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# Identification of suitable sites for select water conservation structures for Chambali Watershed, Purandhar Taluka, Pune, India

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**Abstract**

*This research focuses on the identification of suitable sites for constructing water conservation structures (WCSs). It also validates the results by comparing the locations of the existing sites of water conservation structures with the sites identified through GIS analysis. The area selected for this research is Chambali river watershed in Purandar Taluka, Pune District of Maharashtra, India. Since the water conservation structures are already constructed in this area, it was possible to compare the results of the analysis that was carried out. Three types of WCSs namely – percolation tanks, check dams and continuous contour trenches (CCTs) are considered for the present research. Criteria layers are identified by applying a spatial multi-criteria approach. These are landuse-landcover, soil types, slope and distance from river channel (in case of check dams). Pair-wise comparison is separately carried out for comparing the relative importance of these criteria and the classes of the criteria for each type of WCS. It is found that slope and landuse-landcover are the most decisive criteria in the case of percolation tanks and CCTs. In case of check dams, distance from channel and slope is found to be important criteria.*

**Keywords:** *Spatial multi-criteria analysis, pairwise comparison, overlay analysis, weightages, water conservation structures.*

## Introduction

Water is the most basic to human life and survival. Availability of water depends not only on the amount of rainfall received by an area but also on the methods of water conservation followed by the respective communities. Water scarcity is experienced not only in areas of low rainfall but even in areas that receive medium to heavy rainfall as well. The solution to the problem of water scarcity lies in better and sustainable management of the available water resource. The best way to make water available at the grassroots level is to conserve water in a decentralized way by constructing water conservation structures (WCS) suitable to the climate and topography of the areas. The structures such as check dams, continuous contour trenching, gulley plugs, percolation tanks, etc. help percolation of water and raise the groundwater level resulting in overall increased availability of water in a particular area. Sabale *et al* (2017) have assessed the effects of the watershed management project in the Malhargad watershed in Purandar

Taluka, Pune District and have found that watershed development projects play a key role in the overall development of a region.

Identification of suitable sites for WCSs is one crucial step in this direction. Slope, soil type, landuse/landcover and distance from streams are the main factors that should be considered while planning construction of WCSs. If sites suitable for various types of WCSs are identified, it will be of great help to the local people. GIS techniques for identification of water conservation structures (WCSs) is increasingly used for the purpose. Haji, *et al* (2015) has emphasized the importance of remote sensing and GIS techniques for effective identification of suitable sites for WCSs. Most studies now select rainwater harvesting sites using GIS in combination with hydrological models and multi-criteria analysis (Adham *et al*., 2016). If validated, this technique can be implemented for actual construction of WCSs at the sites identified. Gebre *et al* (2015) have also sed remote sensing data (DEM and satellite images) to study watershed attributes for water resource management for micro-watershed in Ethiopia. Kadam *et al* (2012) have also identified potential sites for rainwater harvesting in the basaltic region of Maharashtra.

Validation is a process designed to determine if the system or the technique complies with the requirements and performs functions for which it is intended and meets users' needs[1]. Validation of a technique should be done before it is implemented for the specific purpose for which it is developed. Validation can bring out the appropriateness of the number of criteria used, the choice of criteria and the method of data processing. The water conservation structure is the basic unit of the subject of water conservation. The structures include all mechanical or structural measures that control the velocity of surface runoff and thus minimize soil erosion and retain water where it is needed. Water conservation structures should be given importance mainly in drought prone regions[2].

There are many types of water conservation structures such as continuous contour trenches (CCTs) compartment *bunding* (retaining wall around storage) (CB), farm ponds (FP), gabion dams (GD), earthen dam (ED), loose boulder structures (LBS), cement dam (CD) and earthen gulley plugs (ECP). There are various methods of identification of suitable sites too. One of the most modern methods is the GIS-based (spatial) multi-criteria analysis technique used for the identification of suitable sites. Mishra *et al* (2015) have elaborated on using the multi-criteria decision-making technique for watershed management structures. By employing this technique, criteria for WCSs are compared for their importance as per the nature of each WCS and suitable sites for water conservation in the study area. For the current study, three types of Water conservation structures are considered. These are CCT, Percolation tank and Check dam.

