ISSN 2229-5518

Site Suitability Analysis of Water Harvesting Structure on Hilly Terrain using Geo-informatics Technology in Valsad District, Gujarat state, India

Rushang R. Dave[1], Gautam Dadhich[1], Vijay Singh[2], Ajay Patel[2], Khalid Mehmood[2], Sumit Prajapati[2], Manik H. Kalubarme[2], Balkrishen Pandit[3] and R.N. Shukla[3]

[1] Pandit Deendayal Petroleum University (PDPU), Gandhinagar, Gujarat, India

[2] Bhaskaracharya Institute for Space Applications and Geo-informatics (BISAG) Department of Science & Technology, Government of Gujarat, Gandhinagar 382 007 (Corresponding Autor email-d; mhkalubarme@gmail.com)

[3] Gujarat Water Supply and Severage Board (GWSSB), Government of Gujarat, Gandhinagar, Gujarat, India

Abstract— Surface water availability varies spatially and temporally based upon the terrain. The scarcity of water affects overall development of any area. To improve water infrastructure, small water harvesting structures, construction across streams is popular. In the present study, site suitability analysis was carried out for construction of rainwater harvesting structures in the hilly terrains of Dharampura and Kaprada taluka using Geo-informatics technology. Indian Remote Sensing Satellite (IRS-P6) LISS-III digital data and CARTOSAT PAN data with spatial resolutions of 24 m and 2 m respectively, covering Valsad District in Gujarat State was analyzed.

Various thematic maps such as Landuse/Landcover, geomorphology and lineaments, etc. were prepared from the satellite data. These layers along with geology and drainage were integrated using GIS techniques to derive suitable water harvesting sites. Each theme was assigned a weightage depending on its influence on surface water recharge (for example weightages 0,1,2,3,4,…,10 were assigned to geomorphology, landuse, geology, lineament, drainage and road and villages respectively). Each class or unit in the map was assigned a knowledge based ranking of one to four depending on its significance in storage and transmittance of ground water. 3-D visualization of the Remote sensing along with GIS data, Weightage Analysis method, Geo-spatial method, profile method, etc. were adopted for selecting the site on the hilly terrains. Further, the best potential sites were selected based on the query analysis and Weightage analysis method. The final maps showing different categories of suitability sites for water harvesting structures such as Check dams, Contour bunding, Recharge pits, Wells and Contour trenching have been prepared. The final best suitable sites determined were submitted to Gujarat Water Supply and Severage Board (GWSSB) for the field verification and suitability evaluation. The GWSSB carried out the execution of the next stage of constructing the water harvesting structure at some of the selected sites.

Index Terms—Indian Remote Sensing Satellite (IRS), LISS-III digital data, Cartosat-1 DEM-10 m, Geo-spatial method, , Land use classification, Weightage Analysis, Water Harvesting Structures,

1 Introduction

Dharmapur and KapradaTaluka in Valsad region of South Gujarat receive heavy rainfall during rainy season, but complex geology, unsuitable natural topography and lack of water harvesting structures result in high runoff in the area. Water percolation to the subsurface is minimal and runoff flows down to plains and also to the Maharashtra region. Therefore, tribal people inhabiting this area, face acute water scarcity during summer season in spite of getting ample amount of rainwater during rainy season. The solution to this problem has been studied in two stages:

i) Determining the natural depressions (potential sites) for rain water harvesting on impervious soil strata using Remote Sensing and GIS, and ii) Laying the pipeline on hilly terrain right from the source to destination, so that tribal villages can get benefit of that rain water through pipeline. The present paper discusses with first stage of project only. The natural depressions on the hilly terrains of Dharampur and Kaprada region were determined using Advanced Techniques i.e Remote Sensing and GIS. Satellite images of CARTOSAT and IRS-P6 LISS-III images were used for determining the natural depressions on hilly terrain as well as for carrying out site suitability analysis to determine the best potential sites out of the determined sites. Data Analysis and Geo-referencing was carried out in Arc GIS 9.1 software. Natural depressions were determined with the help of two methods: i) Analytical meth-

- *Authors* Rushang R. Dave & Gautam Dadhich *are currently pursuing Bachelors degree program in Civil engineering in Pandit Deendayal Petroleum University (PDPU), Gandhinagar, Gujarat, India,*
- Co-Authors, Vijay Singh, Ajay Patel, Khalid Mehmood are Project *Managers. And Sumit Prajapati is a Project Scientist, Bhaskaracharya Institute for Space Applications and Geo-informatics (BISAG) Department of Science & Technology, Government of Gujarat,Gandhinagar 382 007.*
- Co-Authors Balkrishen pandit and R N Shukla are Hydrogeologists at GWSSB, Govt. of Gujarat, Gandhinagar
- *The corresponding autor* Manik H. Kalubarme *is a Former Scientist, Space Applications Centre (ISRO) & currently Project Director, BISAG.*

od and ii) Geo-spatial method. In Analytical method, the sites were determined by generating the Digital Elevation Model (DEM) of LISS-III and CAROSAT image of given area of interest and 3-D visualization of the same in Arc SCENE software. While in Geo-spatial method, the sites were determined using Arc GIS 9.1 Software by sink method.

