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Identification of erosional and inundation hazard zones in Ken–Betwa river linking area, India, using remote sensing and GIS

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Abstract Ken–Betwa river link is one of the pilot projects of the Inter Linking of Rivers program of Government of India in Bundelkhand Region. It will connect the Ken and Betwa rivers through a system of dams, reservoirs, and canals to provide storage for excess rainfall during the monsoon season and avoid floods. The main objective of this study is to identify erosional and inundation prone zones of Ken–Betwa river linking site in India using remote sensing and geographic information system tools. In this study, Landsat Thematic Mapper data of year 2005, digital elevation model from the Shuttle Radar Topographic Mission, and other ancillary data were analyzed to create various thematic maps viz. geomorphology, land use/land cover, NDVI, geology, soil, drainage density, elevation, slope, and rainfall. The integrated thematic maps were used for hazard zonation. This is based on categorizing the different hydrological and geomorphological processes influencing the inundation and erosion intensity. Result shows that the southern part of the study area which lies in Panna district of Madhya Pradesh, India, is more vulnerable than the other areas.

Keywords Ken–Betwa river link project (KBLP) · SRTM · NDVI · Erosion · Inundation

Introduction

Water crisis is the reality of the day. But the crisis is not actually about lack of water to satisfy our needs. It is rather a lack of competent management of the available water resources that has given birth to this crisis, which is affecting billions of people and deteriorating the environment (World Water Council 2000).

Water is the elixir of life and is essential for sustainable development of human civilization. The present scenario poses new challenges for water resource planners and managers to keep pace with the increasing demand from population, irrigation, and industrialization. Effective and efficient use of water resources are one of the most effective ways to deal with water crises problem in India. This is possible through development of new water resource projects like Inter Linking

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of Rivers (ILR) to deal with increasing demand of irrigation and inadequate surface water supplies (NWDA 2005; Khare et al. 2007).

The main factor acting against the sustainability of agricultural production is land degradation. Among the different land degradation processes, soil erosion is the biggest threat to the conservation of soil and water resources. It is a serious environmental problem as it removes nutrient-rich soil and increase sediment in the rivers and reservoirs and reducing their storage capacity and life span (Pandey et al. 2007). It can result to direct economic loss as fertility of the land decreases due to removal of fertile topsoil. Soil erosion has accelerated in most parts of the world in recent decades due to population pressure and limited resources, which have also led to the increased and more continuous use of steeper lands for agriculture (Millward and Mersey 1999; Singh and Phadke 2007). Increasing population, deforestation, land cultivation, uncontrolled grazing, and higher demands for fire wood often cause soil erosion (Reusing et al. 2000).

The basic objective of the Inter Linking of River project in India is to transfer water from "excess" to "deficit" basins, keeping in view the needs of the concerned states ensuring equity, efficiency of water use, and cost effectiveness. The primary aim to mitigate problems of floods and droughts in different regions of the country. Moreover, it is also correlated with positive implications on national water security, energy, transport, agriculture, and human health sectors (NWDA 2007; Gurjar 2003). ILR project will cause heavy construction work for creation of storage dams and link canals to transfer water from excess to deficit basins. This will lead to the development of new or augmentation of existing irrigation canals, water supply, and sanitation schemes. Under the proposed ILR project, 14 probable links of the Himalayan rivers and 16 probable links of the peninsular rivers were proposed (NWDA 2007; Mishra et al. 2007).

Ken–Betwa link project (KBLP) is one of the first links among 30 river links proposed by the government of India's National Water Development Agency (NWDA), involving Madhya Pradesh (MP) and Uttar Pradesh (UP) in the Bundelkhand region. Till now no links have been built, the KBLP is being pursued as the pilot project of the national program to serve as a "litmus test" for the national ILR plan (Krueger 2007). Critics suggest that the KBLP has been chosen as the first because of remote location and backward area, which minimizes opportunity for controversy. Other reason is minimum construction activity because of closeness of Ken and Betwa rivers. The outcome of KBLP will be useful for further nationwide river linking projects. KBLP is a diversion cum storage scheme envisaging the transfer of 1,020 million cubic meters surplus water from Ken River basin to water deficit Betwa basin (NWDA 2007). This linking project will cause heavy construction work which will affect stability of slope, deforestation, and other ecological imbalance between different ecosystems of Panna tiger reserve forest.

The objective of this study is to identify the erosional and inundation hazard zones in the Ken–Betwa river linking area. Therefore, during the project development, project planners will take suitable decisions regarding site suitability to mitigate the hazard and to minimize the environmental impacts of river linking projects.

