

Site Suitability Analysis of Water Harvesting Structure in Ghaggar River Basin Using Analytical Hierarchical Process and Geographical Information System Approach - A Case Study

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Abstract The increase in water demand due to increase in anthropogenic activities and changes in the hydrological phenomenon has led to water scarcity. The groundwater exploration, utilization, management and recharging by creation of appropriate water harvesting structure is an important aspect for its sustainable management. This current study was carried out for Ghaggar river basin to delineate groundwater potential zones using analytical hierarchical process based multi criteria decision analysis followed by identification of suitable sites and structures for water harvesting. The thematic layers for Landuse landcover, drainage density, soil texture, geomorphology, slope, lineament density and runoff were prepared and weights were assigned to each thematic layer. The weights were then normalized using the analytical hierarchical process based on their characteristic and relationship with groundwater recharge. Finally, the groundwater prospect zones were delineated by integrating the thematic maps using the weighted sum overlay analysis tool in ArcGIS 10.5. The areal distribution of the groundwater potential reveals that 0.02, 36.55, 43.18, 19.29 and 0.96 % falls under very poor, poor, moderate, good and very good groundwater potential category, respectively. The groundwater potential map was validated using the existing well data. The resultant groundwater potential zones falling in good to very good zones were integrated with slope and stream order as per the Integrated Mission for Sustainable Development (IMSD) guidelines and three types of water harvesting structures were suggested i.e. check dam (24), percolation tank (27) and farm ponds (50).

Keywords: groundwater, water harvesting, AHP, GIS

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1. Introduction

The multifaceted socio-economic growth of a nation can be achieved by the sustainable water resource development. The Indian river systems contribute globally about 4% of the total annual water. But India is facing great pressure of water scarcity because 16 % of the world population resides here, making it difficult to cope up with the current demands. Similarly, groundwater resources are also in high demands but due to monsoon failure and over exploitation it also has depleted. Although measures have been taken by the government in sustainable utilization of the water resources and its development in last 50 years, still over exploitation of the surface and groundwater resources have worsened the scenario. These problems can be sorted out to some extent by directing efforts in the development of

water harvesting structures and subsequently artificially recharging the potential aquifers. The process of water harvesting is the efficient utilization of the excess surface runoff by collecting it for its conservations as groundwater and surface water. Watershed is considered as an optimum unit for implementing these water harvesting activities for water resource management purposes. The site suitability analysis of the potential water harvesting is a vital step in maximizing water availability. The conventional approach for identification of potential sites for water harvesting structures is time consuming and non-viable. The space borne technologies such as remote sensing and analytical tools of geographical information system have gained attention in recent years as the salvation tools for site suitability analysis because of their ability to handle multidisciplinary data. The site suitability requirements involve various layers such as geomorphology, lithology, drainage density, Landuse/landcover, soil characteristics, rainfall and runoff characteristics. Analytical Hierarchical

Process (AHP) is a multi-criteria evaluation (MCE) technique which is widely used for decision making in the fields of natural resource management especially for varied suitability analysis. This technique coupled with the GIS technology is used world-wide for analyzing criteria for spatial choices [1]. Keeping in this view, the present study was taken to identify the potential water recharge zones for Ghaggar river basin by assigning of the weights and ranks using the Analytical Hierarchy Process (AHP) and weighted overlay analysis in a GIS environment. The groundwater potential zones identified were used for site suitability analysis of the appropriate water harvesting structures based on various criteria's being laid down by various researchers specially the Integrated Mission for Sustainable Development (IMSD) [2].

2. Material and Methods

For the current research, upper part of the Ghaggar river basin up to confluence of Medkhali river was studied. The study area extends from 76° 51' 45.06" and 30° 36' 46.50" to 77° 12' 45.30" and 30° 54' 27.18" and covers an area of 559.14 km² (Figure 1). The geomorphology,

Landuse landcover, lineament density, drainage density, soil texture, stream order and runoff were used for groundwater prospecting and identification of suitable site for water harvesting structure. The slope, stream order, drainage density and lineament density, were calculated from Sentinel -1 interferometrically derived digital elevation model having spatial resolution of 13.92 meters. The soil texture was calculated from the National Bureau of Soil Survey and Landuse Planning 1:5,00,000 scale maps and NBSS Publications [3,4,5]. The Landuse Landcover map was created from Landsat 8 satellite data having spatial resolution of 30 meter for the year 2015. The different thematic layers were reclassified into categories very good, good, moderate, poor and very poor groundwater prospecting layer and weights were given to them. The weights of the thematic layer were adjusted using the analytical hierarchical process and weighted overlay analysis was performed in ArcGIS 10.5 resulting in a groundwater prospecting map classified into very good, good, moderate, poor and very poor. Finally, the very good and good groundwater prospecting zones were chosen to suggest the suitable water harvesting structure based on the Integrated Mission for Sustainable Development (IMSD) [2] guidelines.