Finally the site suitability analysis was carried out to determine the best potential sites satisfying all the criteria, out of the determined sites. For this, a new method known as “Weightage Analysis” was adopted apart from the conventional method for determining the best potential sites. In Weightage Analysis method, many thematic maps such as Land usability, geomorphology, soil taxonomy etc. were prepared using remote sensing. These layers along with geology and drainage were integrated using GIS techniques to derive suitable water harvesting sites. Each layers were assigned a weightage depending on its influence on surface water recharge for example weightages 0,1,2,3,4,…,10 were assigned to geomorphology, land use, geology, lineament, drainage and road and villages cluster. While in Conventional method, the best suitable potential sites were determined using Profiling method and Querry Analysis method in Arc GIS 9.1 software. The advantages, disadvantages of the weightage analysis method over conventional method are discussed in the present paper. At last, the best suitable sites determined were submitted to organization for the Field verification and for execution of next stage.

2. STUDY AREA

The study area selected for the project covers Dharampur and Kapradataluka in Valsad district of South Gujarat state. The location map of the study area is given in **Figure-1**.

Dharampur: is a talukafalling in Valsad district in the southern portion of Gujarat State. Valsad district is bordered by Navsari District to the north and Maharastra to the east and south. Dharampur is located at 20°32′N 73°11′E / 20.53°N 73.18°E / 20.53; 73.18. It has an average elevation of 74 metres (242 feet). The taluka had a population of 19,932 as of 2001 Census data.

Kaprada: Kaparada is a taluka in Valsad district, Gujarat, India, near the border to Maharashtra. It is located in the Western Ghats. It is a predominantly tribal district. The taluka had a population of 202,862 [as of 2001. Kaprada covers 130 (habited) and 2 (inhabited) villages. Total geographical area of Kaprada is 936.62 sq. kms.The drainage networks like river, drainage, and waterbodies map is given in **Figure-2**.

3. MATERIALS AND METHOD

3.1 Data Used

3.1.1 Satellite data

Indian Remote Sensing Satellite (IRS-P6) LISS-III & LISS-IV and CARTOSAT digital data covering study area of different dates was analyzed for land use mapping, terrain analysis and generation of DEM. The details of satellite data used in the study area are given in Table-1.

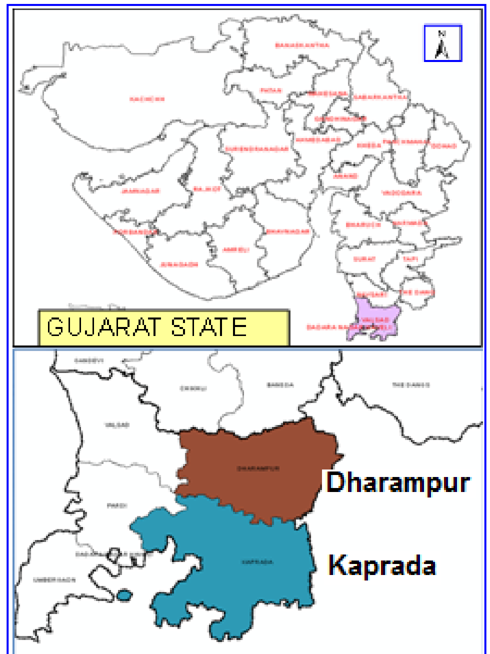


Figure-1: Location map of the Study Area

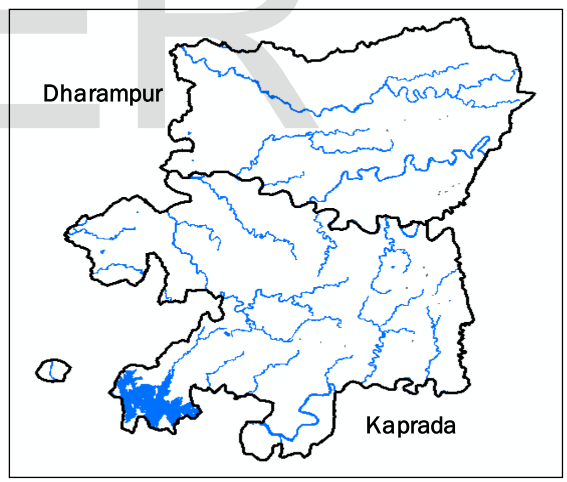


Figure-2: Drainage and waterboy Map of the Study Area

3.1.2 GIS data

The GIS layers like drainage network, transport network, district and taluka boundaries etc. were used in this study.

Table-1: Details of Indian Remote Sensing Satellite Data used

ISSN 2229-5518

No	Satellite	Sensor	Path/Row	Date of Pass
1	IRS P6	LISS-III	92/57	26-Jan-2010
2	IRS P6	LISS-IV	201/102	12-May-2008
3	IRS P6	LISS-IV	202/80	24-Feb- 2009
4	IRS P6	LISS-IV	202/96	31-Jan- 2009
5	IRS P6	LISS-IV	203/57	30-Mar-2008
6	**Cartosat**	PAN	502/297	Feb-2010
7	**Cartosat**	PAN	502/298	Feb-2010

3.2 Satellite Data Analysis

The IRS LISS-III and LISS-IV digital data covering study area was analyzed and it broadly consists of following steps:

i) Image processing and geo-referencing using GCP library
ii) Administrative boundary superposition on satellite data
iii) Satellite aata extraction covering study area using taluka boundaries
iv) Digital Elevation Models (DEM) generation using CARTOSAT data of 10-m
v) Identification of natural depression on the hilly terrain
vi) 3-D visualization
vii) Selection of best suitable site of natural depression

The IRS LISS-III digital image along with taluka boundaries of Dharmapur and Kaprada is given in **Figure-3**.

