Site Selection for Rainwater Harvesting using remote sensing, GIS and AHP

ABSTRACT

Aims: The research work was carried out to find suitable sites for rainwater harvesting in Dhatarwadi river basin of Amreli district of Gujarat, India using remote sensing and geographic information system along with analytic hierarchy process.
Study design: -
Place and Duration of Study: This study was carried out at College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh, Gujarat, India.
Methodology: In present study, suitable sites for runoff water harvesting structures were identified using guidelines of IMSD (1995) and FAO (2003). Five criteria i.e. rainfall, land use/land cover, soil texture, lineament density and slope were selected. Thematic layers of these layers were analysed using overlay process using ArcGIS software and weights for criterias were derived with experts' opinion using AHP.
Results: Results obtained were for water harvesting site selection, AHP generated weight for criteria were 36.1%, 20.6%, 18.6 %, 13.1 % and 11.7 % for rainfall, land use/land cover, soil texture, lineament density and slope, respectively. In study area, 66.79 % area found very high suitable, 24.89 % highly suitable, 5.63 % moderately suitable, 0.88 % less suitable and remaining 1.81 % area found not suitable for water harvesting sites. As per suitability and ground truth, 24 check dam sites on scrubland, 52 check dam sites on cropland, 11 check dam sites on the river bed were obtained and 29 farm ponds sites were proposed in the study area. The result indicates that 72.27% of existing RWH sites are in very high suitability and 26.73% located in high suitable whereas only 0.49 % and 0.49 % are in the moderate suitable and not suitable area, respectively.
Conclusion: To find suitable sites for runoff water harvesting experts can use remote sensing, GIS and AHP in integration for precise work.

Keywords: Dhatarwadi, river basin, rainwater harvesting, site selection, IMSD, AHP

1. INTRODUCTION

Water is one of the foremost vital substances on earth. All plants and animals or can say living and also nonliving need water to survive. If there will be no water there would be no life on earth. Therefore, the judicious use of water is a compulsion.

"India received the average annual precipitation is 4000 BCM, out of which 700 BCM is lost into the atmosphere immediately, 1150 BCM is available as surface runoff and 2150 BCM gets absorbed by the ground. India's total water resources have been estimated as 1953 BCM. The Ganga-Brahmaputra-Meghna basin contributes nearly 62% or 1202 BCM of the total water resources and the remaining 38% or 751 BCM is contributed by remaining 23 basins. The annual water availability in India is 1122 BCM in terms of utilizable water resources. On the other hand, due to increased use from irrigation, domestic and industrial purposes the quantity of 123 BCM to 169 BCM additional return flow will also be available by the year 2050. In the year 1951 the per person usable water availability, was about 3,000 m^3, which has been drastically decreased to 1,100 m^3 in 1998 and is still expected to go lower that is to 687 m^3 by year 2050" [1].

“Many researchers have used remote sensing and GIS to identify suitable sites for macro-catchment water harvesting structures” [2-9]. “However, many other studies are found in the literature about the suitability of on-farm micro-catchment (catchment area less than $1000m^2$) water harvesting” [6, 10-11].

“For relatively small areas, a field survey carried out by experienced people will be the best technique to select the appropriate sites and to determine the suitable methods for water harvesting. For larger area application of Geographic Information System (GIS) and remote sensing can be the most relevant means” [6, 12-13].

In recent years, Geographical Information Systems (GIS) have provided a flexible, powerful platform for integrating remote sensing data and runoff model outputs in order to optimally situate water harvest structures [14-17], typically by using spatial analysis tools [18]. “Delineating suitable areas for water harvesting is often performed by integrating different factors using GIS overlay and index-based multi criteria decision analysis (MCDA), which for GIS can provide a set of powerful techniques and procedures for making critical decisions” [19].

“Among MCDA approaches, the analytic hierarchy process (AHP) is a widely used method in decision-making processes in various fields” [20]. “It offers an adaptable, low-cost, and understandable output for complex decision making” [21]. “In reviewing the application of MCDA methods for water resource management, Hajkowicz and Collins indicated that AHP perhaps is the most widely used technique over all other available methods”. [22] “Indeed, the GIS-based AHP strategy been broadly acknowledged by the global academic community as a powerful technique for analyzing spatial decision-making problems” [23].

GIS based site suitability analysis has been applied in a vast range of situations that even include ecological approaches for defining land habitant/suitability for different animals and various plant species [24], environmental impact assessment [25], land suitability assessment for agricultural use [26], site selection for private and public sector facilities [27-28].

Site suitability analysis makes a distinction between the site selection problem and the site search problem. The goal of an analysis for site selection is to identify the best possible site for an activity from potential (feasible) sites. In this type of analysis all the characteristics (such as location, size relevant attributes, etc.) of the candidate sites are recognized. The issue is to rank or rate the different sites depending on their attributes so that the finest site can be distinguished. If there isn’t a pre-decided set of possible sites, the problem is considered as site search analysis. By solving the problem the characteristics of the sites (their boundaries) have to be defined. The aim of the site search analysis is to explicitly identify the areal extent of the best site [29].
The focus of this research work was on site search analysis using thematic layers generated in form of spatial raster layers and applies the analytical hierarchy process which considers the spatial variability of all the input layers.

2. MATERIAL AND METHODS

2.1 Study area

In Amreli district of Saurastra region of Gujarat, India the Dhatarwadi river basin is located between 20^o 50' to 21^o 20' North latitude and 71^o 05' to 71^o 35' East longitude as shown in figure 1. Dhatarwadi river basin covers an area of 85899 ha river and flows through five taluka i.e. originating from Savarkundla moving through Khambha, Jafrabad and Rajula encompassing tributaries namely Likhala, Sonardi and Surajwadi.