For validation of results, it is necessary to compare the sites identified (for the proposed WCSs) with those of the existing WCSs. Such WCSs are found more in drought-prone

[1] http://istqbexamcertification.com/what-is-validation-in-software-testing-or-what-is-software-validation/

[2] http://www.jkuat.ac.ke/departments/warrec/wp-content/uploads/2016/08/Design-of-Soil-and-water-conservation-structures-Prof.-Bancy-Mati-Notes.pdf

areas. So while choosing the study area, a watershed in the drought-prone area of Maharashtra, India is chosen.

The watershed of Chambali River in Purandhar *taluka* (a sub-district) in the Pune district is one such area that has experienced water scarcity and where a number of WCSs already exist. This watershed contains a huge range of mountains. Water conservation structures such as check dams, percolation tanks, and continuous contour trenches can be constructed in this area.

### *The characteristics of the select water conservation structures*

A check dam is a small barrier built across the direction of water flow on shallow rivers and streams for the purpose of water harvesting[3]. The small dams retain excess water flow during monsoon rains in a small catchment area behind the structure. Following geographical conditions are required for this structure: (a) The slope should be less than 15 percent (b) The land use may be barren, shrub land and riverbed (c) The infiltration rate of the soil should be less and (d) The type of soil should be sandy clay loam.

A percolation tank is a structure for recharging groundwater. These tanks are generally constructed across streams and bigger gullies in order to impound a part of the run-off water[4]. Some of the important geographical conditions required for these structures include (a) slope should be less than 10 percent (b) The land use land cover may be barren land (c) The infiltration rate of the soil should be moderately high and (d) The type of soil should be silt loam.

Continuous contour trenches are artificially dug along the contour lines. Water flowing down the hills is retained by the trench and allowed to infiltrate the soil below. Between two trenches, the crops grown there can benefit during the growing season (when there is less rain) from the subsoil water reserve gathered during the rainy season[5]. The slope should be less than 8 percent for these CCTs.

### *Aims and objectives*

Identification of suitable sites for these structures depends on soil, slope and suitable landuse-landcover and distance from the river channel. Every structure however has a different set of criteria for determining suitable sites. The aim of this research is to validate the technique of site suitability for water conservation structures. To achieve this, the following specific objectives are set before the research:

i. To identify suitable sites using spatial multi-criteria analysis.
ii. To prepare a digital database for existing WCSs in the study area.
iii. To compare the identified sites with the existing sites of the selected WCSs.

### Significance

Water conservation structures play an important role in recharging groundwater reserves and water storage in drought-prone areas. If the sites suitable for the construction of water conservation can be identified with the GIS-based technique, it will be possible to undertake massive programmes of construction of the structures. This will save

[3] https://www.indiaagronet.com/indiaagronet/Agri%20engineering/contents/Percolation%20Tank.htm

[4] https://www.sciencedirect.com/science/article/pii/S0022169414007033

[5] https://en.wikipedia.org/wiki/Contour_trenching

time and money required for training huge manpower and surveying. At the same time, a digital database of these structures will also be simultaneously generated. This will help monitor and maintain the functioning of structures.

The present study aims at validating the results of site suitability analysis. If the results (i.e. identified sites for each type of structure) match with sites of the already existing structures, then the models (consisting of criteria layers and respective weights assigned to them) can be used for areas having similar physico-climatic conditions.