Study area

Most part of the study area lies in Bundelkhand which is divided between the states of Uttar Pradesh (UP) and Madhya Pradesh (MP). The command area of this link lies between latitude 24°40′ E, 78°60′ N to 25°65′ E and longitude 78°40′ N, 25°30′ E to 80°00′ N (Fig. 1). It covers approximately 61,750 km^2 of area. The climate of the area is semi-arid with a mean maximum temperature of 44.2°C in June, and a minimum temperature of 6.7°C in January. The climate of the area is highly variable depending on the region and the time of year. The average annual rainfall varies from 750 to 1,250 mm. Of the total rainfall per year, 90% is received during the monsoon season July to September. The dry plains in the north usually receive less rainfall while the southeast benefits from more. The maximum and minimum values of humidity are 95% and 9% during monsoon and summer season, respectively.

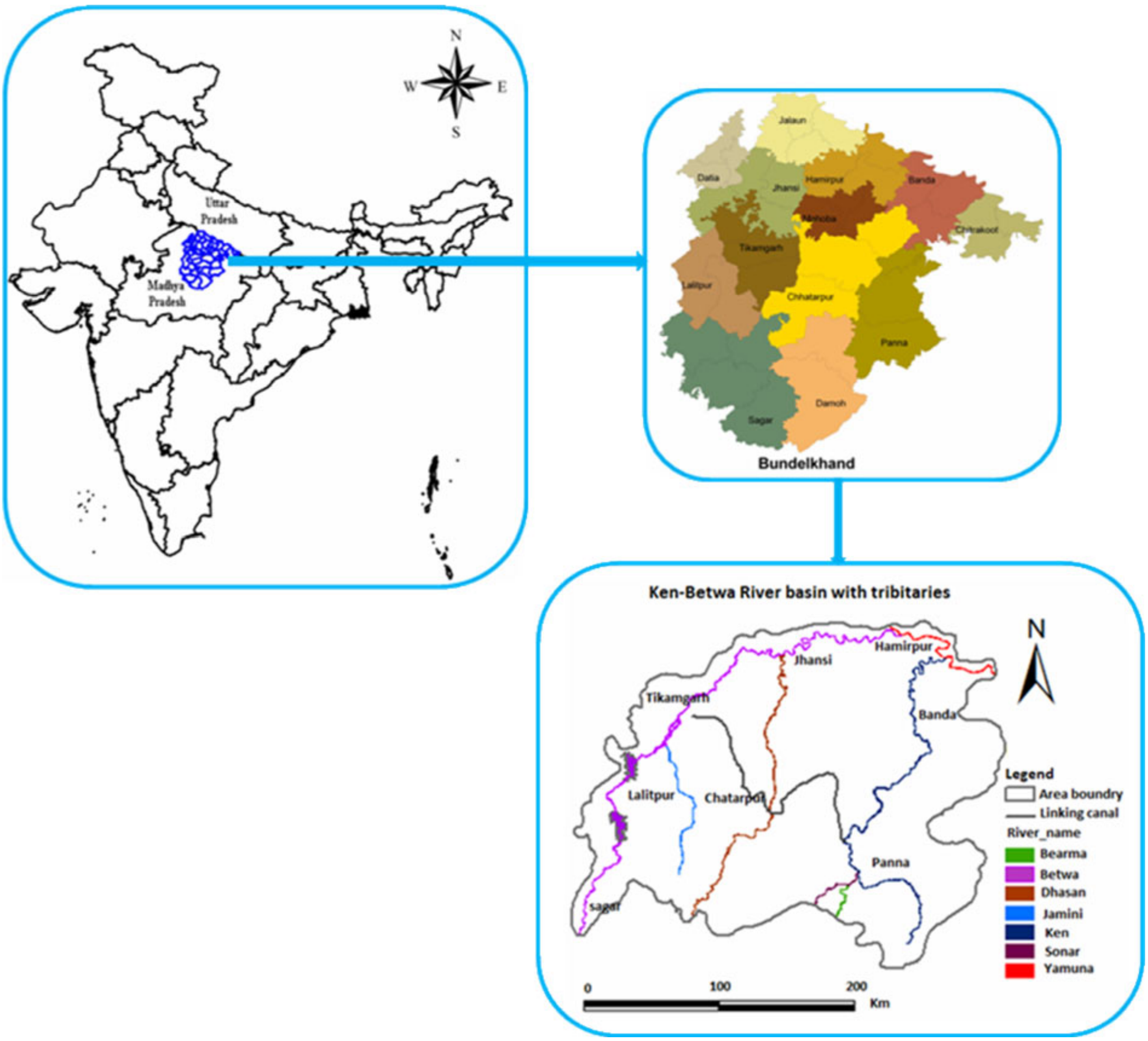

Fig. 1 Map showing study area Bundelkhand, India