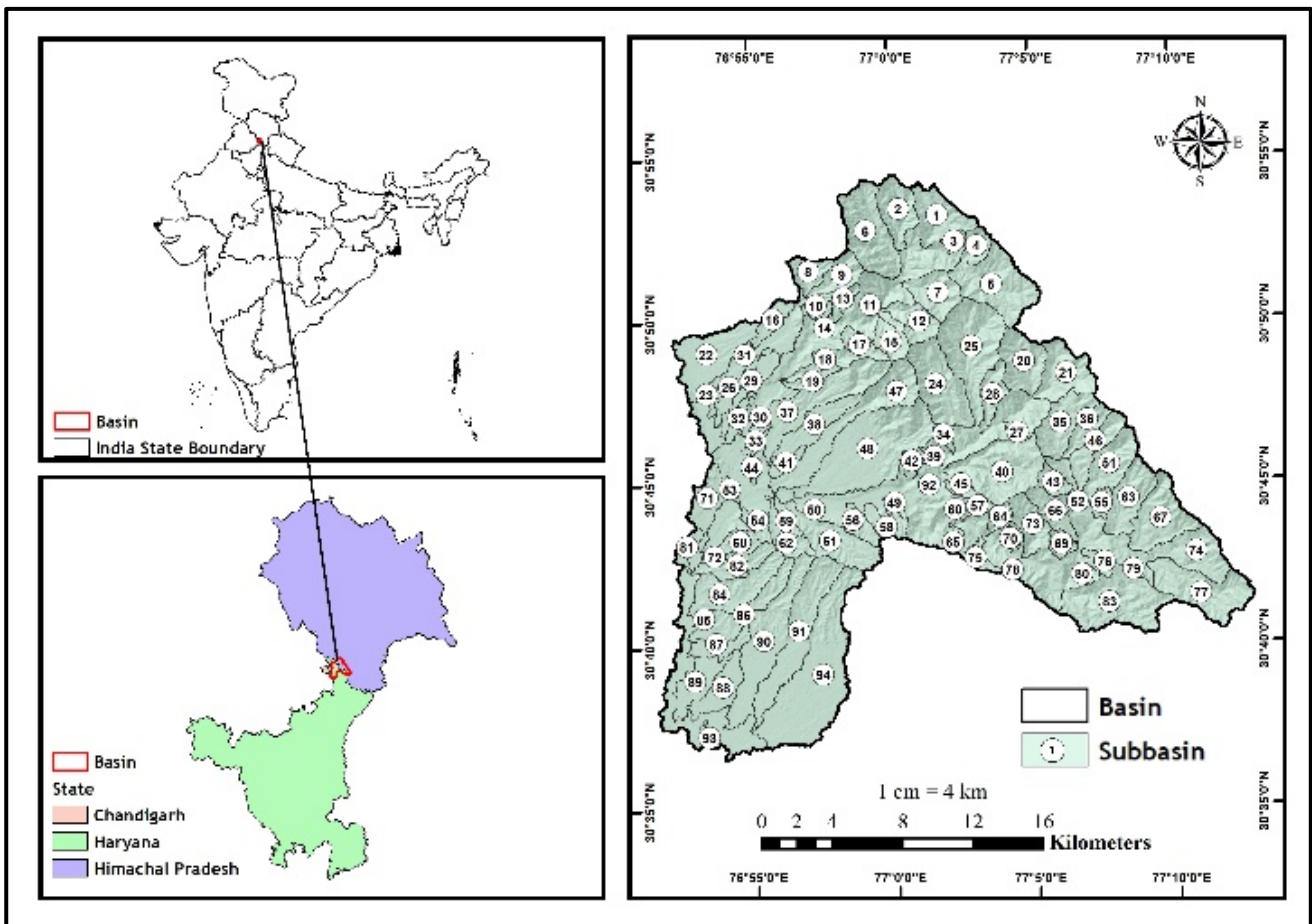


Figure 1. Study Area

3. Results and Discussion

3.1. Groundwater Prospect Zone Mapping

The Geomorphology is a vital layer for groundwater prospect mapping which ultimately leads to site suitability of water harvesting structures needed to recharge these zones. The geomorphological features were mapped based on the maps of Geological Survey of India. The area was classified into Fluvial origin, waterbodies, Anthropogenic origin and structural origin occupying 19, 3.5, 9.4 and 68.1%, area of the watershed respectively. In terms of groundwater prospects, the Fluvial origin, waterbodies, Anthropogenic origin and structural origin is reclassified into very good, good, good and very poor, respectively (Table 4). The Landuse landcover was created from Landsat 8 Orbital Land Imager (OLI) sensor for the year 2015. The major Landuse pattern prevalent in the study area includes cropland, forest, barren land, scrubland, built up and waterbodies occupying 22.8, 58, 0.6, 8.8.1 and 2.5 %, respectively. The cropland, waterbodies are very good to good while the barren land, scrubland, forest and built up are poor to very poor in terms of groundwater prospects (Table 4). Lineaments are the most important hydrogeological features which favors the groundwater movement [6]. These lineaments act as an excellent groundwater potential zone as they increase the infiltration. The area was divided into 5 classes of lineament density having different groundwater potential as very high (2.3 - 7.8 km/km²), high (1.5 - 2.3 km/km²), moderate (1.1 - 1.5 km/km²), low (0.8 - 1.1 km/km²) and very low (0 - 0.8 km/km²) (Table 4). The areas having higher lineament density are considered optimum for groundwater recharge. The steep slopes owing to increased velocity of the water results in rapid runoff. Whereas the gentle sloped regions increase the time of concentration of the water at a particular place and thus favoring water penetration into soil [7]. The Ghaggar river basin is divided into five categories based on the slope. The slope 1°-4°, 4°-9°, 9°-16°, 16°-26° and greater than 26° corresponds to very high, high, moderate, low and very low groundwater potential, respectively (Table 4). Drainage density act as a permeability indicator of the drainage basin surface. High drainage densities are pertinent to the regions having impervious subsurface with weak structure and therefore have poor groundwater prospects. The study area was divided into 5 classes of drainage density having different groundwater potential as very high (0.5 - 2.5 km/km²), high (2.5 - 3.0 km/km²), moderate (3.0 - 3.5 km/km²), low (3.5 - 4.0 km/km²) and very low (>4 km/km²) (Table 4). The groundwater

potential of an area has a major impact of its soil texture [8]. The study area having sandy loam, loam, sandy clay loam and clay loam was classified into hydrological soil group A, B, C and D respectively resulting in high, moderate, low and very low infiltration, respectively. These soils are an excellent indicator of very good, good, poor, very poor groundwater potential, respectively (Table 4). The surface runoff volume is computed using modified SCS (Soil Conservation Service) curve number method using the Indian Meteorological Department (IMD) gridded rainfall data having spatial resolution of 0.25° x 0.25° [9]. The surface runoff values are in agreement with the Landuse classes and the built-up areas have high runoff due to less infiltration by the impervious layer.

The different thematic layers created were reclassified in GIS environment into different groundwater potential zones ranking from 1 to 5 and progressively demarcated as very poor, poor, moderate, good and very good respectively. The weights of the different layers were given based on the Analytical Hierarchy Process [10]. The priority of a thematic layer over the other and its association was decided based on the literature review done by various researchers [11,12,13,14,15]. The AHP technique reduces the subjectivity and biasness associated with the weight assignment. The consistency ratio for different thematic layers is computed based on eq. 1 and eq. 2 to assess consistency of normalized weights and it should be within 10%.

$$CI = \frac{\lambda_{max} - 1}{n - 1} \tag{1}$$

$$CR = \frac{CI}{RI} \tag{2}$$

Where CI = Consistency Index
 CR = Consistency ratio
 RI = Random index
 n = number of factors.