## The study area

The study area– Chambali River watershed is located in Purandar Taluka of Pune District, Maharashtra, India (fig.1). The area extends from 73° 53' E to 74°3' E longitude and 18° 20' N to 18° 25'N latitude and has 69.726 km$^2$ area within the watershed. Chambli River is one of the tributaries of the Karha River. Karha River in turn is a tributary of the Nira River, which constitutes the natural boundary between the Pune and Satara districts. The River Chambali originates in the plateau region of Maharashtra; flows towards the east for 20.25 km before it meets the River Karha. Villages such as Asakarwadi, Bhivari, Bopgaon, Chambli, and Hivare,

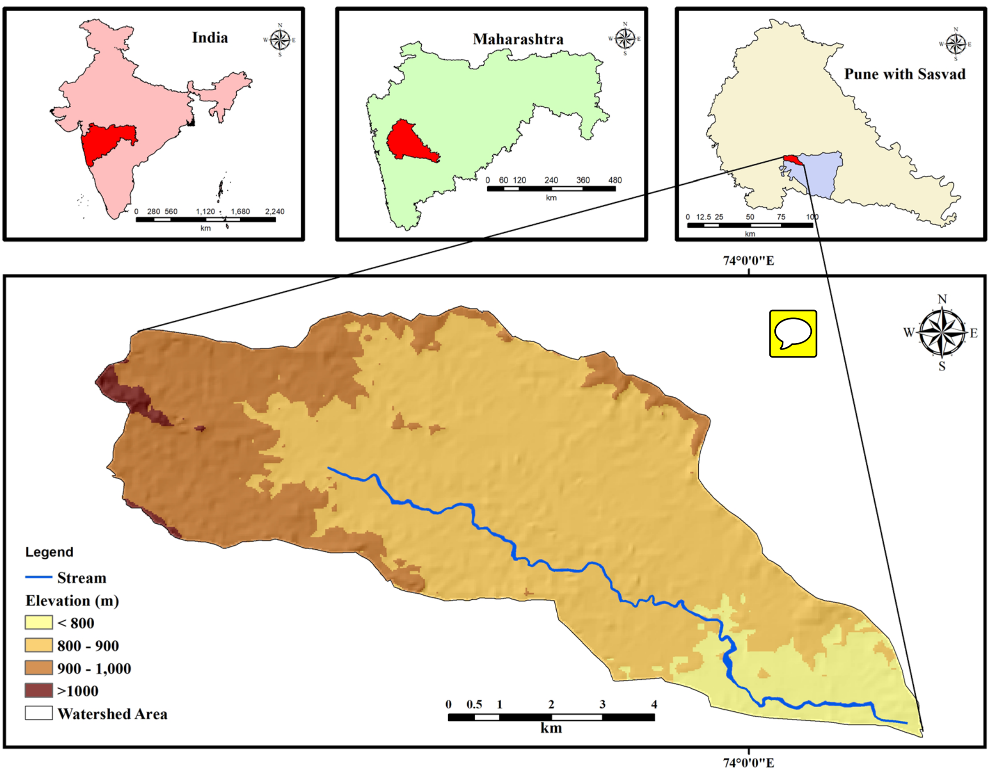


Fig. 1: Chambali river watershed – the study area

Table 1: Details of Data

| Criteria layer | Data source | Details of data source |
|---|---|---|
| Multi-buffer layer is created from the 4th and 5th order streams in the drainage network. (buffer distances: 5 and 10 meters) | Toposheet | Toposheet No: 47 F/15 and 47 J/3 Scale: 1:50,000; Published in: 1979-80 |
| Landuse-landcover map | Multispectral satellite image | Sensor: Operational Land Image (OLI). [7] Satellite: Landsat 8 Date: February 11, 2018 Spatial Resolution: 30 M Path No: 147, Row No: 47 |
| Soil map | Modified after Kadam et.al (2012) | Scale:1cm: 3km (original scale)[8]. |
| Slope map | Generated from Digital Elevation Model (DEM) file | From Global Land Cover Facility (GLCF) Spatial Resolution: 90 meter Path No: 147, Row No: 47; Year: 2000. |

(Taluka: Purandhar, Dist. Pune) are situated on the banks of the Chambli River[6]. North-East, western, and northern part of the Chambli River watershed is hilly and has rugged topography. The terrain height of the watershed varies between 800 and 1180 m. Silty loam and sandy clay are the two types of hydrological soil groups which are found in Chambli watershed area.

