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Water Management and Water Governance

Hydrological Modeling

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Vijay P. Singh, Department of Biological and Agricultural Engineering & Zachry Department of Civil and Environment Engineering, Texas A&M University, USA
Email: vsingh@tamu.edu

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Editors
Ashish Pandey
Indian Institute of Technology Roorkee
Roorkee, India

S. K. Mishra
Department of Water Resources
Development and Management
Indian Institute of Technology Roorkee
Roorkee, India

M. L. Kansal
Department of Water Resources
Development and Management
Indian Institute of Technology Roorkee
Roorkee, India

R. D. Singh
Indian Institute of Technology Roorkee
Roorkee, India

V. P. Singh
Texas A&M University
College Station, TX, USA

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About the Editors

Prof. Ashish Pandey did his B.Tech. in Agricultural Engineering from JNKVV, Jabalpur, and obtained M.Tech. in Soil and Water Engineering from JNKVV, Jabalpur. He received Ph.D. in Agricultural Engineering from IIT Kharagpur. He joined IIT Roorkee in 2007 and is currently working as Professor at the Department of WRD&M, IIT Roorkee. His research interests include irrigation water management, soil and water conservation engineering, hydrological modeling of watershed, remote sensing and GIS applications in water resources. He guided ten Ph.D. and 78 M.Tech. students at IIT Roorkee. He published 155 research papers in peer-reviewed and high impact international/national journals/seminars/conferences/ symposia. He has also co-authored a textbook on *Introductory Soil and Water Conservation Engineering*.

He also served as Guest Editor for two issues of *Journal of Hydrologic Engineering* (ASCE). He is Editor, *Indian Journal of Soil Conservation*. His laurels include Eminent Engineers Award-2015 given by the Institute of Engineers (India), Uttarakhand State Centre, DAAD scholarship and ASPEE scholarship. He was offered prestigious, JSPS Postdoctoral Fellowship for Foreign Researchers, Japan, and BOYSCAST fellowship of DST, GOI. He is a fellow member of (1). Institution of Engineers (India); (2). Indian Association of Hydrologists (IAH) and (3). Indian Water Resources Society (IWRS).

Dr. S. K. Mishra is a 1984 Civil Engineering graduate of the then Moti Lal Nehru Regional Engineering College (presently MNNIT), Allahabad. He obtained his M.Tech. degree in Hydraulics and Water Resources from IIT Kanpur in 1986 and doctoral degree from the then University of Roorkee (presently IIT Roorkee) in 1999. He served the National Institute of Hydrology Roorkee at various scientific positions during 1987–2004. During the period, he also visited Louisiana State University, USA, as a postdoctoral fellow during 2000–2001 and Department of Civil Engineering, IIT Bombay, as Visiting Faculty during 2002–2003.

He joined IIT Roorkee in 2004 and is presently working as Professor. Besides having been Head of the Department of Water Resources Development and Management, he is also presently holding Bharat Singh Chair of the Ministry of Jal Shakti, Government of India. He is specialized in the fields of hydraulics and water resources, environmental engineering, design of irrigation and drainage works, dam break analysis, surface water hydrology. He has published more 250 technical articles in various international/national journals/seminars/conferences/ symposia. His reference book on *Soil Conservation Service Curve Number Methodology* published by Kluver Academic Publishers, the Netherlands, has received a significant attention of the hydrologists/agriculturists/soil water conservationists around the globe. Of late, he has been associated with the *Journal of Hydrologic Engineering* as Guest Editor of two special issues and Executive Vice President and Editor of Indian Water Resources Society. He has visited several countries during the period and is on the role of several national/international professional bodies. Among several others, the Eminent Engineers Award and Dr. Rajendra Prasad Award are worth citing.

Dr. M. L. Kansal currently working as NEEPCO Chair Professor and Head in the department of Water Resources Development and Management at Indian Institute of Technology (IIT) Roorkee (India). He is a Civil Engineering graduate with post-graduation in Water Resources Engineering. He obtained his Ph.D. from Delhi University (India) and holds the post-graduate diploma in Operations Management. Previously, he worked as Associate Professor in the department WRD&M, IIT Roorkee, and served at Delhi Technical University, Delhi (erstwhile, Delhi College of Engineering, Delhi), NIT Kurukshetra, IIT Delhi and NIH, Rookree (India) at various levels. He has published more than 150 research papers and two books. He has got best paper awards from Indian Building Congress, Indian Water Works Association, and received star performer award from IIT Roorkee. He acted as a reviewer for several international journals and research agencies. He has visited various countries as International Expert and Visiting Professor. He acted as International Expert for RCUWM of UNESCO and IUCN, etc. He is working as Executive Vice President of Indian Water Resources Society and served as expert panel member for All India Council for Technical Education (AICTE), India. He has contributed substantially by providing consultancy services to various national and international agencies of repute. He has worked in various administrative capacities such as Associate Dean of Students Welfare and as Chairman, Co-ordinating Committee of Bhawans at Indian Institute of Technology Roorkee and National Expert for several bodies.

R. D. Singh did B.E. Civil Engineering and M.E. Civil Engineering with Specialization in Hydraulics and Irrigation Engineering from University of Roorkee (Now IIT Roorkee). He did M.Sc. in Hydrology from University College Galway, Ireland. Presently, he is working as Visiting Professor, Department of Water Resources Development and Management, IIT Roorkee. He worked as Director, National Institute of Hydrology (NIH), Roorkee, for more than 9 years. Before taking over as Director NIH, he was holding the charge of Nodal Officer Hydrology Project-II, a World Bank Funded Project for Peninsular region of India completed by NIH during the year 2016. During his service at NIH, he had worked on more than eighty sponsored/consultancy projects for solving the real-life problems in water sector. He had also worked as well as guided eleven international collaborative projects at NIH.