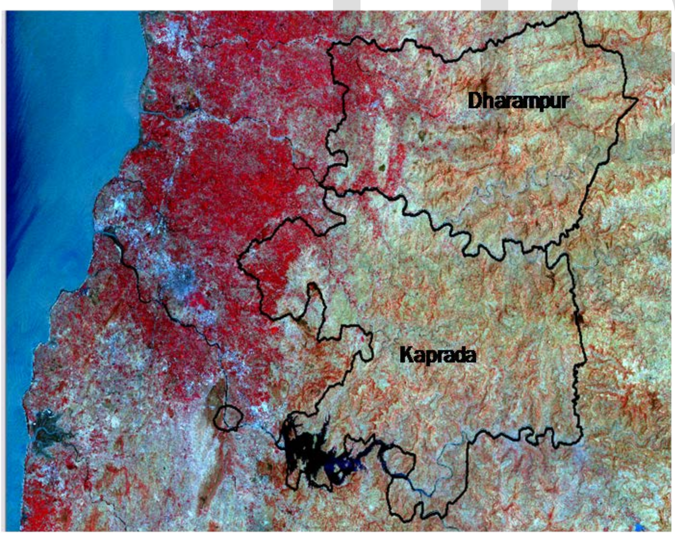


Figure-3: IRS LISS-III image along with taluka boundaries

3.2.1 Study Area Extraction from Satellite data

The taluka boundaries of Dharampur and Kapradatalukas were superimposed on IRS LISS-III digital and CARTOSAT PAN data and using ERDAS IMAGINE image processing software the the data inside the taluka boundaries was extracted for further analysis. The extracted images of IRS LISS-III and CARTOSAT PAN data are given in **Figure-4.**

3.2.2 DEM Generation

Digital Elevation Models (DEM) are required for several tasks like generation of ortho-images, flood planning, erosion control, generation of contour lines, visibility check, 3-D views and others. The achieved accuracy of DEM based on space images is mainly depends upon the image resolution, the height-to-base-relation and the image contrast. A digital elevation model (DEM) is based on a higher number of points with X-, Y- and Z coordinates describing the area under consideration. Digital Elevation Models do play a fundamental role in mapping as well as in visualization. Cartosat-1 stereo-data was used to generate 10 m spatial resolution Digital elevation Model (DEM) covering the study area. The CARTOSAT DEM image of the study area and the enlarged portion of Kaprada taluka are given in **Figure-5.**

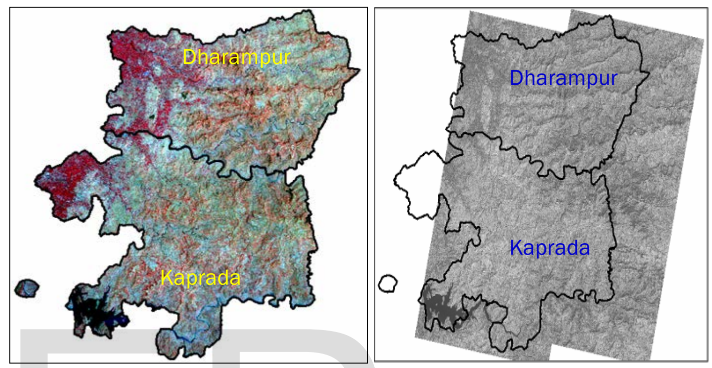


Figure-4: IRS LISS-III and CARTOSAT images covering study talukas

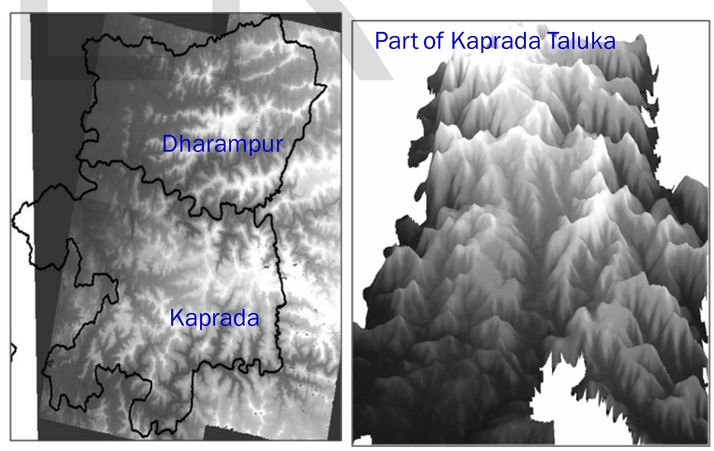


Figure-5: CARTOSAT DEM image of study talukas along with enlarged portion of Kaparda taluka

4. Results and Discussion

4.1 Methods adopted for identification of natural Depression

For the identification of natural depression on the hill tops mainly two methods were adopted:

i) Analytical Method

In this method, the sites were identified by visualizing the 3-D DEM and CARTOSAT-1 image and LISS- III image of Area of Interest and potential sites were identified. The best potential sites were further identified by analyzing various parameters and equating them visually in GIS environment. While visualizing following parameter are taken into consideration:

a) Road network: Site should be well connected to the road for better accessibility.
b) Drainage network: drainage gives better idea about origin of source.
c) Settlement: water intake should fulfill the requirement of maximum villages.