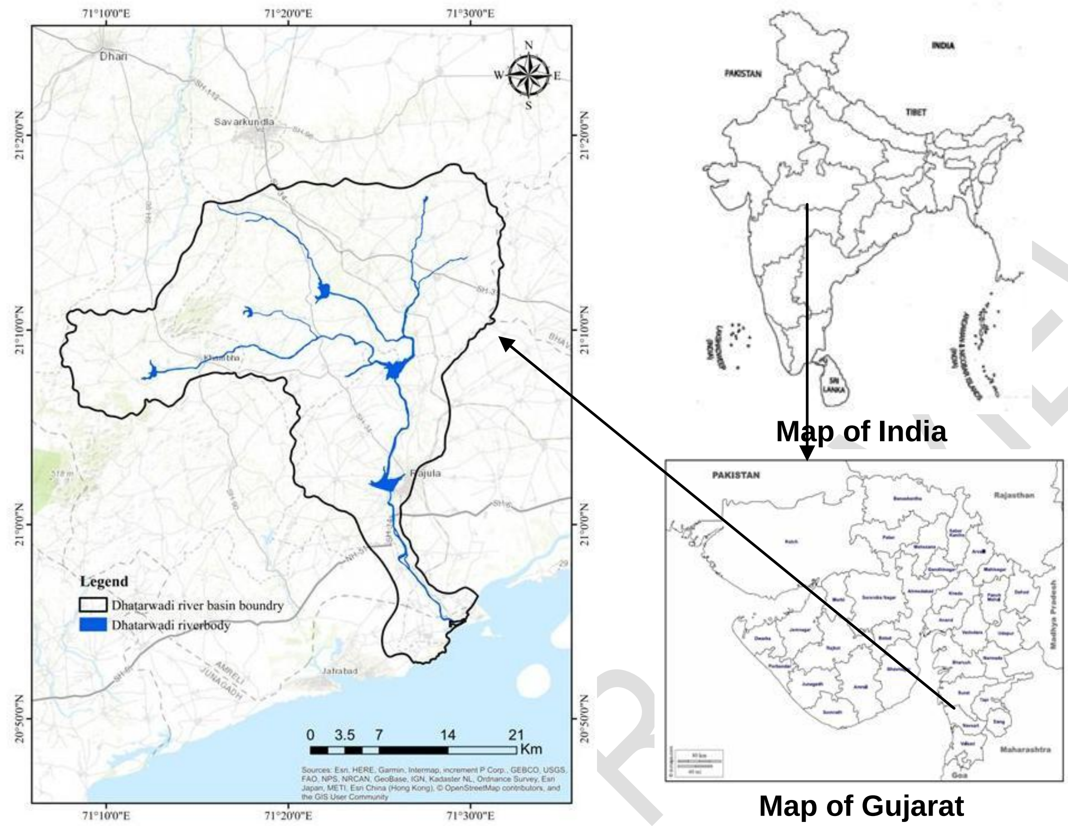

Fig. 1. Location map of Dhatarwadi river basin

The climate of the basin is arid to semi arid. During winter season, which start from the month of November, and ends in the middle of March having minimum temperature 19°C and 20°C, respectively, during which January is the coldest month. Whereas, summer season comprises of the months from middle of March to middle of June, mid April to mid of June being the hottest period during the year, during May month maximum temperature is recoded near about 42℃. The rainy season generally starts from the mid of June and ends in September or October. The average annual rainfall in the Dhatarwadi river basin is 660 mm (year 1988 to 2017).

Dhatarwadi river basin has four earthen dams namely, Mobhness dam, Krushnagadh dam, Dhatarwadi dam-1 and Dhatarwadi dam-2 and one masonry/gravity dam i.e. Surajwadi dam. Water stored in these dams is being used for irrigation purpose in various villages of Dhatarwadi river basin by three medium irrigation projects that are Dhatarwadi-1, Dhatarwadi-2 and Surajwadi, created irrigation potential of 2480 ha, 2680 ha and 1220 ha, respectively; total 6380 ha area. Further rainwater harvesting can increase irrigation potential in Dhatarwadi river basin [30].

2.2 Materials

The materials used for this study include Daily rainfall data of 5 raingauge stations falling in study area (from year 2002 to 2017) obtained from State Water Data Center, Gandhinagar and remote sensing data i.e. 30 m resolution SRTM DEM, Land use/Land cover map, Soil map, Lineament map, River body and basin boundary provided by Bhaskaracharya Institute for Space Application and Geo-informatics (BISAG), Gandhinagar.

The remote sensing and GIS software used for the study was ArcGIS-ArcMap 10.3. It was used to generate maps, integration of geographic data, analyzing map information, discovering and also sharing geographic information and managing geographic information in a database.

2.3 Methodology

2.3.1 Selection of the criteria for rainwater harvesting site selection suitability

In present study, suitable sites for water harvesting structures were identified using guidelines of Integrated Mission for Sustainable Development (IMSD) [31] and Food and Agriculture Organization (FAO) [32]. Adham *et al.* [33] studied various guidelines for rainwater harvesting site selection. As per their study result, in IMSD [31] guidelines, given criteria are found more flexible as per soil texture and slopes and FAO [32] guidelines are found very broad guideline, covering all possible criteria for potential rainwater harvesting sites selection. Kahinda *et al.* [34] given "six main criteria for identifying RWH sites: climate, agronomy, hydrology, topography, soils, and socio-economics. Based on literature review of previous studies, specific conditions of the Dhatarwadi river basin and data availability, 5 criteria considered as main factors were chosen for this study including: rainfall as parameters for climate, lineament density as a parameter for hydrology, slope as a parameter for topography, land use/cover as a parameter for agronomy and soil texture as a parameter for soils".

2.3.1.1 Rainfall

Rainfall is the main source of runoff water. In other words, rainfall has a positive influence on runoff amount of runoff water. Therefore, it is a major component to be considered for any type of RWH structure site selection, because any structure will be useful if the area receive sufficient rainfall [33].

2.3.1.2 Slope

"Slope is a very important parameter influencing runoff and thus it also influences the amount of sediment, the speed of water flow and the material required to construct dams (dyke height)" [33]. As per Critchley *et al.* [35] runoff water harvesting for areas having slope ≥5% is not advisable, because of irregular runoff distribution they are susceptible to high erosion and large earthworks are required [36].

2.3.1.3 Soil texture

Soil texture influences both the rate of infiltration and the surface runoff. The textural class of a soil is ascertained by the proportion of sand, silt and clay. Soil texture leads to different soil infiltration rate hence different influence on runoff amount. White [37] advised to select sites having fine and medium textured soil for RWH because of their higher water retention property, which was also advocated by Adham *et al.* [33]. Generally, clay soil has high water retention capacity and low permeability, which makes it desirable soil texture for RWH structures [10]. Therefore, soil texture is a critical criterion for selection of a RWH site, specifically if the purpose of storage is to preserve the water for agriculture, human and livestock [38].