He has research and development experience of more than 40 years in different areas of hydrology and water resources. He has an extensive experience in flood estimation, flood management, drought management, hydrological modeling, environmental impact assessment and climate change and its impact on water resources, etc. He has published more than 316 research papers in the reputed international and national journals, international and national seminar/symposia, workshops, etc. He has received C.B.I.P. Medal, Institution of Engineers Certificate of merit, Union Ministry of Irrigation Award and best Scientist Award form from NIH, Roorkee. He guided three Ph.D. and fourteen M.E. and M.Tech. and one M.Phil. dissertations. He has widely traveled abroad for different assignments.

Prof. V. P. Singh is University Distinguished Professor, Regents Professor and Caroline and William N. Lehrer Distinguished Chair in Water Engineering at Texas A&M University. He received his B.S., M.S., Ph.D. and D.Sc. degrees in engineering. He is a registered professional engineer, a registered professional hydrologist and an honorary diplomate of ASCE-AAWRE. He is a distinguished member of ASCE, a distinguished fellow of AGGS and an honorary member of AWRA. He has published extensively in the areas of hydrology, irrigation engineering, hydraulics, groundwater, water quality and water resources (more than 1290 journal articles; 30 textbooks; 70 edited reference books; 105 book chapters; and 315 conference papers). He has received more than 95 national and international awards, including three honorary doctorates. He is a member of 11 international science/engineering academies. He has served as President of the American Institute of Hydrology (AIH), Chair of Watershed Council of American Society of Civil Engineers, and is currently President of American Academy of Water Resources Engineers. He has served/serves as Editor-in-Chief of three journals and two book series and serves on editorial boards of more than 25 journals and three book series.

Chapter 1
Integrated Watershed Management and GIS: A Case Study

Sabita Madhvi Singh, Pabitra Ranjan Maiti, and Neetu Singh

Abstract To optimize the use of available land area and to meet the multiple demands of food and forest cover, planning and process use a series of cooperative, iterative steps to characterize existing conditions, identify and prioritize problems of land and water resources, define management objectives, and develop and implement protection or remediation strategies as necessary through watershed development-based programs. A watershed plan is a strategy and a work plan for achieving water resource goals that provide assessment and management information for a geographically defined watershed. Remote sensing and GIS, which plays an important role in detecting and monitoring the physical characteristics of watershed area by reflected and emitted radiation, is also efficiently used for watershed management. In the present study an attempt has been made to study the extensive use of GIS in watershed management. For this purpose, Khajuri Watershed is selected which is situated at the border of Marihan block. The study area is almost fully covered by metamorphic rocks, which include different limestone, gneiss and sandstone. The area's topography is generally mountainous and rugged dissected by many distributaries of Khajuri river. The catchment covers an area of about 126 km^2 (30,000 acres or 12,600 ha). Three commercially available GIS software tools are used in this project, which are ARCMAP v 8.1, ArcView and ERDAS IMAGINE v 8.5. ARCMAP is used as a tool to create and manage geographic information, and ArcView is used as a tool to visualize, explore, query, interpolate, update and analyze geographic information. As

S. M. Singh (✉)
Ministry of Jal Shakti, GOI, New Delhi, India
e-mail: sabitamadhvi@gmail.com

P. R. Maiti
Department of Civil Engineering, Indian Institute of Technology, Banaras Hindu University, Varanasi, India
e-mail: prmaiti.civ@itbhu.ac.in

N. Singh
Centre for Technology Alternatives for Rural Areas, IITB-Monash Research Academy, Mumbai, India
e-mail: neetusingh2701@gmail.com

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the total area is very large, it is sub-divided into sub-watersheds and micro watersheds to determine the available water resources of the study area, current water demand and future projection and technological options for water resource management and, in turn, to improve water availability and management of crop yield of a watershed, largely for optimum utilization of water resources to derive maximum benefits.

Keywords Watershed · GIS · Micro-watershed · Remote sensing

1.1 Introduction

Remote Sensing is defined as the technology by which the characteristics of the objects of interest can be identified, measured or analyzed without direct contact. Electromagnetic radiation which is emitted or reflected from an object is the usual source for remote sensing data (Lillesand et al. 2015). A device that detects the electromagnetic radiation emitted or reflected from an object is called a "remote sensor" or "sensor". Cameras, scanners are a few examples of remote sensors. A vehicle thatcarries the sensor is called a "platform". Aircraft or satellites are used as platforms (Campbell and Wynne 2011).

To generate a host of inter-related data and studied in relation to each other requires micro-watershed level planning. Remotely sensed data provide useful, helpful and up-to-date spatial and temporal information on physical terrain parameters and natural resources (Chowdary et al. 2009). Geographical Information System (GIS) with its capability of integration and analysis of spatial location and organizes layers of information into visualizations using maps have proved to be an effective tool in planning for micro-watershed development (Makhamreh2011).