## Data and methodology

### *Data*

For identification of the suitable sites for WCSs, it is necessary to build a GIS model using the necessary criteria layers. These criteria layers and the sources from which these are generated are mentioned in mentioned in table 1.

### Methodology

Identification of suitable sites for WCSs is carried out by employing the spatial multi-criteria approach (Malczewski, 2006). The technique facilitates the comparison of a number of criteria that play an important role in site selection. On the basis of this comparison relative importance of the criteria can be decided in the form of weights out of 1. There are a number of methods to compare the criteria such as ranking and assigning weights by Pair-wise comparison (Saaty, 2008). Out of these, the pair-wise comparison method is used for assigning weights. Abhay *et al* (2012) have explained the criteria to be considered for WCSs, the categories of the criteria and the weights to be assigned to each criterion and its classes in the next stage. The present research adopts the same approach. In the first stage, the criteria themselves (LULC, slope, soil, and distance from the stream) are compared with each other and weights are assigned. In the second stage,

[6] http://www.devalt.org/newsletter/apr01/of_3.htm

[7] https://www.google.com/search?q=landsat+8+bands&ie=utf-8&oe=utf-8&client=firefox-b

[8] https://www.researchgate.net/figure/Soil-map-of-upper-Karha-watershed_fig4_257672801?_sg=je2b-EqPeuZ3k_qt2IsQgfcWEPRgNv6OsAFJVYC3fl3uWtKRkrG84o_fwroAag-uBCTv17qmcoM8YPN9DeSKmw

Table 2: Weightages assigned to the classes of criteria layers – Percolation tank

| Criteria layers | Categories | Total weight | Normalized weight in % | Weights of the criteria layers |
|---|---|---|---|---|
| Slope | <10° | 0.8 | 80 | 56 |
| | >10° | 0.2 | 20 | |
| Soil | Silt loam or loam | 0.8 | 80 | 14 |
| | Sandy Clay | 0.2 | 20 | |
| LULC | Waterbody | 0.8 | 11.42 | 30 |
| | Settlement | 0.4 | 5.71 | |
| | Barren land | 3 | 42.85 | |
| | Agriculture | 2.8 | 40 | |

the classes within each criterion are compared and weights are assigned. This comparison is separately done for each WCS where the priority classes are different. The weights are then normalized and put on the 10-point scale from 0 to 9. The highest weights are assigned to the most suitable criteria or classes of criteria whereas the lower ones are assigned to the least suitable criteria or classes. Based on the normalized weights, overlay analysis is carried out separately for each WCS using ArcGIS software. The results obtained are classified as most suitable, suitable and less suitable areas where respective WCSs can be built.

### *Field observations and validation*

Field visits are conducted for confirmation of the locations of the existing WCSs. Four out of the five villages in the Chambali watershed are visited. Locations of WCSs are collected with the help of GPS as well as from Google Earth images. The results (identified sites) are compared with actually constructed structures in the study area.

## Analysis and results

### *Identification of percolation tanks*

For this particular type of structure, the following criteria layers are considered: slope, soil, and land-use land cover (LULC). Percolation tanks are built on relatively plain land and preferably in the barren land. Since slope and landuse/landcover are the major actors influencing site selection for percolation tanks, these two are given higher weightage (Table 2) through pairwise comparison. Each criteria layer is then classified into relevant classes. The slope layer is classified into two categories. Since percolation tanks are built on land having less than 10° of the slope, this category is given more weight. The LULC layer is classified into four major classes found in the study area by applying supervised image classification. Higher weights are assigned to barren land followed by agricultural land. Two types of soils are found in the study area - i) silt loam or loam ii) sandy clay. So the soil layer is classified into two classes. The silt loam or loam type of soils have moderate rates of infiltration whereas sandy clay loam has a low infiltration rate when thoroughly wetted. For percolation tank, silt loam type of soils is more suitable since these have a moderate rate of infiltration. This allows water to percolate to raise the groundwater level. So this type of soil is given more weightage.