2.3.1.4 Land cover/Land use

Land cover plays a crucial role in generation of the runoff from each rain within the area. Kahinda *et al.* [39] stated that, dense vegetation is related with higher rate of infiltration and interception loss, thus generate lower runoff. Since the focus of this study is on irrigation water, the priority of agricultural land is higher, also non-agricultural land like shrub or forest covers are also under consideration.

2.3.1.5 Lineament density

A lineament is a large scale linear structural feature, which may represent joints sets, deep seated faults and master fractures, also boundary lines and drainage lines of different rock formations [40]. Lineament density an important role in RWH site selection for storage as well as for groundwater recharge, because it causes water to pass away from the storage site. Hence, if an area is having high lineament density, is not good site for water storage, but is best site for groundwater recharge structure [40-41].

2.3.2 Weight Determination for Selected Criteria Using AHP

"Analytical Hierarchical Process (AHP) is a method of Multi-criteria decision analysis (MCDA) that is implemented within GIS, which defines weights for criteria. AHP was initially developed by Saaty" [21]. The AHP approach is a stepwise process for deriving weights of various criteria. The AHP has the ability to deal with inconsistent judgments [21;42].

AHP is a very effective method for solving complex problems of decision making. It helps decision makers to take best possible decision based on their fixed priorities. A series of pairwise comparison matrix is adopted to solve complex decisions and then results are analyzed. As AHP analysis depends upon experts' opinion, checking the consistency of the obtained results become compulsory, so that, biasness in the decision can be reduced. Consistency ratio is determined to verify if perceptions are consistent or not. This is the main advantage of using AHP [43]. It helps in understanding significance of one criterion than the other criteria, also to estimate its level of priority. The pairwise comparison matrix allows user to convert qualitative parameters into quantitative data with the help of experts by generating a pairwise comparison matrix with the help of Saaty's scale [21]. Saaty suggested a widely known 5-point scale (1-3-5-7-9) (Table 1) to be used for evaluation.

Table 1. Scales for the pairwise comparison [21]

Intensity of Importance	Definition	Explanation
1	Equal importance in a pair	Two criteria furnish equally to the objective.
3	Moderate importance	Judgment and Experience moderately favours one criterion over another.
5	Strong importance	Judgment and Experience strongly favour one criterion over another
7	Very strong importance	Judgment and Experience very strongly favour one criterion over Another
9	Extreme importance	The evidence favouring one criterion over another is of highest possible validity
2, 4, 6, 8	Intermediate values	When compromise is needed
Reciprocals	Values for inverse comparison	If criterion i had one of the above numbers assigned to it when compared with criterion j, then j has the reciprocal value when compared with i

Source: Saraf and Choudhury [42]

A crucial issue is to safeguard the consistency of the matrix. The AHP method evaluates the consistency of each expert's estimates. Consistency index is defined [21;44-45] as a relationship:

$$CI = \frac{\lambda_{max} - m}{m-1}$$

in which λmax is the largest eigenvalue of the comparison matrix and *m* the order of the comparison square matrix.

The smaller the consistency index, the higher the consistency of the matrix. In the ideal case, *CI* = 0. The consistency degree of matrix P may be ascertained quantitatively by comparing the calculated consistency index of the matrix with a randomly generated consistency index (based on the scale 1-3-5-7-9) of the inverse symmetrical matrix of the similar arrangement. The appropriate value of the random consistency index (RI) is determined from Table 2.

Table 2. Average random consistency indices (RI) for different number of criteria

Number of criteria (N)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Random consistency indices (RI)	0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57	1.59

Source: Saraf and Choudhury [42]

The relationship between the calculated consistency index *CI* of a particular matrix and the average random index value *RI* is referred as consistency relationship which determines consistency of the degree of matrix.

$$CR = CI/RI$$

In which CI is the consistency ratio and RI the consistency index of a comparison matrix. If CR is greater than 0.1, then the set of judgment is inconsistent; if CR is smaller than or equal to 0.1, then judgment is acceptable and if CR equals 0, then the judgment is wholly consistent [46].

2.3.3 GIS Data Integration and Analysis

Data integration refers to the use of various data layers together in display or analysis. In order to utilize data layers together various parameters available must match. First, the reference system must match. This is important because often combining separate themes based on their spatial characteristics. For rates layers to be used in image-to-image operations such as OVERLAY, the extent of the image, the number of rows and columns in the images and the pixel resolution of the images must also match. Following steps were followed to determine Rainwater harvesting suitability zones using ArcGIS software.

- The thematic layers which are generally in vector form are converted into raster database which is called Rasterization. Important points to be kept in mind during this process that all the thematic layers must be converted into raster layer having same cell size and geo-reference.
- After rasterization process, Reclassification of Reclassify is done to make analysis understandable to software as per objective requirement.
- Next is OVERLAY analysis. In this step all the reclassified layers are provided respective weights from 10 or 100. In this study, weighted overlay analysis is used.

Following above steps will give raster layer based on given weight of criteria having cell numbers which are referred as not suitable, low suitable, moderate suitable, high suitable and very high suitable (based on cell ranking i.e. 5 for high suitable, 4 – moderate suitable, 3 – low suitable, 2- low suitable and 1 for not suitable). Ranks from 5 to 1 were provided to sub categories of selected criterions as per there suitability for rainwater harvesting site selection.

2.3.4 Rainwater harvesting/ conservation structures site selection

In present study, an analysis was made to identify the suitable mechanisms for runoff water harvesting based on various controlling terrain parameters in the study area. Various runoff water harvesting structures and their sites suitability are discussed in the following paragraphs. The following criteria have been followed for making decision on selecting suitable sites for various water harvesting structures as per IMSD and FAO guidelines as shown in Table 3.

Table 3. Preliminary site selection criteria for the planning of different water harvesting structures

Structure	**Slope**	**Stream**	**Catchment**	**Soil**	**Rainfall**

	(%)	order	area (ha)	texture	(mm)
Farm ponds	0–5	1–2 or without drains	>1–2	Clay, fine, loamy	>200
Check dams (scrubs/ trees/river bed)	<15	3–6	25	Clay, fine, loamy	<1000
Check dams (crop land)	<=3	3-6	25	Clay, fine, loamy	<1000

Sources: Ramakrishnan et al. [16;47], Kadam et al. [48] and Shanwad et al. [49]

The comparatively third order and higher, command area up to 50 ha and nearly level to gently sloping land i.e. less than 5 per cent are suitable for the construction of water harvesting structures [50].