4.1.1 3-D Visualization

Visualization of the study area is done by the tool "3-D ANALYST" provided by Arc GIS (v.10). It is a technique which enables a user to visualize the image in a 3-D pattern. The advantage of 3-D lies in the way we see the information. Geographic Visualization depends on psychological cues to create a natural 3-D scene on a 2-D computer monitor. In a sense, visualization models are not photographs, but pictures or renditions. Hence, the process of generating a scene is termed rendering. To render the most realistic scene, the geographer might rely on such visual clues as simple perspective rules or the subtle change of color or texture with distance. The Cartosat DEM was draped on the IRS LISS-III data of Dharampur and Kaprada talukas for generating 3-D visualization images showing undulated terrain and natural depressions on the hilly areas (**Figure-6)**.

These 3-D visualization images of Dharampur and Kaprada talukas were interpreted using fundamental picture elements interpreted in the satellite images. Visual interpretation was done on basis of image characteristics like tone/color, texture, pattern, shape, size, location, shadow as well as associated elements in order to get best natural depression in hilly terrain.

4.2 Selection of best suitable site for natural depression

The major objective of this project is selection of suitable sites for water storage in hilly terrain of Dharampur and Kaprada-talukas. The procedure adopted for this consists of specific data processing functions in GIS to select best suitable site for water reservoir based on some physical parameter such as Road network, Drainage network and settlements. Selection of best possible potential sites for water harvesting structures is carried out using following methods:

4.2.1 Query Method

The best possible potential site for water storage should have
- ✓ High elevation of potential site
- ✓ Less elevation of settlement

Distance between site and settlement should be less

To fulfill above requirement following query is applied in ArcGIS (V.10):

Site elevation > 500
Settlement elevation < 300
Distance between site and settlement < 5000 m

The procedure adopted for query generation in Arc GIS is given in **Figure-7**.

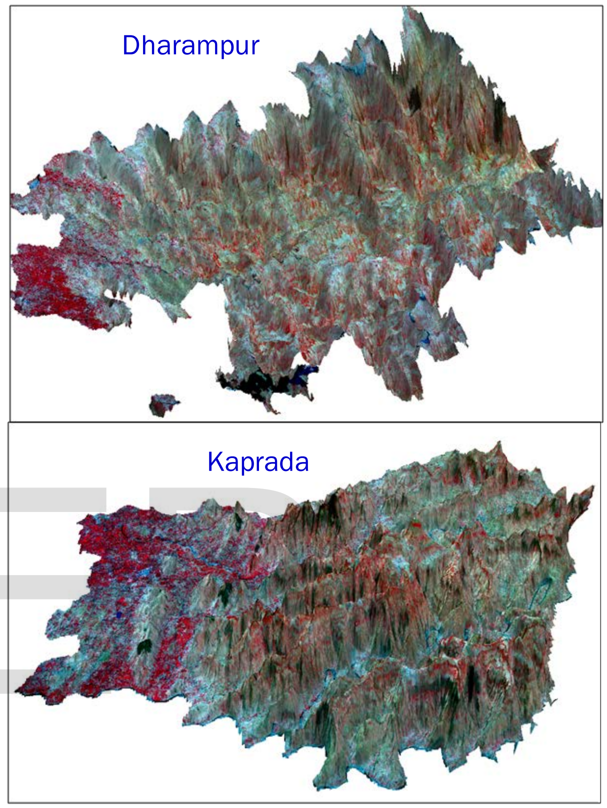


Figure-6: Digital Elevation Model (DEM) Draped on IRS LISS-III data for 3-D visualization

4.2.2 Profiling Method:

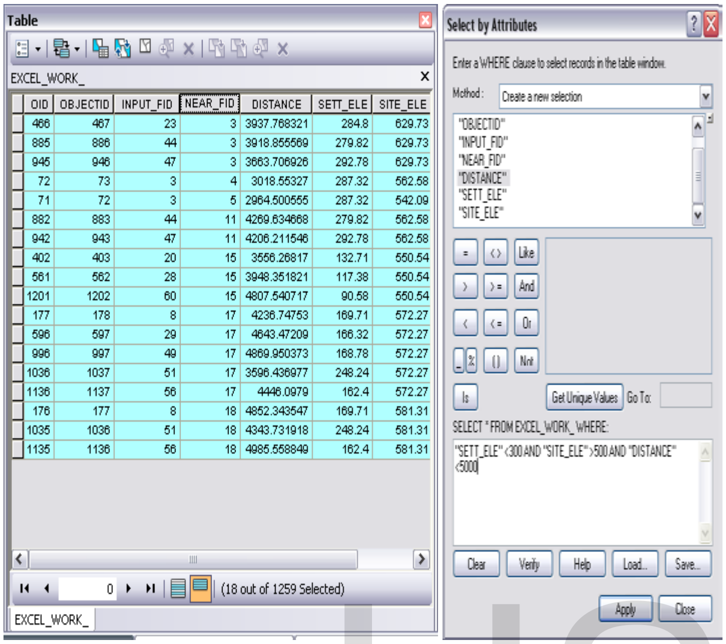
After identifying different sites for water storage the pipeline has to be laid from source to destination. In that situation profile of hilly terrain should be gently sloping and plane to get good and cost-effective pipeline network. The profiles generated for two different sites are given in **Figure-8**.