Table 1. Pairwise comparison of the different thematic layers of Ghaggar river basin (GEO - Geomorphology, DRD- Drainage Density, SLP- Slope, SOL - Soil, LND - Lineament Density, LULC - Landuse Landcover)

Factors	GEO	DRD	SLP	SOL	LND	LULC
GEO	1	2	3	3	4	5
DRD	0.5	1	2	3	4	4
SLP	0.33	0.5	1	2	3	2
SOL	0.33	0.33	0.5	1	2	3
LND	0.25	0.25	0.33	0.5	1	2
LULC	0.2	0.25	0.5	0.33	0.5	1
Column Total	2.61	4.33	7.33	9.83	14.5	17

Table 2. Normalization of the weights (GEO - Geomorphology, DRD- Drainage Density, SLP- Slope, SOL - Soil, LND - Lineament Density, LULC - Landuse Landcover)

Factors	GEO	DRD	SLP	SOL	LND	LULC	Row Total	Average Priority Vector	λ_{max}
GEO	0.38	0.46	0.41	0.31	0.28	0.29	2.13	0.36	6.26
DRD	0.19	0.23	0.27	0.31	0.28	0.24	1.51	0.25	6.29
SLP	0.13	0.12	0.14	0.20	0.21	0.12	0.91	0.15	6.30
SOL	0.13	0.08	0.07	0.10	0.14	0.18	0.69	0.11	6.12
LND	0.10	0.06	0.05	0.05	0.07	0.12	0.44	0.07	6.07
LULC	0.08	0.06	0.07	0.03	0.03	0.06	0.33	0.06	6.17
Column Total	1.00	1.00	1.00	1.00	1.00	1.00	6.00	1.00	

The pairwise comparison of the different thematic layers is given in Table 1. This is followed by the normalization of the weights of individual thematic class by dividing the weight by the column total and is shown in Table 2.

The next step in AHP is calculation of consistency measure which requires λ_{max} for which matrix multiplication function of Microsoft excel is utilized and is shown in Table 2. The Consistency index is calculated by:

$$CI = \frac{Average \lambda_{max} - n}{n - 1} \tag{3}$$

$$CI = \frac{6.20 - 6}{6 - 1} = 0.04. \tag{4}$$

The consistency ratio is finally calculated by dividing the CI (Consistency Index) calculated above by RI (Random index) (eq.5). The values of Random Index based on number of factors used are predefined by [10] and are given in Table 3. The consistency ratio is less than 0.10 i.e. 10% and hence the weights are consistent.

$$CR = \frac{CI}{RI} = \frac{0.04}{1.24} = 0.03 \tag{5}$$

Table 3. Random Index table

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

The weighted Sum overlay tools in Spatial Analyst toolbox of ArcGIS 10.5 was used to overlay the thematic layers with weights of individual layer generated from AHP to identify groundwater potential zone using weights given in Table 4. The areal distribution of the groundwater potential reveals that 0.02, 36.55, 43.18, 19.29 and 0.96 % falls under very poor, poor, moderate, good and very good groundwater potential category, respectively (Figure 2). The results were validated with the water table depth data of observation tube well/dug well/borewell and Handpump wells data from Central Groundwater Board and State departments which were overlaid on the groundwater prospect map.

3.2. Site Suitability Analysis of Water Harvesting Structures

The groundwater potential zones identified were used for site suitability analysis of the appropriate water harvesting structures based on various criteria's being laid down by various researchers specially the Integrated Mission for Sustainable Development (IMSD). These criteria were based on various thematic layers such as slope, stream order, runoff, permeability of soil and groundwater potential (Table 5). In present study three types of water harvesting structures were suggested i.e. check dam (24), percolation tank (27) and farm ponds (50) based on overlay analysis of the various thematic layers. The location map of the different water harvesting structure in Ghaggar river basin is shown in Figure 3.