2.3.4.1 Check dams

"Check dams are small dams (impermeable structures) constructed across water courses in narrow wadis with gentle slopes. They are feasible both in hard-rock and alluvial formations" [51]. "These dams have the benefit of being low cost to build, however the number of suitable sites available is typically limited. Check dams are a highly prevalent type of RWH. They are of great importance because they can also control soil erosion" [51]. "Check dams can effectively harvest and store storm runoff from large catchments. They are the invaluable source of auxiliary water and can be designed and constructed using local materials and labour force. They are a common feature of rural landscapes in many parts of the world such as Iraq, Tunisia, China and India" [52].

Table 3 shows criteria for check dam and farm pond site selection which is IMSD [31] guideline, have been used in this study.

2.3.4.2 Farm Pond

Ponds are amongst the most reliable and economical sources of water in semi-arid regions. The harvested water is used either for all or supplemental irrigation or for other purposes such as domestic use, watering livestock, controlling erosion and stabilizing water channels. Farm ponds are the most suitable water harvesting structures for semi-arid regions [38]. Ponds are established on the higher parts of farms to block and store the runoff rainwater by constructing an embankment across a watercourse, excavating a pit or a combination of both [53].

3. RESULTS AND DISCUSSION

3.1 Criteria for water harvesting site selection

Criteria identification based on available data of any study area is useful for indicating the degree of influence to which selected criteria are suitable for the rainwater harvesting structure site selection. Determining the criteria is an important method for the site selection of rainwater harvesting structures, where site selection is based on the appropriate literature reviews. FAO [32] had listed six key factors for the assessment of sites for soil water conservation i.e. climate, hydrology, topography, agronomy, soils and socioeconomics [54-55]. Five of these criteria were selected for identify potential sites for water conservation based on a literature review and most importantly available data. In this study the recommendations of the FAO are followed and used rainfall as parameter for climate, lineament density as a parameter for hydrology, slope as a parameter for topography, soil texture as a parameter for soils and land use/cover as a parameter for agronomy.

3.2 Developing AHP model

After defining the criteria, the questionnaire was used to identify the relative importance of all the selected criteria by experts based on the scale of 1-9 to assess the relative importance of each individual criterion. Opinions were obtained from 10 experts with the background of soil water conservation, rainwater harvesting, groundwater recharge, remote sensing and geographic information system. The experts were selected based on their knowledge of the study area in particular.

Next step is to prepare pair wise matrix of selected criteria based on opinions of experts. The pair wise comparison matrix is shown in Table 4, was prepared from the comparison factors listed on each criterion. The diagonal element of the square matrix always 1 because comparing the same factors have the same weight, therefore the upper and lower triangular matrix was generated by comparing the factors with each other as decided by the experts.

Table 4. Pair wise comparison matrix of factors with intensive judgements

WH (Goal)	Rainfall	Soil texture	LU/LC	Slope	Lineament density
Rainfall	1	$2\frac{2}{7}$	$1\frac{5}{8}$	$2\frac{5}{9}$	$3\frac{2}{7}$
Soil texture	$\frac{4}{9}$	1	$\frac{2}{3}$	2	$1\frac{7}{9}$
LU/LC	$\frac{3}{5}$	$1\frac{1}{2}$	1	$1\frac{2}{3}$	$1\frac{1}{5}$
Slope	$\frac{2}{5}$	$\frac{1}{2}$	$\frac{3}{5}$	1	$\frac{7}{8}$
Lineament density	$\frac{1}{3}$	$\frac{4}{7}$	$\frac{5}{6}$	$1\frac{1}{7}$	1

For ease of further calculation, values shown in Table 4 were converted into decimal form. Now each element of a column of the matrix was summed up and again each element of the column was divided with the sum of its column (Table 5) to get the normalized relative weight presented in Table 6.

Table 5. Column addition

WH (Goal)	Rainfall	Soil texture	LU/LC	Slope	Lineament density
Rainfall	1	2.285	1.625	2.56	3.285
Soil texture	0.444	1	0.667	2	1.778
LU/LC	0.6	1.5	1	1.667	1.2
Slope	0.4	0.5	0.6	1	0.875
Lineament density	0.333	0.571	0.833	1.143	1
Sum	2.777	5.856	4.725	8.37	8.138

Table 6. Normalized matrix

WH (Goal)	Rainfall	Soil texture	LU/LC	Slope	Lineament density
Rainfall	0.360	0.390	0.344	0.306	0.404
Soil texture	0.160	0.171	0.141	0.239	0.218
LU/LC	0.216	0.256	0.212	0.199	0.147
Slope	0.144	0.085	0.127	0.119	0.108
Lineament density	0.120	0.098	0.176	0.137	0.123

After normalized matrix was calculated, the weights of the pair wise matrix were estimated by considering an average of the normalized relative weights in a row for each class within a factor. Overall priorities or weights of the criteria were obtained by simply calculating the average value of each row, presented in Table 7.

Table 7. Calculation of weights: row averages

WH (Goal)	Rainfall	Soil texture	LU/LC	Slope	Lineament density	Weight
Rainfall	0.360	0.390	0.344	0.306	0.404	0.361
Soil texture	0.160	0.171	0.141	0.239	0.218	0.186
LU/LC	0.216	0.256	0.212	0.199	0.147	0.206
Slope	0.144	0.085	0.127	0.119	0.108	0.117
Lineament density	0.120	0.098	0.176	0.137	0.123	0.131

According to the results in Table 7, based on estimated weights the maximum weightage is given to Rainfall i.e. 0.361, followed by Land use/ Land cover: 0.206, Soil texture: 0.186, Lineament density: 0.131 and minimum weight 0.117 to Slope for water harvesting site selection decision process. The outcome revealed that Rainfall has 36.1% of the overall importance among all the criteria, followed by Land use/ Land cover 20.6 %, Soil texture 18.6%, Lineament density 13.1% and Slope 11.7%, respectively.