4.2.3 Sink Method:

Sinks are depressions or holes in the land surface that occur due to hydrological and surface condition. They can be shallow or deep, small or large, but all are a result of the dissolving of the underlying limestone. Sinks are considered to have undefined flow directions and are assigned a value that is the sum of their possible directions. Sinks can be located using the

ISSN 2229-5518

Sink tool. This tool requires a direction raster that is created by the Flow Direction tool. The result is a raster that identifies any existing sinks in the data. Natural depressions on high elevation were identified by the help of this tool.



OID	OBJECTID	INPUT_FID	NEAR_FID	DISTANCE	SETT_ELE	SITE_ELE
466	467	23	3	3937.768321	284.8	629.73
885	886	44	3	3918.855569	279.82	629.73
945	946	47	3	3663.706926	292.78	629.73
72	73	3	4	3018.55327	287.32	562.58
71	72	3	5	2964.500555	287.32	542.09
882	883	44	11	4269.634668	279.82	562.58
942	943	47	11	4206.211546	292.78	562.58
402	403	20	15	3556.26817	132.71	550.54
561	562	28	15	3948.351821	117.38	550.54
1201	1202	60	15	4807.540717	90.58	550.54
177	178	8	17	4236.74753	169.71	572.27
596	597	29	17	4643.47209	166.32	572.27
996	997	49	17	4869.950373	168.78	572.27
1036	1037	51	17	3596.436977	248.24	572.27
1136	1137	56	17	4446.0979	162.4	572.27
176	177	8	18	4852.343547	169.71	581.31
1035	1036	51	18	4343.731918	248.24	581.31
1135	1136	56	18	4985.558849	162.4	581.31

Figure-7: Query Generation in Arc GIS

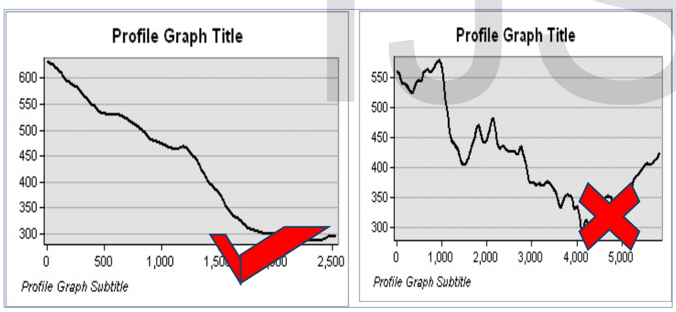


Figure-8: Profiles of two sites in Hilly Terrain

4.3 Geo-Spatial Method:

This method is based on weightage analysis method. First of all various parameters governing the suitability of the best potential sites were decided. Sites were then identified by assigning weightages based on their importence to different layers and then applying queries to identify the best suitable sites. The various parameters which were considered for weightage analysis are as follows:

i) Site Elevation :

Site elevation plays significant role while designing pipeline network. High elevation provides high pressure to water flowing in pipe. When some ground sufficiently high above the city area is available, this can be best utilized for water distribution in maintaining pressure in water mains. The water flows in the mains due to gravitational force. As no pumping is required therefore it is the most economic system for the distribution of water.

ii) Settlement Elevation :

Settlement elevation is taken into consideration while designing pipeline network. Settlement should be less elevated than water storage. If settlement elevation is more than that of water storage, then pumping of water is requird so in that situation it will be uneconomical.

iii) Distance between Sites and Settlements:

Distance between water storage potential sites to settlement should be less to reduce the cost of pipeline lying from source to destination. As the distance between sites and settlements increases the chances of losses of water will be more.

iv) Undulating Path between Sites and Settlements:

When we are designing any pipeline network in hilly terrine, we are mainly faces problems due to undulating terrine which creates obstruction while laying pipeline.

v) Volume of Sites :

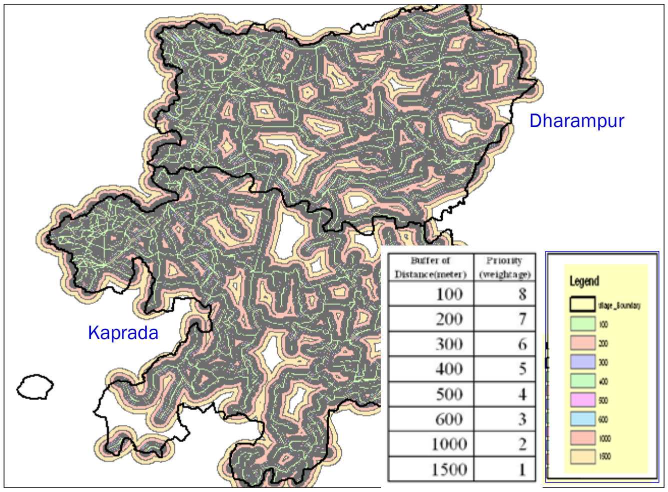
Volume of water storage should be as max as possible. As compare to other parameters, maximum priority is to be given to volume of site. If any potential site not having enough volume which fulfill need of localities then we have an option to construct any structure around it to increases its water capacity.