Table 4. Thematic layer weights for groundwater prospect mapping of Ghaggar river basin

Sr. No	Thematic Layer	Classes	Groundwater Potential	Rank	Normalized Weight
1	Geomorphology	Structural Origin	Very Poor	1	36
		Anthropogenic Origin	Good	4	
		Waterbodies	Good	4	
		Fluvial Origin	Very Good	5	
2	Drainage Density	>4.0	Very Poor	1	25
		3.5 - 4.0	Poor	2	
		3.0 - 3.5	Moderate	3	
		2.5 - 3.0	Good	4	
3	Slope	0.5 - 2.5	Very Good	5	15
		10° - 40°	Very Poor	1	
		5° - 10°	Poor	2	
		3° - 5°	Moderate	3	
4	Soil	1° - 3°	Good	4	11
		0° - 1°	Very Good	5	
		Clay Loam (D)	Very Poor	1	
		Sandy Clay Loam (C)	Moderate	3	
5	Lineament Density	Loam (B)	Good	4	7
		Sandy Loam (A)	Very Good	5	
		0 - 0.8	Very Poor	1	
		0.8 - 1.1	Poor	2	
6	Landuse Landcover	1.1 - 1.5	Moderate	3	6
		1.5 - 2.3	Good	4	
		2.3 - 7.8	Very Good	5	
		Built- Up	Very Poor	1	
		Barren Land	Poor	2	
		Forest	Poor	2	
Scrubland	Moderate	3	6		
Waterbodies	Good	4			
		Cropland	Very Good	5	
					100

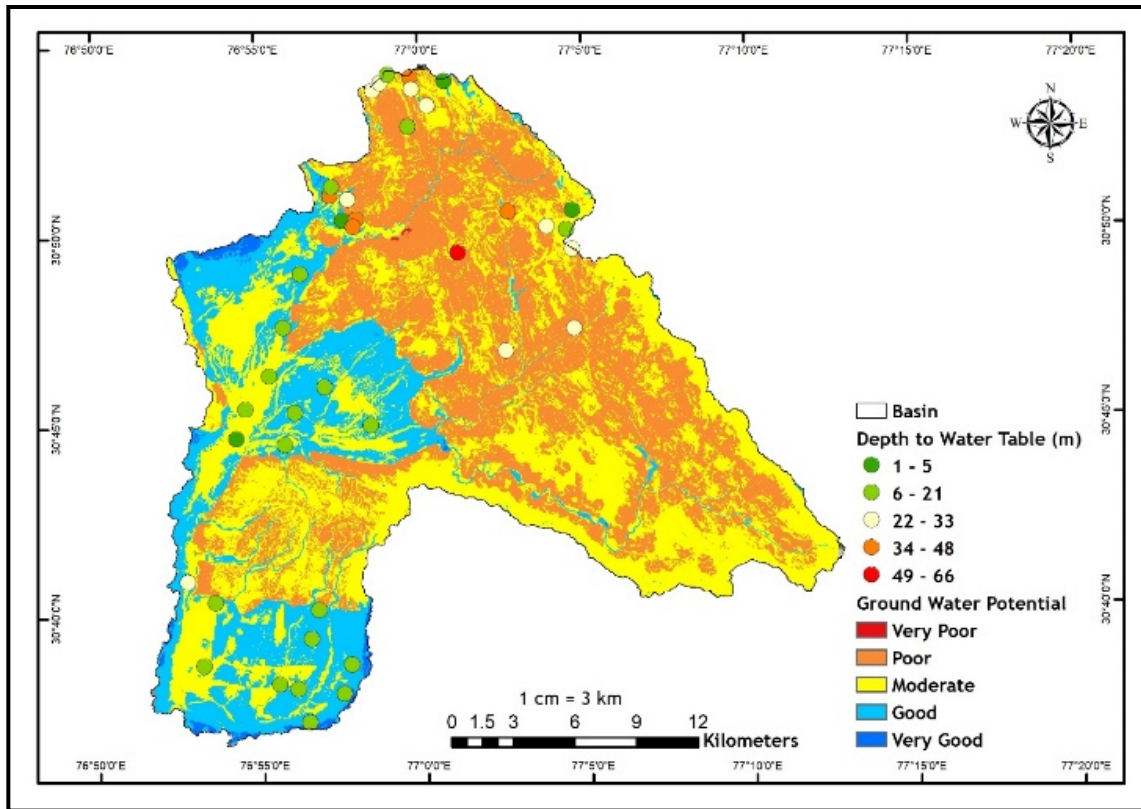


Figure 2. Groundwater potential map of Ghaggar river basin

Table 5. IMSD Guidelines for identification of Water Harvesting Structures

Structure Type	Slope (Degree)	Soil Porosity	Runoff Potential	Stream Order	Catchment area (ha)	Groundwater Potential
Check Dam	< 15	Low	Medium/High	1 -4	> 25	Good - Very Good
Percolation Tank	< 10	High	Low	1 -4	25 - 40	Good - Very Good
Farm Pond	0 - 5	Low	Medium/High	1	1	Good - Very Good