Table 8. Prioritization results along with Pair wise comparison matrix

WH (Goal)	Rainfall	Soil texture	LU/LC	Slope	Lineament density
Weight	0.361	0.186	0.206	0.117	0.131
Rainfall	1	2.285	1.625	2.56	3.285
Soil texture	0.444	1	0.667	2	1.778
LU/LC	0.6	1.5	1	1.667	1.2
Slope	0.4	0.5	0.6	1	0.875
Lineament density	0.333	0.571	0.833	1.143	1

After the judgement has been developed, it is necessary to check that whether the judgement is consistent or inconsistent. However, some inconsistency is expected and allowed in AHP analysis and it is impossible to avoid inconsistency in the final matrix of the judgement. A consistency ratio tells how much present the decision is consistent or inconsistent; inconsistency ratio results, a higher number means the judgement has been less consistent whereas a lower number means a judgement has been more consistent. However, in AHP the consistency ration (CR) of less than 0.1 or 10% is acceptable to continue the AHP analysis. If the consistency ratio is greater than 0.1 or 10 %, it is necessary to revise the judgement to identify the cause of the inconsistency and correct it. Table 8, 9 and 10 shows results of steps followed for finding consistency. At last, the consistency of the rating for each factor was tested.

Table 9. Weights as factor and calculation of weighted column

WH (Goal)	Rainfall	Soil texture	LU/LC	Slope	Lineament density	Weighted Sum
Weight	0.361	0.186	0.206	0.117	0.131	
Rainfall	0.361	0.425	0.335	0.300	0.430	1.851
Soil texture	0.160	0.186	0.137	0.234	0.233	0.951
LU/LC	0.217	0.279	0.206	0.195	0.157	1.054
Slope	0.144	0.093	0.124	0.117	0.115	0.593
Lineament density	0.120	0.106	0.172	0.134	0.131	0.663

Table 10. Calculation of λ_{max}

WH (Goal)	Weighted Sum	Weights	Result (Weighted Sum/ Weights)
Rainfall	1.851	0.361	5.127

Soil texture	0.951	0.186	5.113
LU/LC	1.054	0.206	5.117
Slope	0.593	0.117	5.068
Lineament density	0.663	0.131	5.061
		Total	25.486
		Divided the total by 5 (No. of criteria) to obtain λ_{max}	5.097 (= 25.486/5)
		CI	0.02425
		RI value for present study number of criteria i.e. for 5	1.12
		CR	0.02 (CI/RI)

From Table 10, it is easily evidence that the value of CR is 0.02 for the proposition of inconsistency is less than 0.1 the judgements matrix is consistent so that AHP decision is acceptable for further process.

3.3 Ranks for criterion features

The next task done was of assigning weights and ranks for thematic layers. The weights were assigned to thematic layers and ranks on 1-5 scale were assigned to features of thematic layers. The more significant features have been assigned higher ranks. Thereafter, the score was calculated by multiplication of rank and weights assigned to each parameter which affects the site selection suitability. The values of weights and ranks for various water harvesting structures are given in Table 11.

Table 11. Weights and ranks assigned to thematic layers

Thematic layer	Feature Class	Reclass Rank	Weight	Ranks
Rainfall (mm)	617.4 - 646	1	36	1
	646 - 675	2		2
	675 - 704	3		3
	704 - 733	4		4
	733 - 793	5		5
Land use/Land cover	Agriculture	1	21	5
	Wastelands	2		4
	Others	3		1
	Built-up	4		Restricted
	Water bodies	5		5
	Forest	6		1
Soil texture	Loamy	1	18	2
	Fine	2		5
	Clayey	3		5
	Rockout crops	4		1
Lineament density (km/km^2)	0 – 0.25	1	13	5
	0.25 - 0.45	2		4
	0.45 – 0.65	3		3
	0.65 - 0.85	4		2
	> 0.85	5		1
Slope (Percent)	< 3	1	12	5
	3 – 5	2		4
	5 - 10	3		3
	10 - 15	4		2
	> 15	5		1

3.3.1 Ranking and reclassification of criteria

Ranking and reclassification of criteria for selecting rainwater harvesting site suitability is an important step. Each criterion is first classified into groups and ranked accordingly in raster form i.e. each cell is given rank 1 to 5 shows in which class it falls. Then the raster file prepared and reclassified into low suitability to high suitability by giving each group reclassified ranking from 1 to 5 as per that group's suitability for the water harvesting purpose. In reclassification ranking from 1 to 5 shows low suitable to the high suitable groups. Further, these reclassified raster layers are used for the weighted overlay process, where in ArcGIS software the overlay process is placed in which the specified files according to their weight and cell by cell process are done and suitability layer is generated.

Main layers of Rainfall, Land use/Land cover, Soil texture, Lineament density and Slope were converted into raster file using ranking from 1 to 5 values and were reclassified to work in the Weighted Overlay process. Reclassified maps of Rainfall, Land use/Land cover, Soil texture, Lineament density and Slope are presented in Figure 3, 4, 5, 7 and 8, respectively were generated using ArcMap software.

3.3.1.1 Rainfall

Thiessen polygon method was used to derive rainfall for the whole Dhatarwadi river basin. Gauge station influence area for rainfall is shown in figure 2. The study area has only 3 rainfall gauging stations i.e. Khambha, Rajula and Hindorna. Therefore nearby 2 more influencing stations Savarkundla and Jafrabad of Amreli district are used for interpolation on the entire district and then interpolated rainfall map of the study area was clipped. Interpolation was used to estimate rainfall for the areas not having rainfall point measurements. The interpolation has been done in ArcGIS using Inverse Distance Weight (IDW). IDW interpolation determines cell values in a raster layer using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance (ArcGIS). The output of IDW interpolation was in vector form, which was converted to raster form with rainfall classification as 617.4 – 646 mm given 1 value, 646 – 675 mm given 2 value, 675 – 704 mm given 3 value, 704 – 733 mm given 4 value and 733 – 793 mm given 5 value.

Figure 3 shows a reclassified raster map of rainfall of the study area. The high rainfall area shows high opportunity for water harvest. Therefore, in this study, high rainfall area was given the highest priority and vice versa. Reclassification of rainfall was done on said need and ranks were allotted as 617.4 – 646 mm given lowest ranking as 1, 646 – 675 mm given 2, 675 – 704 mm given 3, 704 – 733 mm given 4 and 733 – 793 mm given 5. Al-Komaim [56] has followed a similar trend of giving the highest ranking to the highest rainfall and vice versa for finding suitability area for the terrace, check dam, ponds and spate irrigation. Shadeed *et al.* [57] also followed a similar ranking system for rainwater harvesting site selection. Similarly, Al-Shabeeb [58] has given the highest priority to high rainfall and lowest priority to lowest rainfall.