vi) Number Of Villages Covered By The Sites And Their Population:

Number of settlement should be more near the water storage. If the number of settlement is very less(one or two) than in place of laying pipeline to that settlement we can go for other alternative site.

vii) Road Accessibility:

Road accessibility is one of the important parameter while selecting the water storage potential site. Road accessibility is required for maintenance and water treatment at water storage. Maximum priority should be given to site which is away from the road, so that the waterbody will not submerge the road. The buffers of 100m to 1500m were superimposed on the maps of Dharampur and Kaprada talukas and the priorities of road accessibility were assigned. The map showing the buffers of 100m to 1500m and the priorities is given in **Figure-9**.



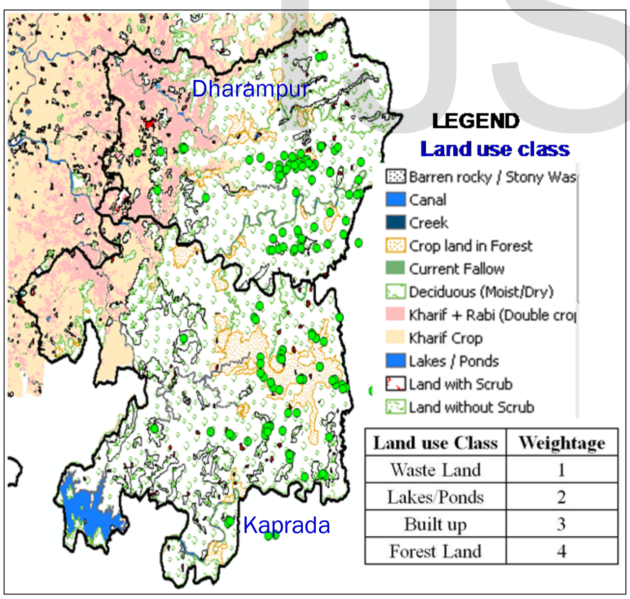
Buffer of Distance(meter)	Priority (weightage)
100	8
200	7
300	6
400	5
500	4
600	3
1000	2
1500	1

Figure-9: Priorities of road accessibility

viii) Terrain Parameters:

a) Land Usability:

The water storage should be located in waste land or water bodies. If our Site's land comes under any built up land or forest then we have to go for alternative method i.e. maximum priorities should be given to water bodies or waste land. The land use map along with the priorities is given in **Figure-10**.

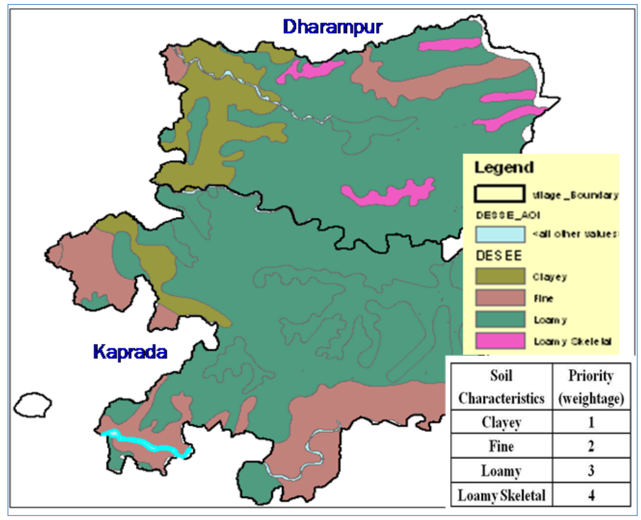


Land use Class	Weightage
Waste Land	1
Lakes/Ponds	2
Built up	3
Forest Land	4

Figure-10: Priorities of Land Use Classes

b) Soil Taxonomy:

Soil taxonomy becomes important parameter while selecting best possible potential site. The water storage should be selected in that area where water should not percolate through soil mass or permeability of that soil should be less, so the maximum priority is given to clayey soil and minimum priority is given to loamy skeletal and sandy soils. The soil Texonomy map of the study area along with weightages assigned to each class is given in **Figure-11.**