Geographical Information System (GIS), which is typically required for hydrological studies has evolved as a highly sophisticated data management and analyzing system to collect and store large data. Thus, remote sensing and GIS reveal deeper insights into data, such as patterns, relationships and situations helping users for efficient management of water resources make smarter decisions (Strager et al. 2010). The synoptic view provided by remote sensing and the analysis capability provided by GIS offers the most appropriate method for studying these resources. (Jain et al. 2000; Khan et al. 2001) have said that land resource development programs are applied generally on a watershed basis. Delineation of watersheds of a large drainage basin and their assessment is required for proper planning and management of natural resources for sustainable crop production (Willis et al. 1989). Rao et al. (2004) described that watershed management as the rational utilization of the land and water resources for optimum production with minimum loss of natural resources. The basic principle of watershed management is to use the land according to its capability and treat the land according to the needs for the sustainable development of the people living in that area (Thiruvengadachari et al. 1994). The land that was used beyond its capability generates adverse effects on the environment like soil degradation in the form of erosion, ground water depletion, etc. In the present study, optimization and watershed management are carried out for Khajuri Watershed and few results are presented to give an idea about the application of GIS in watershed management.

1.2 Study Area

The study area is located in the southeastern part of Mirzapur District of Uttar Pradesh, bounded by Varanasi and Sant Ravidasnagar Bhadohi, district in north and Chandauli district in the east, by Sonbhadra, Siddhi and Rewa (Madhya Pradesh) districts in south and southeast, respectively, and by Allahabad in the west. Mirzapur has five development blocks with 694 villages.

1.2.1 Location of the Khajuri Watershed

Khajuri Watershed is situated at the border of City Block and Marihan block as shown in Fig. 1.1. The catchment is located between 25°0′ 0″ and 25°5′ 0″ N latitude and 82°30′ 0″ to 82°40′ 0″ E longitude. It covers an area about 126 km^2 (30,000 acres or 12,600 ha). As the total area is very large for the study as a watershed, so here on the basis of subwatershed and micro-watershed study is done and the result is also shown accordingly. The study area also Barkachhakhurd and Barkachhakalan where the South Campus of Banaras Hindu University Barkachha KVK centre is located. In this subwatershed Khajuri, Tand, Bhukwa, Belahra, Hardi Kurd, Phullari and Bahmandeva villages are also studied. Thus, the total area of around 9000 ha for the present study is considered in which the main emphasis is given on Barkaccha KVK centre of around 1104 ha.

1.2.2 Physiography and Drainage System

It is located between the forest areas of Barkachha Reserve Forest on the East and the Danti Forest Reserved Forest on the west and has a seasonally dry climate dominated by dry deciduous forest and dry savannah grasslands. It is situated approximately 160 m height from Khajuri River flowing along the western end of subwatershed. The lowest elevation is about 90 m from the mean sea level (MSL). The study area has a complex alignment in distribution and orientation, structure, relief, slope, morphology, climate and vegetation. This is an impact of lineament on the drainage routes. The main river system in the study area is the Ganga river system with 2760 km^2 covering 55.74% of the district with the coverage of Khajuri tributary for a length of 50 km and of basin area 171 km^2. The drainage pattern is dendritic and some of the tributaries of Khajuri drain the eastern terrain of the whole area.

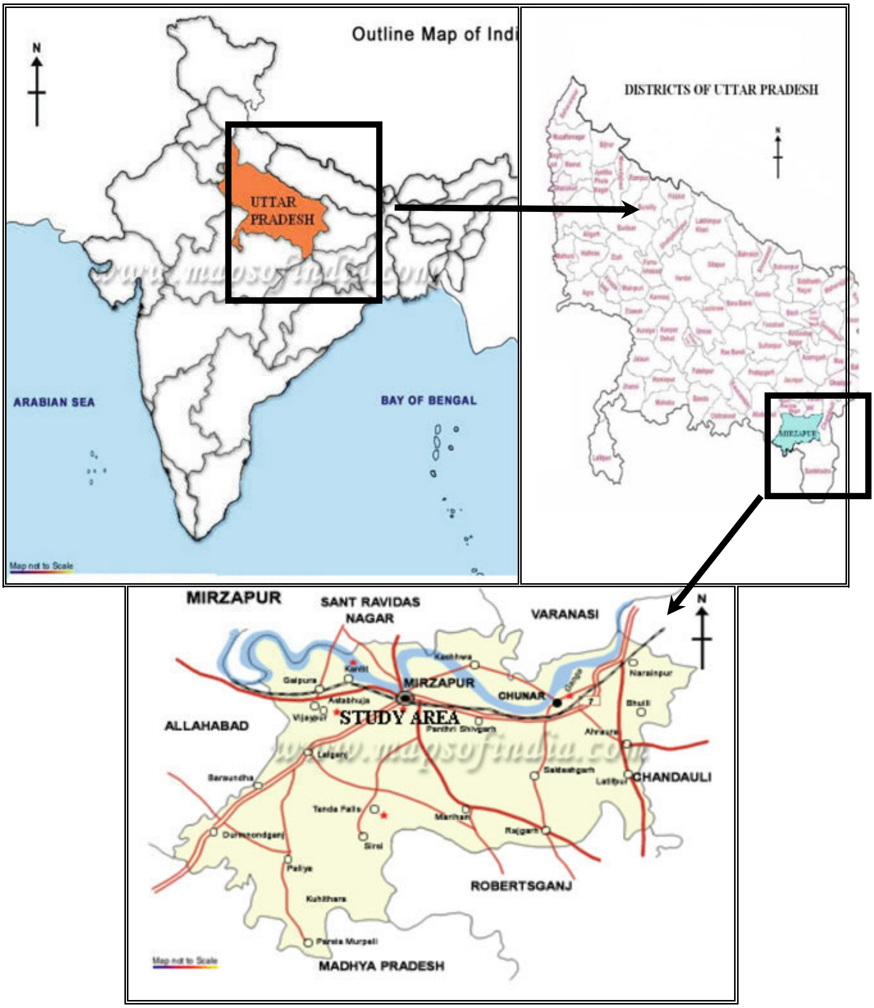

Fig. 1.1 Location of study area

1.2.3 Geology

The study area is almost fully covered by metamorphic rocks, which include different limestone, gneiss and sandstone. The area's topography is generally mountainous and rugged dissected by many distributaries of Khajuri river. It is dominated by the Vindhyan plateau system. The study area comes under the Kaimur series of variegated sandstone, limestone, inter-bedded shale with or without alluvium.