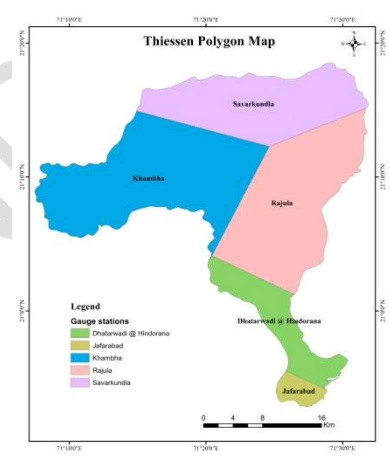

Fig. 2. Thiessen Polygon Map of Rainfall

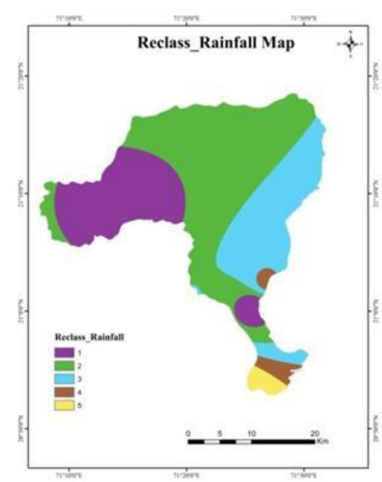

Fig. 3. Reclassified Rainfall Map

for study area

3.3.1.2 Land use/Land cover

Dhatarwadi river basin is having land use/ land cover of agriculture, wastelands, built-up, water bodies, forest and others. The vector layer of land use/ land cover polygon map was converted into raster form by giving values to the classes. Agriculture class as 1, Wastelands as 2, Others as 3, Built-up as 4, Water bodies as 5 and Forest as 6. Aster conversion of land use/ land cover layer in raster form, it was further processed, to get reclassified layer.

Now for reclassification, from water harvesting prospective agriculture and water bodies were given the highest priority, the wasteland was a moderate priority and, forest and others was of lowest priority and built-up as restricted i.e. highest ranking 5, moderate ranking 4, low ranking 1 and Restricted, respectively in reclassification. Reclassified Land use/ Land cover map is shown in Figure 4. Ali [54] has given farmland and grass, moderately cultivated, bare soil, and mountain: highest priority to lowest priority, respectively. The urban area was considered restricted for water harvesting sites. Similarly, Prasad *et al.* [58] has selected water body and agriculture as the highest suitable ranking 9 and 8, respectively, wasteland, forest and built-up as moderate to low suitable i.e. 5, 4 and 1 ranking, respectively, which supports the present study ranking for reclassification.

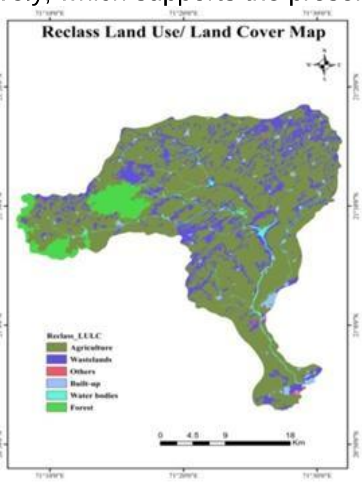

Fig. 4. Reclassified Land use/Land cover Map

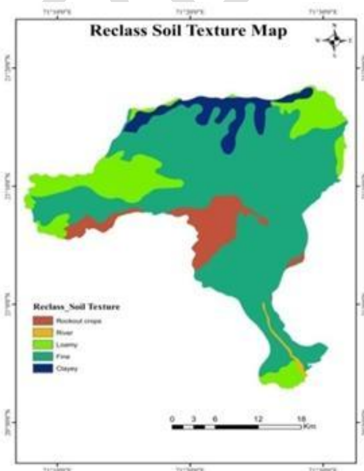

Fig. 5. Reclassified Soil Texture Map

3.3.1.3 Soil texture

The texture of the soil indicates the comparative content of various particle sizes, such as clay, silt and sand in soil. When runoff water harvesting is to be considered, soil texture is an indispensable component to be considered. Generally, clay soils has good water holding capacity, hence are good for water harvesting structures that allow retention of water, which can be used next season for crop irrigation and livestock [60]. The study area consists of fine, clayey, loamy and rock outcrop soil texture. During raster conversion of soil texture map cells having loamy soil, fine soil, clayey soil and rock outcrop soil textures were given 1, 2, 3, 4 and 5 value. Further, this raster soil texture layer was reclassified and as fine and clayey soil texture is most suitable for water harvesting and good for water holding was given highest ranking i.e. 5, loamy soil is less suitable for water harvesting as it cannot hold water for longer period, therefore, it was ranked as 2 and rock outcrops are least suitable for water harvesting structures as it cannot hold water, therefore, it was ranked as 1. The similar ranking was followed by Mugo and Odera [41], very clayey, clayey, loamy and sandy ranked as 9, 7, 8 and 3 respectively. Similarly, Asala [60] had given 7 highest ranking to clayey heavy and 6 to clayey light soil texture.

3.3.1.4 Lineament density

Figure 6 shows the lineament density map of the Dhatarwadi river basin. High lineament density in a region reflects that the area contains many faults and sharp changes in linear alignment that is not adequate for the storage of water. This happens due to that it is expected the water will drain through the faults or it will find a connected channel of drainage along the line direction. The area consisting of low lineament density is good for storage due to the rock strata structure formation that is free of cracks, allowing for longer water storage period [41]. Lineament density was considered, whereby the high-density regions of >0.85 km/km^2 were considered least suitable and regions of low densities 0-0.25 km/km^2 most suitable. This criterion was selected based on that; high lineament density will utilize harvested water for groundwater recharge. So, for runoff water harvesting sites for check dam and farm pond to store water, low lineament density is given 5 ranking for highest suitability and 1 for high lineament density for lowest suitability. Similar criteria were selected by Mugo and Odera [41] for site selection for rainwater harvesting structures in Kiambu County-Kenya. Al-Shabeeb [58] had also preferred low lineament density as the highest priority and high lineament density as the lowest priority for harvested water storage structure.