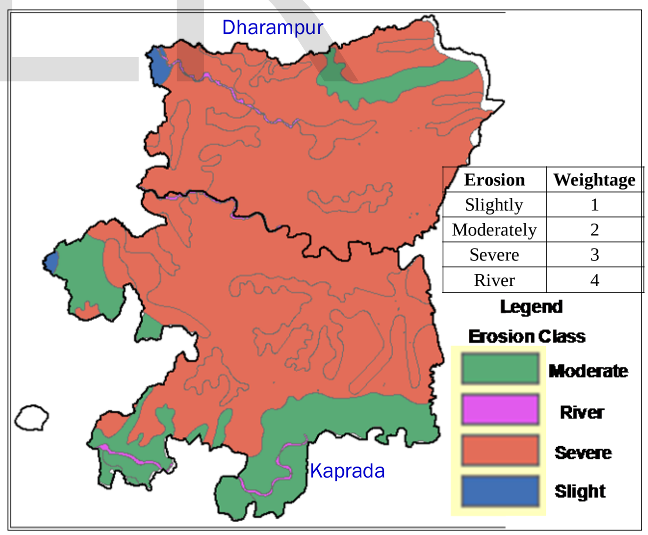


Soil Characteristics	Priority (weightage)
Clayey	1
Fine	2
Loamy	3
Loamy Skeletal	4

Figure-11: Soil Texonomy Classes and their Priorities

c) Erosion Intensity:

The erosion intensity map of the study area was alos prepared using IRS LISS-III digital data along with field data of the study area. The erosion map along with the priorities assigned to different erosion classes is given in **Figure-12**.



Erosion	Weightage
Slightly	1
Moderately	2
Severe	3
River	4

Figure-12: Erosion intensity Classes and their Priorities

d) Contour:

Contour line (often just called a "contour") joins points of equal elevation (height) above a given level. Contour gives an idea about elevation of water storage. While selecting potential site care should be taken that the site should have high elevation to get gravity flow. This parameter is to be given highest priority while selecting best possible potential site. The contours of the study area were generated from the Cartosat

ISSN 2229-5518

DEM data of the study area. The cnyour map of the Kaparda taluka is given in **Figure-13**.

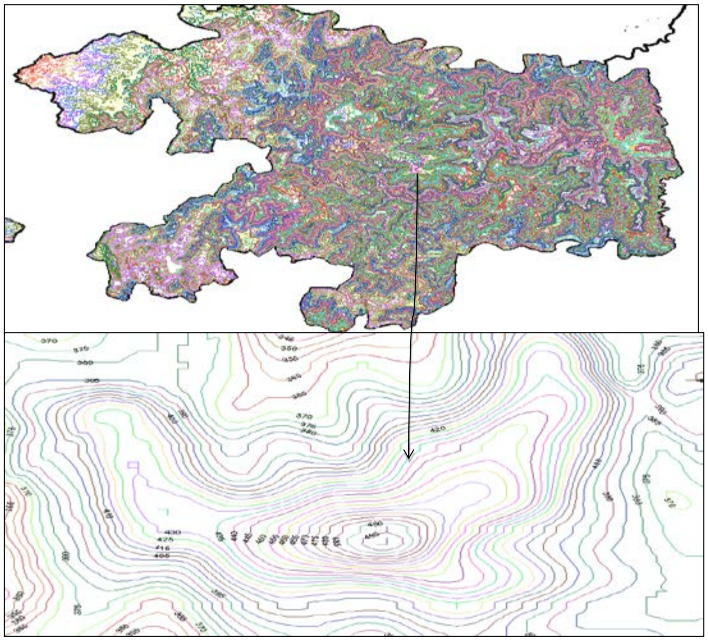


Figure-13: Contour Map of the Kaparda Taluka

4.4 Best potential sites selection

The best potential sites were selected from the given sites with the help of following criteria:

- First of all various parameters governing the suitability of the best potential sites were decided.
- Sites were then identified by assigning weightages based on their impotence to different layers and then applying queries to identify the best suitable sites.
- The following various parameters were considered:

Elevation of sites, settlement elevation, distance between sites and settlements, undulating path between sites and settlements, volume of sites, number of villages covered by the sites and their population, road accessibility, terrain parameters like: i) land usability ii) soil taxonomy, iii) drainage density, iv) slope, v) Contour, vi) river & water body, vii)Micro-watershed etc. The weightages were given to the all the parameters after deciding their prioties.

All the parameters were entered into the Analytical Hierarchy process and analysis was performed. Finally sites best possible sites in all the respect wer selected. The potential sites slected based on the analytical and geospatial method are given in Table -2 and Table-3.

Table-2: Potential site slected based on Weightages

Taluka	Potential sites	Taluka	Potential sites
Dharampur	Pangarbari	Kaprada	Vavar
Dharampur	Pindval	Kaprada	Barpuda
Dharampur	Moti Korval	Kaprada	Huda
Dharampur	Singarmal	Kaprada	Kolvera
Dharampur	Ulaspedi	Kaprada	Nrvad

Table-3: Potential site slected based on Geospatial Method

Taluka	Potential sites	Taluka	Potential sites
Dharampur	Pangarbari	Kaprada	Gothan
Dharampur	Pindval	Kaprada	Velveri
Dharampur	Moti Korval	Kaprada	Huda
Dharampur		Kaprada	Varvath
Dharampur		Kaprada	Vavar

The potential sites were also identified using 3-D visualization of CRTOSAT and DEM images along with GIS data. The 3-D visualization was carried in ArcScene-10 software. The CARTOSAT image was superimposed on the DEM image so as to generate the full 3-D visualization of the hilly terrains of Dharampur and Kaprada Taluka. The potential sites selected by 3-D visualization are shown in Figure-14.

