helps to understand the landforms, lineaments to secondary porosity in hard rocks, slope to the velocity of runoff, drainage density to magnitude of runoff, soil type to percolation rate of rain water etc. Finally the integrated map of all these layers provides an overview to the potentiality for groundwater recharge in the study area. Recharge zone map of the study area shows that about 36% (535.05 km<sup>2</sup>) has highly favorable conditions, 48% (712.44 km<sup>2</sup>) has moderately favorable conditions and 16% area (236.61 km<sup>2</sup>) has least favorable conditions for artificial recharge. Out of the total 155 suitable sites identified for the construction of rainwater harvesting structure, 103 sites lies in the highly favorable zone, 45 sites in moderately favorable zone and only 7 sites lies in the least favorable zone. Further it is suggested that before the construction of rainwater harvesting structure, a detailed study of the targeted sites should be conducted to finalize the size and type of structure. Basic information regarding geology, geomorphology, soil type, percent slope, land use and stream order of a particular site is provided by this study.

### Acknowledgement

The authors of the paper are thankful to the Chairperson, Department of Geography, Kurukshetra University; Chief Scientist, Haryana Space Application Center, Hisar and Hydrologist, Groundwater Cell, Gurgaon for their kind cooperation in providing the required data and lab facility to complete this research work.

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