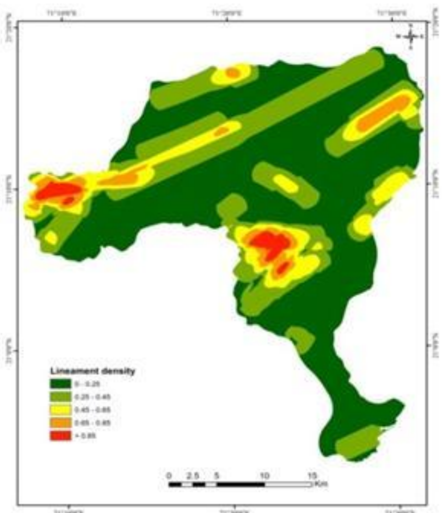

Fig. 6. Lineament Density Map

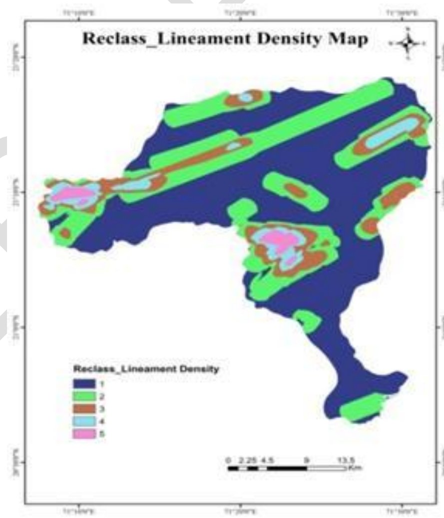

Fig. 7. Reclassified Lineament Density Map

3.3.1.5 Slope

The slope is an important key factor to assess the method of surface RWH technique since it influences the water storage of the targeted area because of the runoff. Thus, different systems of RWH depend on the degree of slope of the area. Water harvesting for some kind of RWH techniques is not recommended for areas with slopes greater than 5% because the distribution of the runoff is uneven and the requirement of large quantities of earthwork which consider as inefficient from an economical perspective [35;56].

A slope can be calculated in two different ways, namely the degree of slope and percentage slope. The second way is the one used in this study, which indicates the percentage ratio of elevation change with horizontal distance. The slope can be generated according to an elevation dataset, such as a DEM, in which the maximum rate of change in elevation over a distance between each cell and its eight neighbors is calculated. As a result, the lower the slope, the flatter the terrain and the higher the slope, the steeper the terrain [56].

In present study slope (%) was divided into five group i.e. < 3, 3-5, 5-10, 10-15 and >15. Reclassification was carried out and five groups < 3, 3-5, 5-10, 10-15 and >15 provided raster values of 1, 2, 3, 4 and 5. For farm pond and check dam construction < 3% slope and upto 5 % slope are more favourable conditions. Naseef & Thomas [61] and Ramakrishnan *et al.* [16] used same classification for Kecheri river basin and Kali watershed, respectively. Al-Komaim [56] classified slope in 0-2, 2-5, 5-8, 8-10 and >10 and given preferred values as 5,4,3,2 and 1 for check dam site selection, similar to the present study. Similarly, Yilma [62] given the highest priority to the gentle slope (< 2) to steeply dissected to mountainous (>30 %) very low suitability.

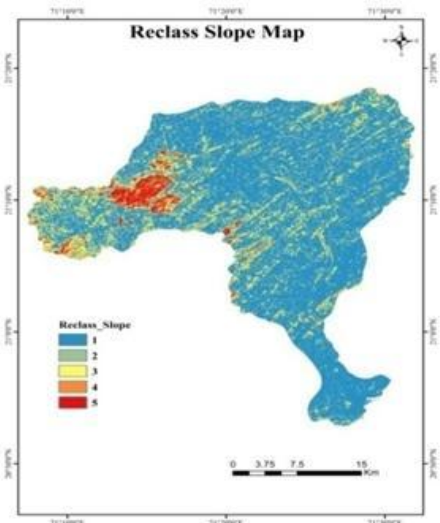

Fig. 8. Reclassified Slope Map

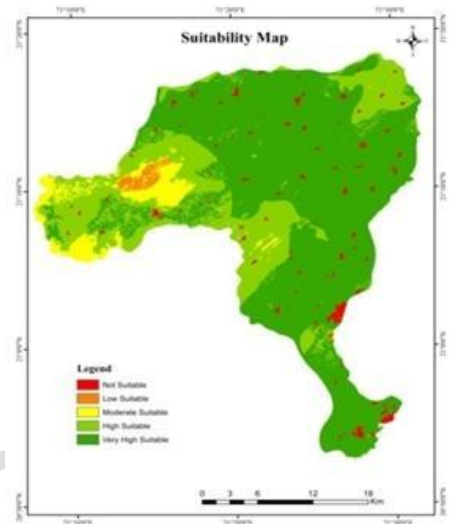

Fig. 9. Site Suitability Map

3.4 Generation of potential RWH suitability map

The suitability map for RWH was generated by integrating the results of each thematic map weighted using the AHP model. All factors and groups of factors were integrated and produced four suitability zones such as not suitable, less suitable, moderately suitable, high suitable and very high suitable. Out of 858.99 km^2 of the study area, about 15.60 km^2 (1.81 %) of the study area was found not suitable, 7.5 km^2 (0.88 %) of the study area was found less suitable, 48.30 km^2 (5.63 %) of the study area was found moderately suitable, 213.43 km^2 (24.89 %) of the study area was found highly suitable and 572.70 km^2 (66.79 %) of the study area was found very high suitable for the construction of rainwater harvesting structures. The suitability map of the Dhatarwadi river basin is presented in figure 9.

3.5 Suitable sites for check dams

A flow chart for site selection criteria for check dam are presented in figure 10. A suitability site selection for check dam construction of for stream 3rd to 6th order, having a gentle slope <15%, for annual rainfall < 1000 mm, the land cover of the area was scrubland and river bed and the soil type of the area was covered by fine, clay and loamy soils. Also, the catchment area of the site considered more than or up to 25 ha. For check dam on cropland slope requirement was <=3%. As per suitability and ground truth, 24 check dam sites on scrubland, 52 check dam sites on cropland and 11 check dam sites on the river bed were selected. These proposed check dams can be very useful as supplementing irrigation during the dry season and water conservation, as well as it may be used as a water supply for livestock, Industry and municipal consumption. Worked out the location of suitable sites for check dam and farm pond are presented in figure 11.