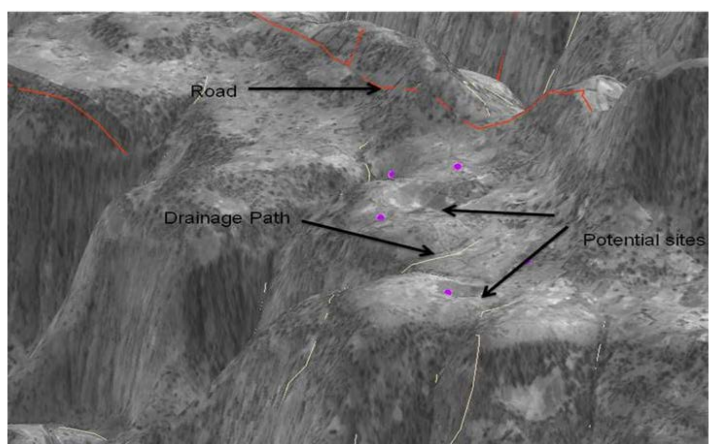


Figure-14: Potential sites selected by 3-D visualization

4.5 Potential sites Field Verification

The final maps showing different categories of suitability sites for water harvesting structures such as Check dams, Contour bunding, Recharge pits, Wells and Contour trenching have been prepared. The final best suitable sites determined were submitted to Gujarat Water Supply and Severage Board

ISSN 2229-5518

(GWSSB) for the field verification and suitability evaluation. The GWSSB carried out the execution of the next stage of constructing the water harvesting structure at some of the selected sites. Field photograph of one of the selected sites where water harvesting structure has been constructed is given in **Figure-15.**

Figure-15: Field Photograph of Water harvesting structure constructed at Kaparda Taluka

5. CONCLUSIONS

The study on locating natural depressions (water harvesting structures) on the hilly terrains of Dharampura and Kaprada taluka was carried out using Indian Remote Sensing Satellite (IRS-P6) LISS-III and CARTOSAT DEM digital data in GIS environment.

Analytical and Geo-spatial methods were adopted for for selecting sites for water harvesting structures. In Analytical method, potential sites were determined simply by the 3- D visualisation of image generated by the super imposing the CARTOSAT/LISS-III image over the DEM of Area of Interest. Further the best possible sites were selected by performing the Querry Anlaysis.

In Geo spatial method, the best possible sites were selected by performing Weightage Analysis. Weightages were defined for various parameters such as soil taxonomy, road accessibility, drainage conditions, cluster of villages, erosion, land use, etc. and the best possible sites satisfying all the parameters with the higher weightages were selected.Further for gravity flow pipe line alignment between source to destination, the basic criteria was to determine the obstacle free path without any undulations. This was accomplished by profile graph which shows the profile of the path where pipe line is to be laid. The best path was selected out of the given paths, where there are minimum undulations and terrain has gentle slope.

The major conclusions derived from the data analysis in this study are as follows:

- The site suitability analysis is carried out using analytical and geospatial methods.
- Geo- spatial method (Weightage analysis) is the best method for best potential sites selection as it considers all the parameters that are required for the ideal water harvesting structures such as soil taxonomy should be clayey so that water to be stored does not percolate to ground, land to be acquired for water harvesting structures should be waste land, not forest or agriculture land, etc. On the basis of all such parameters final sites were selected.
- The potential sites were determined mainly by 3-D visualization and sinks in the Area of Interest.
- The final map showing different categories of suitability sites for water harvesting structures such as Check dams, Contour bunding, Recharge pits, wells and Contour trenching have been suggested.
- The final best suitable sites determined were submitted to Gujarat Water Supply and Severage Board (GWSSB) for the field verification and suitability evaluation. The GWSSB carried out the execution of the next stage of constructing the water harvesting structure at some of the selected sites.

ACKNOWLEDGEMENTS

The authors like to express their sincere thanks to Shri T. P. Singh, Director, Bhaskarcharya Institute for Space Applications and Geo-informatics (BISAG), Department of Science & Technology, Government of Gujarat, Gandhinagar 38200, and Team Members of BISAG, , for fruitful discussions, suggestions and continuous cooperation in carrying out this work.

REFERENCES

1) Anonymous, 2008c. Glossary of remote sensing terms. Canadian center for remote sensing. Online. Internet. From http://ccrs.nrcan.gc.ca/glossary/HYPERLINK "http://ccrs.nrcan.gc.ca/glossary/index_e.php"index_e.php?
2) Al-Hanbali, Nedal., . Textural Mapping And Implementation Aspects 3D GIS Application.
3) Bentley System Incorporated, 2009. The Benefits of a 3D City GIS for Sustaining City Infrastructure.
4) Jacobsen,k. DEM generation from satellite data.
5) Driel, Van.,Nicholas j. 1989. Three dimension display of geographic data, 3D visualization and advantages of 3D over 2D.
6) Majanu, S., and Sumanth Kumar, G., 2005. canal alignment using Geographical Information System (GIS). Proceeding of Conference on Geomatics 2005.
   Al-Rousanet al. (1997), DEM Generation and 3D Visualization.

ISSN 2229-5518
7) Springer Link., 3D GIS for urban purposes.,Geoinformaticavol 2 number 1.,pp 79-103.