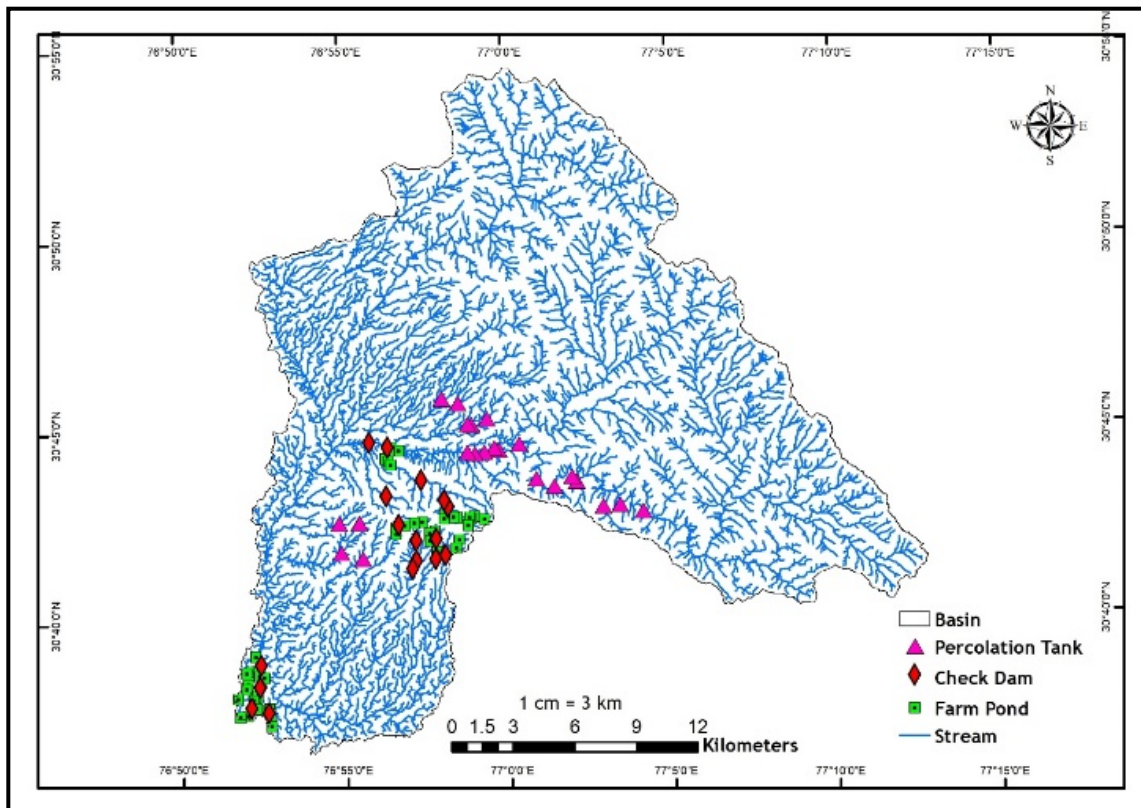


Figure 3. Site suitability for various water harvesting structures in Ghaggar river basin

4. Conclusions

The space technology in synergy with geographical information system has shown its advantage over the conventional survey techniques in the process of site suitability analysis of the identification of water harvesting structure. In present study multilayered integration capability of various relevant thematic layers such as slope, landuse, geomorphology, drainage density, lineament density, and soil of GIS is exploited. The analytical hierarchical approach normalized the weights of individual thematic layer which are further used in multicriteria decision analysis available as weighted sum overlay tool in ArcGIS software. This resulted in a composite layer classified as most suitable, suitable, moderately suitable, less suitable and not suitable groundwater prospect zones. The suitable groundwater areas were validated with the observation well data which indicated good prediction capability. The water harvesting structures such as check dam (24), percolation tanks (27) and farm ponds (50) have been proposed based on the guidelines of Integrated Mission for Sustainable Development (IMSD).

This study is beneficial to the water resource managers and planners in sustainable managing the utilization of the groundwater and the proposed water harvesting structure can help in continuous recharge of these recharge zones.

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