1.2.4 Geomorphology

Geomorphology affects availability of soil moisture, depth, the structure of soil and landholding patterns and yield output. The geomorphic unit of the area is the Vindhyan Upland. The landform features of the area include:

(a) Buried pediment: This area is very good for cultivation and the agricultural quality of the land is regarded as very good. The groundwater potential is also considered very good. These are flat surfaces of the plateau area with thin
(b) Cover of unconsolidated materials mainly gravel, soil (alluvium/colluvium) or weathered rocks. Hence they are considered as good for rice cultivation.
(c) Pediment: These are open rock surfaces and running water is the main agent of its formation. These are transitional zones between hills and plains. These are gently sloping at 1–7°. These are divided into two main classes:

    1. Pediment with vegetation: These have land use of open forest, groves, etc. The agricultural land quality is considered poor. Also, the ground water potential is low.
    2. Pediment with stony surface: These are lands considered as stony waste. The agricultural quality and ground water potential are also very poor.

(d) Dissected plateau: A plateau with various streams cutting across its terrain creates a dissected plateau. Features like gorges, valleys, and scarps lands create an undulated topography. These are forest areas and the agricultural land quality is considered to be moderate but the ground water potential is poor.
(e) Valley fill: Lateral erosion landform with and underlying bed rock with an erosional surface. This land is considered a good quality agricultural land with poor ground water quality.

1.3 Methodology

(i) Data Analysis and Thematic Layer Generation using GIS
(ii) Satellite Image classification of the area.

ArcView v 3.1a: This software has been developed by ESRI Inc. It is one of the leading software for GIS and mapping. ArcView gives the power to visualize, query, explore and analyze data geographically. In this project ArcView is use for display of raster map. Digitizing different features, visualizing the different features, linking attributes of the digitized data with the features and for querying the data geographically and for finding the attribute of any feature of the map.

ArcGIS v 8.1a: This software has been developed ESRI Inc. In this project all the thematic layers have been prepared using this software. Here Arc Hydro Tools are used for delineation of watershed. Arc Hydro is an ArcGIS-based system prepared to support water resources applications. It consists of two key components:

1. Arc Hydro Data Model
2. Arc Hydro Tools.

The tools are accessed through the Arc Hydro toolbar, where they are grouped by functional key into six menus.

Terrain Preprocessing: Digital Elevation Model (DEM) tools deal processing. Prepare spatial information that is mostly used for analysis.

Terrain Morphology: Perform initial analysis of a non-dendritic terrain these tools are used.

Watershed Processing: Dealing with watershed and subwatershed delineation and basin characteristic determination this tool in menu work. They operate on top of the spatial data prepared in the terrain preprocessing stage of delineation.

Attribute Tools: These tools provide many functionalities for generation of some of the key attributes (fields) in the Arc Hydro data model. Some of the tools require existence of a geometric network.

ERDAS IMAGINE v 8.5: This software has been developed by ESRI Inc. USA. This system incorporates the function of both image processing and GIS. This function includes viewing, importing, altering, and analyzing raster and vector data set. In the present study, ERDAS Imagine is used for making Digital Elevation Model of the area, analyzing the IRS data and delineating the sub-watersheds and for classification of satellite data for landuse and other features (ERDAS 2000).

1.3.1 Data Analysis in GIS

The methodology which has been developed is dependent on spatial topographic data, which are partitioned into number of layers for the area under consideration. The data for each tile is divided into many layers of information with common themes or structures. Three commercially available GIS software tools are used in this project: ARCMAP v 8.1, ArcView and ERDAS IMAGINE v 8.5. ARCMAP v 8.1 is used as a tool to create and manage geographic information, and ArcView is used as a tool to query, visualize, explore and analyze geographic information. With the aid of ARCMAP and Arc View, land use and soil type data for the study area are merged to obtain a different number of thematic layers. All the thematic maps are converted into digital form, using a scanner (Mas et al. 2015). The dataset is converted from vector to raster form. The data are imported into ARCMAP GIS v 8.1 on IBM RS6000 workstation and different thematic layers are edited to create an error-free digital database. Several thematic maps are needing to be derived from the basic soil survey data. The attributes chosen are going to be those that influence plant growth through soil–water-air-plant relationships (Gao 2008). These maps help land users to develop an action plan for various areas like conserving soils, ameliorating degraded soils and for using soils in line with their capability (Jain et al. 2000).

(a) **Digitization Steps**:

Scanning of SOI toposheet: The toposheets are vector maps, which are converted to raster form after scanning. This does not contain any information and are merely pixels of colour composites of red, green and blue. The scanned map area does not represent the location on the surface of the earth and is inadequate to perform analysis.