Table 3: Weightages assigned to the classes of criteria layers – Check Dam

| Criteria layers | Categories | Total weight | Normalized weight in % | Weights of the criteria layers |
|---|---|---|---|---|
| Slope categories (in degree) | <15 | 3 | 0.75 | 27 |
| | 15 to 20 | 0.9 | 0.225 | |
| | >20 | 0.1 | 0.025 | |
| Distance from Channel | 5m Buffer | 7 | 70 | 35 |
| | 10m Buffer | 3 | 30 | |
| Soil | Silt loam or loam | 0.2 | 20 | 22 |
| | Sandy Clay loam | 0.8 | 80 | |
| LULC | Waterbody | 1.4 | 23.33 | 16 |
| | Agriculture | 1.4 | 23.33 | |
| | Barren land | 2.3 | 38.33 | |
| | settlement | 0.9 | 15 | |

Using these layers, a weighted overlay model is built. The result is given in the form of a layer showing the most suitable, moderately suitable and least suitable sites for the percolation tanks and the locations of the existing percolation tanks in the study area (fig. 2). The existing locations fall exactly in the areas that are identified as the most suitable areas for percolation tanks.

### *Check dams*

For this type of structure, the following criteria layers are considered: slope, soil, landuse/landcover and distance from the streams. Since the check dams are constructed within channels, the criterion of distance from the stream is of crucial importance and has been given the highest weight followed by the slope (Table 3). Soil and LULC remain less important as the width of the channel defines the locations irrespective of soil type. The layers are classified and each class is assigned a weight as per its suitability for the construction of check dams. Table 3 summarizes the weightages assigned to the classes of the criteria layers. Check dams should not be constructed on streams having more than a 15° of the slope. If the slope of the channel is more than 15°, the velocity of the water will be more. Check dams may not sustain the force exerted by water and may collapse. So the slope category of <15° has been given the highest weightage. Sandy loam soil is more suitable for these types of dams since it has a low infiltration rate. This will allow water to get stored behind the dam for a sufficiently long time. So this type is given more weightage over the silt loam type.

It is necessary to avoid the agricultural land, settlement areas and existing water bodies; so higher weightage is given to barren land where such dams can be constructed. As already mentioned, check dams are constructed within the channels; hence the distance from the centre of the channel is defined by buffer layers. The minimum distance of 5 meters is given the highest weightage. Using the classified layers weighted overlay model is built to identify the suitable sites for check dams. The result is given in the form of a layer showing the