3.6 Suitable sites for farm ponds

A flow chart for site selection criteria for check dam are presented in figure 12. Selecting a suitability area for farm ponds in the Dhatarwadi river basin was performed to ensure long-term success and provide the best opportunity for irrigation and livestock consumption. An area having dual season cropping pattern i.e. *kharif* as well as *rabi* season was selected based on IMSD specification viz., 0-5 % land slope, 1st and 2nd order stream order, catchment area having >2 ha with > 200 mm annual rainfalls are proposed for harvesting water in fine, clayey and loamy soil. Based on selection criteria about 29 farm ponds sites were proposed in the study area.

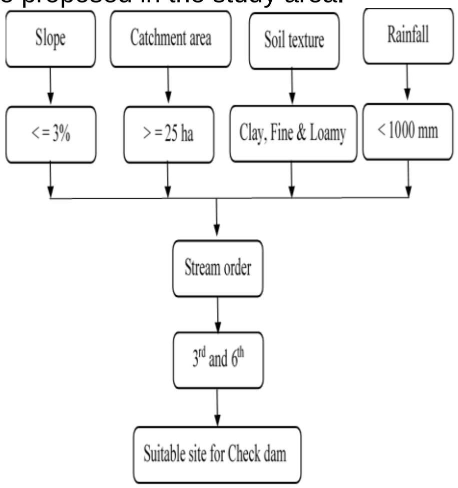

Fig. 10. Site selection criteria for check dam

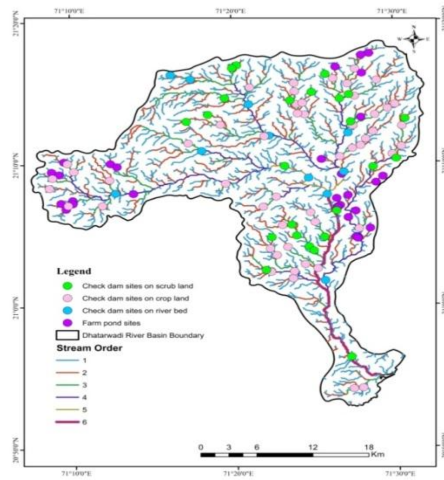

Fig. 11. Proposed Water Harvesting Structure Site Location Map

3.7 Validation of potential sites

To check the suitability of rainwater harvesting sites, the locations of potential RWH identified for constructing different types of RWH need to be validated with existing RWH technologies. The ground truth relating to the location of existing RWH structures (latitudes and longitudes) was collected during the survey and was exported to ArcGIS for further validation. The proposed suitability map for potential rainwater harvesting techniques identified was converted to kml file, exported to Google Earth and validated with the locations of existing structures by visual interpretation. The result is presented in figure 13, indicates that 72.27% of existing RWH sites are in very high suitability and 26.73% located in high suitable whereas only 0.49 % and 0.49 % are in the moderate suitable and not suitable area, respectively. Therefore, accuracy assessment taken into consideration by overlaying the locations of existing RWH ponds identified and the potential rainwater harvesting zones which were developed by the model were agreed with the experiences of the experts. Asala [60], Yilma [62] Shashikumar *et al.* [63] Alene *et al.* [64], Preeti *et al.* [65] and Waghaye *et al.* [66] found similar results.

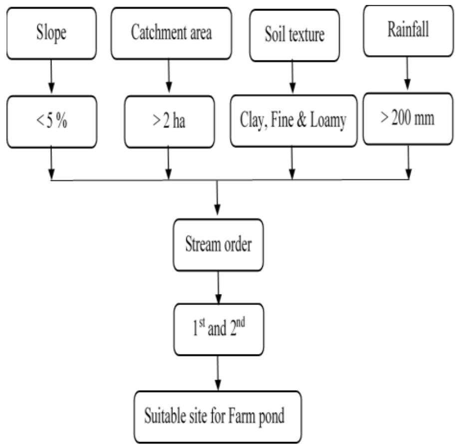

Fig. 12. Site selection criteria for farm pond

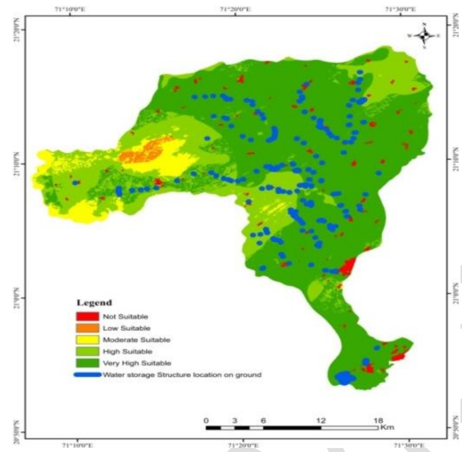

Fig. 13. Model Suitability Validation Map of RWH Site

4. CONCLUSION

Water harvesting site suitability map for the Dhatarwadi river basin was generated using rainfall, soil texture, slope, land use/land cover and lineament density by weighted overlay process in ArcMap software. Relative weights for selected criteria were determined by Analytical Hierarchical Process (AHP) using experts' knowledge. Probable sites for construction of check dam and farm pond for the storage purpose were worked out in ArcMap software based on IMSD and FAO guidelines.

The results obtained are; for water harvesting site selection, AHP generated weight for criteria is 36.1% for rainfall, 20.6% land use/land cover, 18.6 % for soil texture, 13.1 % for lineament density and 11.7 % for slope. In Dhatarwadi river basin, 66.79 % area was found very high suitable, 24.89 % area as highly suitable, 5.63 % area as moderately suitable, 0.88 % area as less suitable and remaining area 1.81 % was found as not suitable for water harvesting sites. 25 sites for check dam on scrubland, 52 check dam sites on crop land and 11 check dams on river bed are possible sites identified within the Dhatarwadi river basin. 29 farm pond sites are identified within the Dhatarwadi river basin. From findings of this research, in Dhatarwadi river basin there is possibility of rainwater harvest and storage to meet future demands of water. Also, integrated use of AHP, remote sensing and GIS will help decision maker, planners and all working for rainwater harvesting site selection.

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