Geo-referencing: The map is then geo-referenced, a process of defining the raster data in map co-ordinates it allows overlaying and analyzing of geographic data. A co-ordinate system or map projection system to define the point, line and area features. Geographic projection systems of the world are selected with Asia, GCS Kalianpur 1975 as the co-ordinate map projection system to align raster to existing spatial data such as streams, contours, roads, etc. Ground control points (GCPs): four ground control points were identified and a ground control shapefile are created in ARCVIEW software. The ARCMAP software wraps the raster by rubber sheeting by taking the reference of ground control points. The transformation is done, followed by interpreting the root mean square error. Resampling is performed by nearest neighbour first to give a final geo-referenced map (Scott and Janikas 2010).

Digitization: The thematic maps are digitized using ARCMAP. Digitization can be said as the conversion of images into digital format (Hamar et al. 1996). The objects stored in a GIS may be of three types, referred to as the geometric base elements:

1. Points: representing objects without any aerial extent such as drilling sites, wells, rainfall stations, etc.
2. Lines: representing linear objects such as roads, railways, rivers, telephone lines, etc.
3. Polygons: representing areas such as soil classification, land cover classes, etc.

Creation of thematic layer: Each layer file is saved as a separate shapefile based on the theme and properties as summarized in Table 1.1.

Thematic layer generation: The following thematic layers are prepared in ARCMAP version 8.1 software developed by ESRI, U.S.A.

Table 1.1 Digitization of various land features in GIS

Feature class	Mode of digitization
Contour	Line
Drainage	Line
Water bodies	Polygon
Road	Line
Soil	Polygon
LULC	Polygon

(a) **Location of Khajuri watershed**

The main map of the study area is prepared from the Survey of India toposheet at a scale of 1:50,000 as shown in Fig. 1.2. Water bodies, drainage networks, roads, etc. are digitized.

(b) **Contour map**

To display the topography of the area an elevation map is digitized from the toposheet. The contour intervals of 10 m interval were mapped from the toposheet. A variation from 90 to 160 m is observed, giving information on the undulating relief features in the area.

(c) **Drainage and water bodies**

A layer file depicting the water resources within the area are created in ARCMAP as shown in Fig. 1.3. The area is drained by the tributaries of the Khajuri river flowing along eastern region. The waterbodies include wells, water harvesting tanks and ponds within the area.

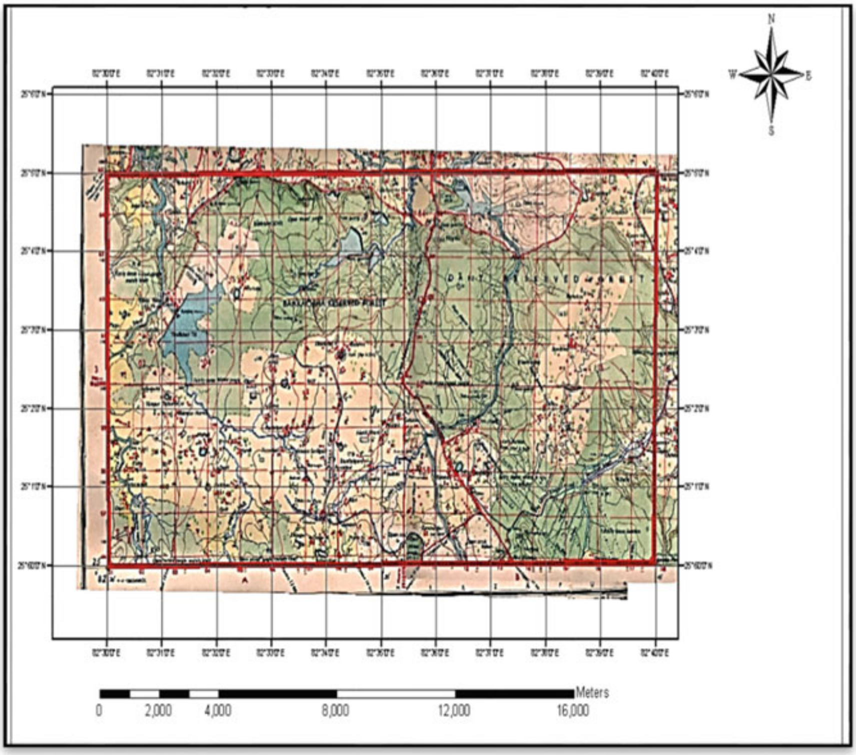

Fig. 1.2 SOI toposheet 63K/12

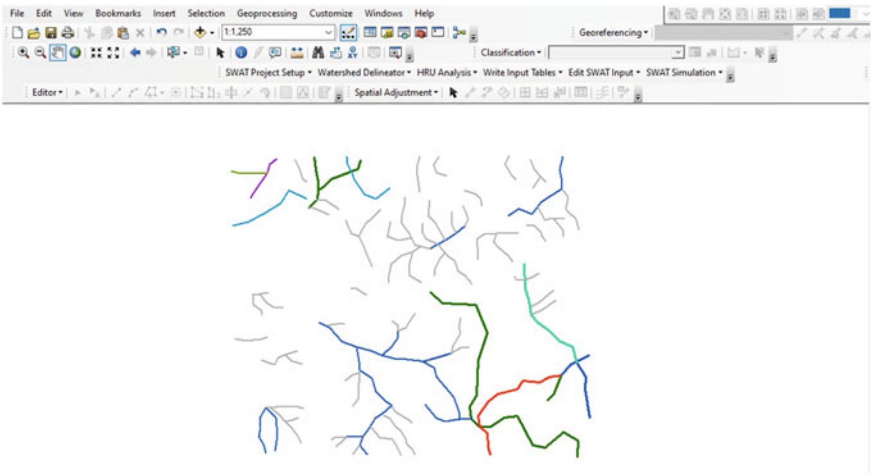

Fig. 1.3 Drainage pattern

(d) **Slope map**

The area has an undulating relief features with slopes varying from very gently sloping land of 1–3% to steeping 15–25% slopes. The slope map is developed from the digitized soil map provided by the Department of Agriculture, B.H.U.