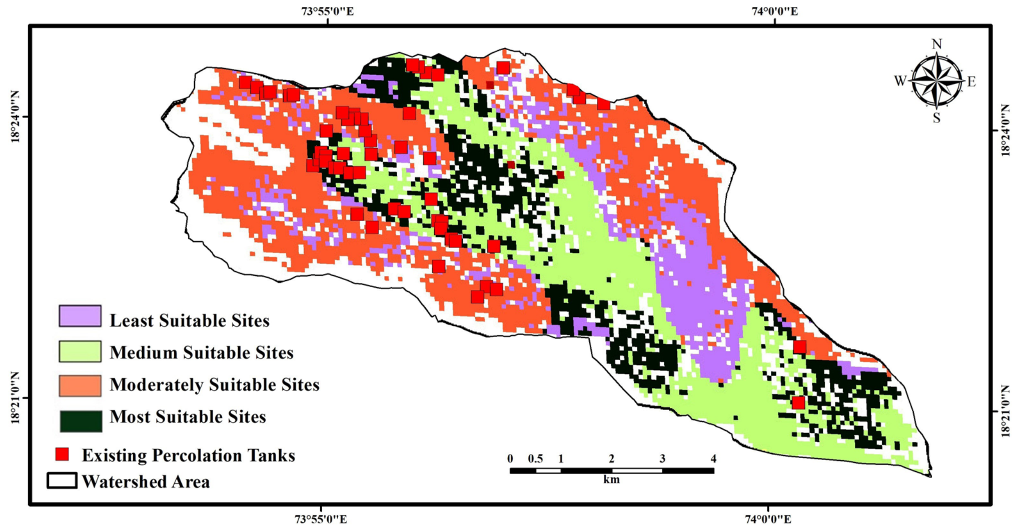


Fig. 2: Suitable sites identified and existing for Percolation Tanks

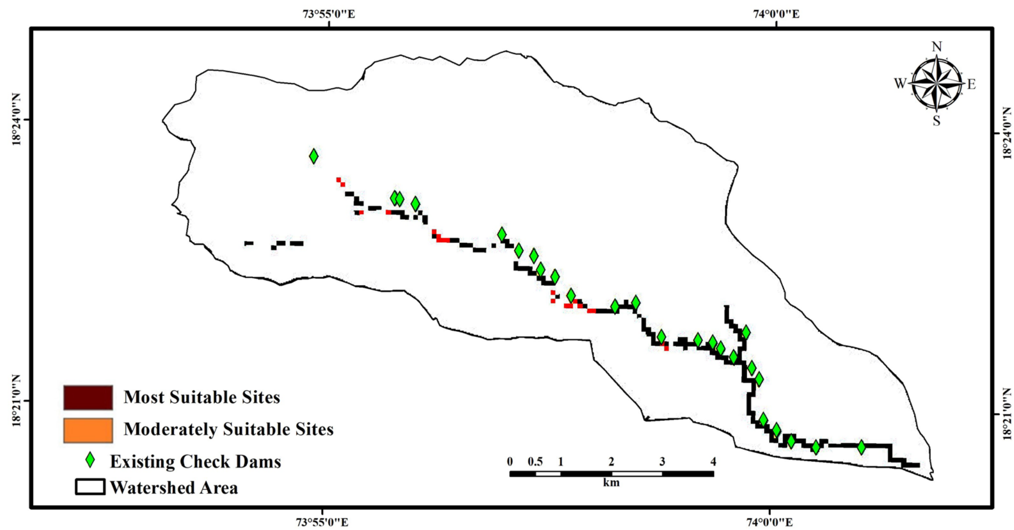


Fig. 3: Suitable sites identified and existing Check Dams

most suitable, moderately suitable and least suitable sites for the check dams in the study area (fig. 3). The same figure also shows the locations of the existing check dams.

### *Continuous contour trenches (CCTs)*

For this type of structure, the following two criteria layers are considered: landuse/landcover and slope (Table 4). The slope is given slightly more weightage (0.6) over LULC (0.4) since slope plays a vital role than LULC. Irrespective of soil type, CCTs are built in barren land having a slope of more than 10°. Barren land, therefore, has been assigned more weightage over other landuses

Table 4: Weightages assigned to the classes of criteria layers – CCTs

| Criteria layers | Categories | Total weight | Normalized weight in % | Weights of the criteria layers (%) |
|---|---|---|---|---|
| LULC | Waterbody | 0.6 | 8.82 | 40 |
| | Agriculture | 0.9 | 13.23 | |
| | Barren land | 3.8 | 55.88 | |
| | Settlement | 1.5 | 22.05 | |
| Slope categories (in degree) | <10 | 0.2 | 20 | 60 |
| | >10 | 0.8 | 80 | |