(e) **Soil texture**

The layer file giving information about the various soil textures found in the area using the polygon features and snapping environment. There different types of soil classes in the map.

(f) **Soil depth**

The soil depth is an important attribute of a land area for ecological planning. Hence a soil depth map is created using the data provided in the soil map of the B.H.U south campus at Barkachha.

(g) **Soil erosion**

Soil erosion details are also mapped from the soil map of Barkachha campus area. It identifies the areas prone to slight, moderate and severe erosion.

1.3.2 Data Analysis Using Remote Sensing

IRS—P6 RESOURCESAT—LISS—IV image dated 27th September 2005 is used for the classification of the area. 3 band multi-spectral LISS IV camera with a spatial resolution better than 5.86 m and a swath of around 25 km across track steerability for selected area monitoring as shown in Fig. 1.4. The spectral bands includes (μ) 0.52–0.59, 0.62–0.68 and 0.77–0.86. The ERDAS 8.5 version software is used for satellite image analysis and terrain analysis is done by DEM (Digital Elevation Model) and Slope Map (ERDAS 2000).

Digital elevation model: Digital elevation models are typically used to represent terrain relief, slope, drainage pattern, etc. It is also referred to as digital terrain model (DTM). For the creation of Digital Elevation Model (DEM), the contour map of the area is prepared by digitizing the contours from the Survey of India toposheet. The data preparation is done by creating a surface in 3D surfacing features that creates three dimensional image files by rubber sheeting the feature shape file imported from ArcGIS. For this purpose, height differences need to be computed in both *X* and *Y* directions, as overall slope gradient is a function of height differences. A slope map can be created from DEM in degree or percentage (Arun 2013).

Slope map: Change in elevation over a distance expressed as slope. Distance is the size of the pixel in this case. Slope is most often expressed as a percentage, but can also be calculated in degrees.

Visual interpretation: Visual Interpretation makes use of following basic characteristics:

(i) Tone (colour)
(ii) Texture
(iii) Shape
(iv) Size
(v) Shadow
(vi) Pattern
(vii) Height
(viii) Association

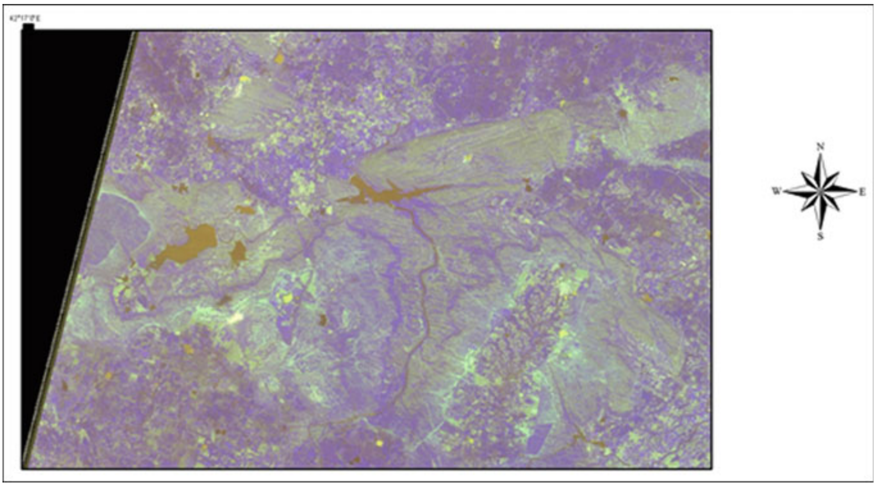

Fig. 1.4 IRS P6(LISS IV) image of study area

Table 1.2 Interpretation key for land cover mapping using remote sensing data

Classes	Tone	Texture	Shape	Association
Forest	Red	Medium-smooth	Irregular	High altitudes
Water body	Blue-black and light blue	Smooth	Linear Irregular polygon	Valley bottom and low altitudes
Barren areas	Brown-creamy white	Medium-smooth	Irregular	None
Shrub and grassland Vegetation	Shades of red	Smooth	Irregular patches	Rocky slopes and water bodies
Hard Rocky slopes	Black-brown	Medium-coarse	Irregular	High hills
Rocky slopes	Creamy white	Coarse	Irregular	High hills
Agriculture	Pink red	Smooth	Geometrical polygons	Habitation

Although the study area falls amidst the Danti and Barkachha reserve area as represented in the SOI toposheet, but the recent satellite image of the area shows rampant degradation and scanty vegetation in the study area. The only forest left is along the ridge line at higher elevations as summarized in Table 1.2. Most of the area is under scanty vegetation with patched of barren land.

Natural colour composite: The landuse map is prepared by digital image processing of Indian remote sensing satellite, IRS-P6, LISS IV data of 27th September 2005. ERDAS 8.5 classified the image into the following different landuse classes by 0.94 convergence factor and six iterations as forest and vegetation, degraded forest, agriculture, barren areas, water bodies in the signature editor (Schrader and Duniway 2011). Natural colour composite is produced by combining bands 3, 2 and 1 as red, green and blue, respectively, as shown in Fig. 1.5.