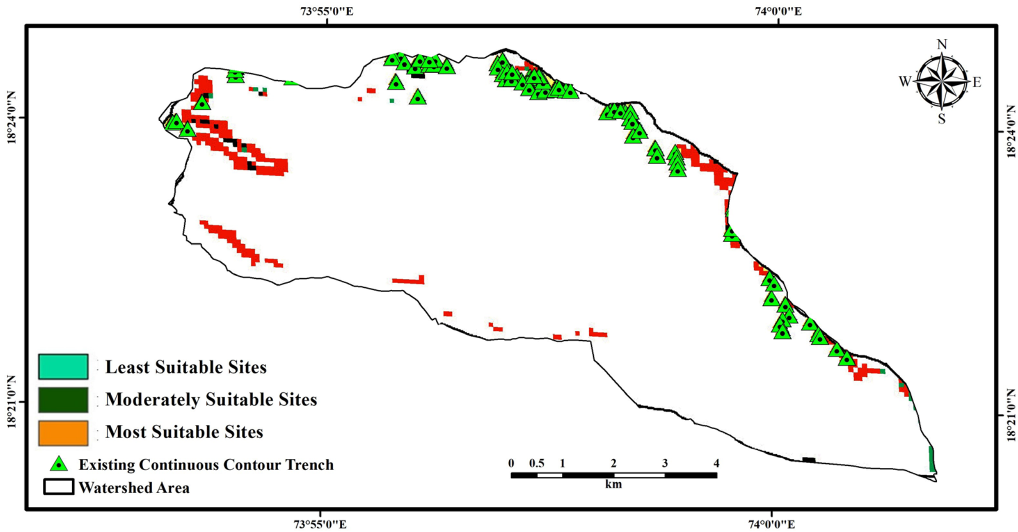


Fig. 4: Suitable sites identified for CCTs and existing CCTs

and landcovers. CCTs are built on a wide range of slopes ranging between 10° to 40°; sometimes even more. So the slope category of > 10° is given more weightage.

As per the categories shown in Table 4, the criteria layers (LULC and slope) for CCTs are reclassified. Using these layers, a weighted overlay model is built. The result is given in the form of a layer (fig. 4), showing the most suitable, moderately suitable and least suitable sites for the CCTs as well as the locations of the existing CCTs in the study area.

## Conclusions and discussions

Identification of suitable sites for WCSs is becoming the need of the hour. If such sites can be identified and suggested at the grassroots level, it will prove to be a very important step in encouraging efforts in water conservation. The present research considers three WCSs for the purposes of water conservation.

### *Conclusions*

Suitable sites are identified for these structures and the results are validated too. Based on the analysis carried out and the results obtained, the following conclusions are put forth:

***The suitability of the technique***

GIS has adopted and integrated several techniques from wide-ranging disciplines such as mathematics, computer programming, physics, electronics and management sciences. Multi-criteria analysis is one such approach adopted in GIS from management sciences. This approach allows the comparison of factors (criteria) that influence site selection. The suitability of sites for WCSs is based on a number of physical factors such as the slope of the terrain, soil type, and landuse/landcover. These factors vary spatially i.e. many categories/classes of a factor are found within a region. This means that the comparative importance of not only the factors has to be decided, but also to be decided for each class of the factor. The relative importance of each factor as well as its subcategories can be objectively determined using the pair-wise comparison method. The spatial multi-criteria approach, therefore, seems to be a more convenient approach for such types of studies.

***Choice of criteria and assignment of weights***

The main criteria applied for the identification of suitable sites are slope, soil and landuse/landcover. The highest weights are assigned to slope followed by LULC and soil in the case of percolation tanks. The <100 class in slope criteria is given more weightage over the others. It is found that the suitable sites identified are at the appropriate locations. The areas of settlement and agricultural lands are avoided as expected. In case of check dams, the identified sites are exactly in the stream channel. The criterion of distance from the river channel has been assigned more weight in the analysis. This has also proved to be the decisive factor and has helped in rightly identifying the sites within the channel. In the case of CCTs, the upslope areas are preferred though the CCTs can be constructed on gentler slopes as well. The results of the analysis (fig. 4) show the areas near the crest line as suitable for CCTs, which is also an acceptable result.

***Validation of results***

To bring a technique to the implementation level, it is necessary to validate the results. In the present study, the results are validated by comparing the sites identified by the technique and the location of existing corresponding WCSs. It has been found that the existing structures are in the areas found as suitable by the way of GIS modeling. Thus it may be concluded that the present technique can be used in the similar physiographic area for the identification of sites.

***Discussion***

The present study has considered only three of the sixteen ways of water conservation. In the future the technique of spatial multi-criteria analysis should be applied for the identification of suitable sites for the other structures as well.

The number of criteria such as geologic structure, rock type, type of streams and rainfall distribution should also be included along with the LULC, slope, soil type and distance from streams before the same technique could be employed for the larger area which has more variability. Also, the sites suitable for one type of structure may be tried for the other similar type of structures so that an integrated approach to identify the suitable sites can be adopted.

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