Landuse classification: ARCMAP classification of raster data is the process of sorting pixels into a finite number based on their data file values, individual classes, or categories of data. If a pixel satisfies a certain set of criteria, then the pixel is assigned to the class that corresponds to that criteria (Rozenstein and Karnieli 2011). There are two ways to classify pixels into different categories:

- Supervised
- Unsupervised.

In unsupervised classification any individual pixel is compared to every discrete cluster to see which one it is closest to. A map of all pixels in the image, classified as to which cluster every pixel is most likely to belong, is created. In supervised classification, spectral signatures are created from specified locations in the image. These specified locations are provided with the generic name 'training sites' and are defined by the user.

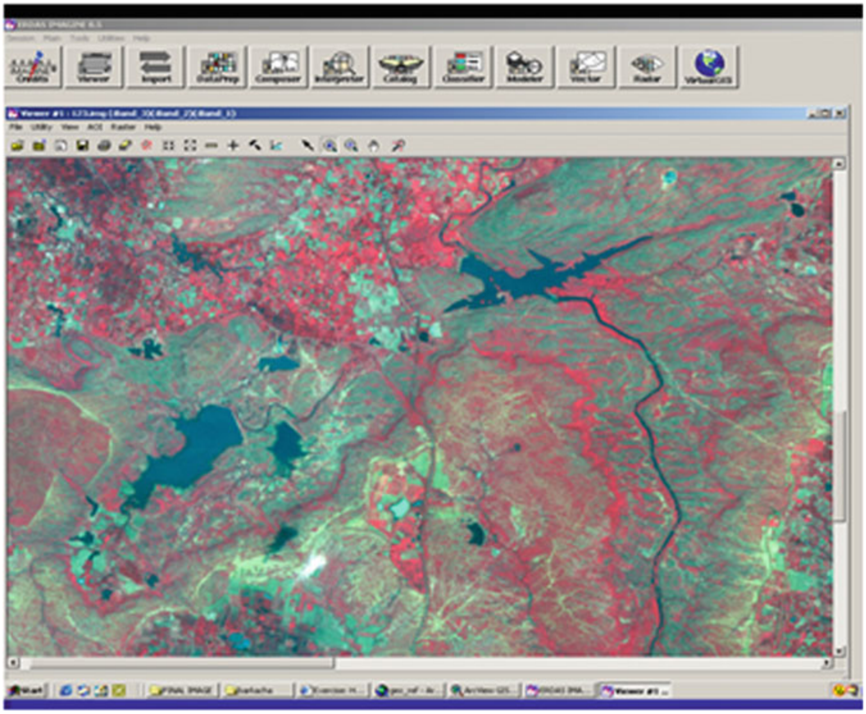

Fig. 1.5 ERDAS image of Khajuri watershed

Supervised classification, the interpreter knows beforehand what classes, are there and whether each is in one or more locations within the scene. These are located on the image and the areas containing examples of the class are circumscribed (making them training sites) along with this, the statistical analysis is performed on the multi-band data for each such class. The parameters choose to differentiate for separation will completely depend on analysis. An area within an image generally, multiple pixels in the same cluster correspond to visually correlating map patterns to their ground counterparts or an already known ground feature or class (Scott and Janikas 2010).

In the present study supervised classification is used. The supervised classification is summarized in Table 1.3 with 40% of the area under rocky terrain. The occurrence of wasteland in approximately 1000 ha of land. The forest cover is left in only about 14% of the area with patches of barren land. The midland with wasteland and grazing lands in the slope show signs of erosion.

Agricultural land: The agricultural area is observed or located by the shapes of fields which used to be regular, with red characteristic tone, and its association with few water bodies.

Table 1.3 Supervised classification of land use classes

S. No	Landuse class	No: of pixels	Apprx. area (ha)	Apprx. area (%)
1	Natural water body	6222	21	1
2	Barren areas	14,912	55	3
3	Forest	63,360	231	14
4	Vegetation	70,306	236	15
5	Rocky terrain	192,601	648	41
6	Wasteland	126,475	425	27

Forest: Forest is observed and located by its dense coverage because of the thick canopy, which may remain green throughout the year according to its type as summarized in Table 1.4. This type of land cover is identified by its tone varying from red to dark red. It mostly shows irregular shape and smooth texture (Thiruvengalacha and Sakthivadivel 1997). Based on the different characteristics the forest cover of the study area is categorized in different types which are:

a. Dense forest cover
b. Open forest cover
c. Degraded forest cover
d. Waste land.

a. **Dense forest**:

Dense forests are characterized by their crown cover which lies up to 40 per cent and over. In the study area, dense forests are located mostly in the eastern part of study area and are found to be confined between the higher and medium altitude areas.

b. **Open forest**:

Open forests are found to have the concentration of trees comparably less. In the study area, the open forest cover is found mainly in northwestern and western and along with this in medium and low altitude areas.

Table 1.4 Forest cover categorization

Land cover	Crown cover	Tone	Association	Texture	Shape
Dense forest	>=40%	Dark red	–	Smooth	Irregular
Open forest cover	(10–40)%	Dark red to Medium red	Dense forest cover	Medium	Irregular
Degraded forest cover	<=10%	Yellow	Other forest cover	–	–
Waste land	0	Brownish and creamy white to yellow	–	–	–

c. **Degraded forest**:

Degraded forests are characterized by limited crown cover of about 10 per cent. It is mainly composed of shrubs, bushes and smaller trees.

d. **Waste lands**:

Waste lands are those which possess zero or limited ability to support vegetation. The different types of waste lands are found in study area. The common feature was the increase in the occurrence of barren and rocky exposures often they are devoid of soil cover and vegetation. They are irregular in shape. They are found close to hill forests in the form of openings, sometimes as scattered like isolated exposures. In the study area they are found as patches of degraded forest land along the ridge line at lower elevations.

e. **Water body**:

It is composed of both natural and artificial water holding structures like.

- Rivers or streams
- Lakes
- Tanks
- Reservoirs.

The water features are found to have bluish-black in tone in the satellite imagery. The low water surfaced especially the newly built water harvesting ponds appear light blue and deep-water features and deep-water bodies are observed by their tone of dark blue. In the study area, many tanks were observed in the western region to support the KVK activities.

1.3.3 Analysis of Landuse in GIS

The various soil and landuse characteristics digitized in ARCMAP are used to analyze the current soil and landuse relationships and to identify the areas of concern.

Slope: Maximum slope encountered in the area is 15–25% with occurrence of rocky surfaces. The area has an undulating and rugged terrain with maximum area under flat land. Table 1.5 shows that more than 60% of the area has flatland or mild slope (upto 5%). Therefore if suitable soil depth is available, a large part of the landscape can harbour vegetation provided protection and conservation measures are taken.

Soil depth: About 40% of the area is under shallow to very shallow soils and are highly susceptible to erosion. Table 1.6 indicates availability of more than 400 ha of land of deep to very deep soils, thus supporting future prospects of agriculture and cultivation in the area.

Soil texture: The different classes of soil texture influences soil water infiltration, retention and drainage conditions of the area. Table 1.7 gives the soil distribution

Table 1.5 Slope distribution of present area

S. No	Slope (%)	Frequency of soil units	Area (ha)	Area%
1	1–3	83	537.27	53
2	3–5	28	70.5	14
3	5–10	7	227.15	22
4	10–15	3	62.77	6
5	15–25	2	32.82	3

Table 1.6 Soil depth profile

S.No	Soil depth	Frequency of soil units	Area (ha)	Area%
1	Very deep (>90 cm)	26	260.18	26
2	Deep (45–90 cm)	36	147.04	14
3	Moderately deep (22.5–45 cm)	36	201.76	20
4	Shallow to very shallow	24	396.88	39

Table 1.7 Distribution of soil texture

S.No	Soil texture	Frequency of soil units	Area (ha)	Area%
1	Clay loam to silty clay	12	65.95	6.50
2	Silty clay loam to clay	42	317.25	31.39
3	Loam	35	195.61	19.32
4	Loam to clay loam	10	29.97	2.95
5	Sandy loam with 70% rock exposure	24	396.88	39.27

pattern in the area with maximum area under loam soil conditions; therefore soil texture is not a limiting factor in the area. Sandy loam soil along the slopes covers about 396 ha with 70% rock exposure.

Soil erosion: The major part of the area is under erosion degradation. Table 1.8 indicates a strong threat of soil erosion with moderate to severe erosion affecting about 50% of the area. Therefore if serious conservation measures are not undertaken the erosion may become a serious limiting factor for vegetation development in the area. The added benefit of erosion control will be prolonged life of water harvesting structures. This problem is particularly severe in the steep areas with rocky terrain and scant vegetation cover, thus needing special attention (Grigg 1996).

Land use and land capability (LULC): The current land use capability for cultivation is for more than 450 ha as indicated by Table 1.9. This accounts for more than 45% of the land area. Hence the land is suitable for productive use if proper conservation measures are taken for sustainable use of the land. (Klingebiel and Montgomery 1961).

Table 1.8 Soil erosion pattern

S. No	Soil erosion	Frequency of soil units	Area (ha)	Area%
1	Slight	64	413.17	40.84
2	Moderate	36	195.61	19.32
3	Moderate-severe	24	396.88	39.27

Table 1.9 Land capability classification

LU/LC Class	Limitations	Possible land use	Frequency of soil units	Area (ha)	Area%
II	Moderate limitations of the cropland	Intense cultivation of the field crops	9	388.37	38.34
III	Severe limitation of the cropland	Moderate cultivation of the field crops	9	28.29	2.81
IV	Very severe limitations of the cropland	Limited cultivation of the field crops	1	51.13	5.06
V	Slight to moderate limitations of the grassland	Intense grazing found	14	19.35	1.90
VI	Severe limitations of the grassland	Moderate grazing found		78.93	7.81
VII	Very severe limitations of the grasslands	Limited grazing found	24	42.79	4.24
VIII	Non-agricultural land	Wildlife and Forest	7	396.88	39.27

(Land capability classification, 1961 USDA Agricultural Handbook).

1.4 Conclusion

The present study is an effort to assess and analyze the available water resources, prevailing current demand and future projection and along with these technological options for water resource management to improve water availability and management of the efficiency of crop yield of a watershed. For optimum utilization of water resources and getting maximum benefit, extensive study has been done. The following conclusions may be summarized from this project work:

(i) The various sources of water are identified and quantified. The Khajuri stream is located in this area and our focus area is Khajuri Watershed and its five sub-watersheds.
(ii) Remote sensing and GIS have been found useful tools in identification and categorization of watersheds on the basis of natural resources and their limitations.

Thematic information can be derived from spatial analysis of remote sensing helpful in the assessment of developmental plans before implemented in the field. An approach for an effective tool for selection of the best management plan to be implemented.

(iii) Remote sensing data compute runoff estimation to provide a quick result for decision-makers, before any experimentation of quantification is taken up. This gives more reliable results and also less time-consuming method. This method can be used effectively in the design of stormwater drains and small water control projects. In this study, GIS has been used as a useful tool to give real authentic topology information.

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