Ken–Betwa basin

The Ken River originates from the northwest slopes of the Kaimur hills in the Jabalpur district of Madhya Pradesh. Ken River is about 427 km long from its origin to confluence near Yamuna River. It joins with the Yamuna River near Chilla village in Uttar Pradesh. The river basin lies between latitudes of 23°12′ N to 25°54′ N and the longitudes of 78°30′ E to 80°36′ E. The total catchment area of the basin is about 28,058 km^2 (NWDA 2007). The Betwa River originates from the Raisen district of Madhya Pradesh at an elevation of about 576 m above mean sea level and flows in a northeasterly direction. Betwa River is about 590 km long from its origin to confluence with the Yamuna. It joins with the Yamuna near Hamirpur in Uttar Pradesh. The river basin lies between the latitudes of 22°54′ N to 25°00′ N and the longitudes of 77°10′ E to 80°20′ E. The total catchment area of the basin is about 43,895 km^2 (Fig. 2) (NWDA 2007).

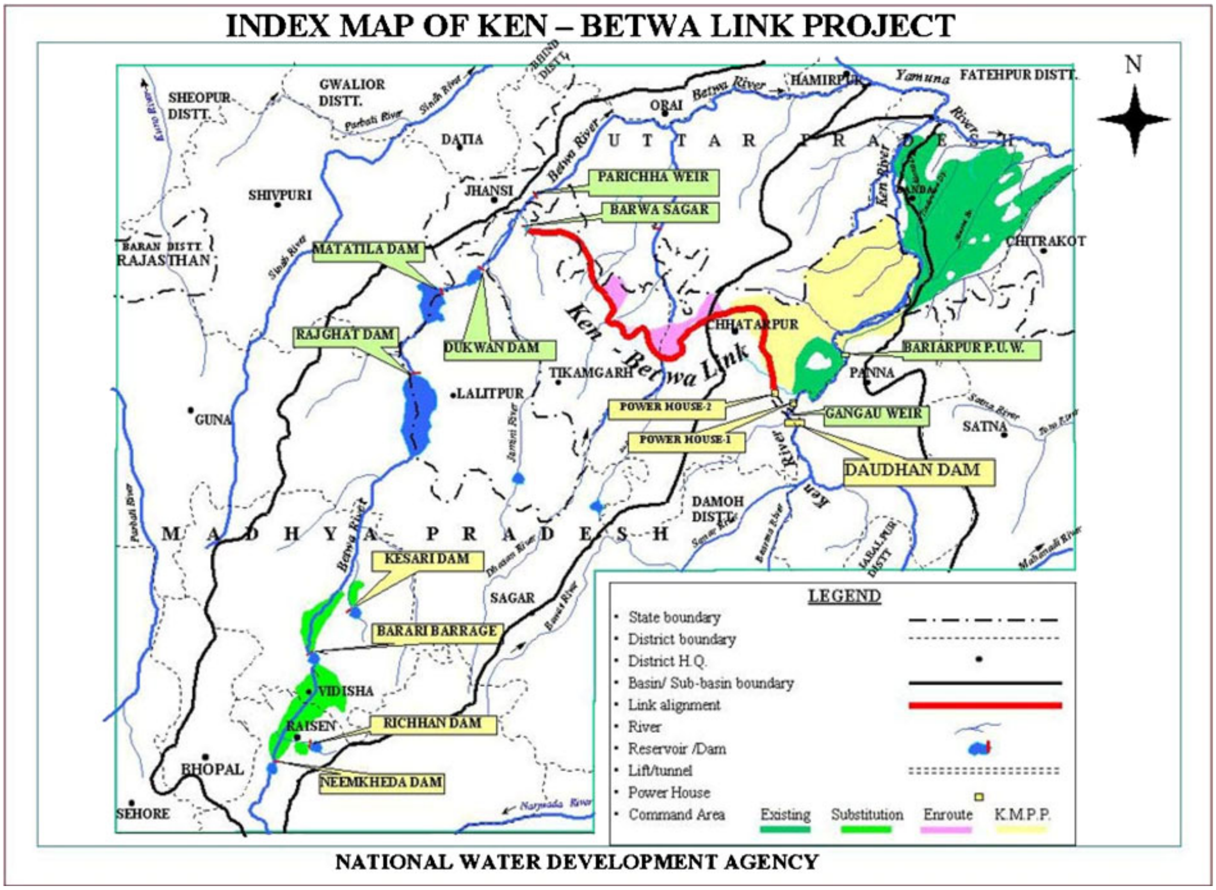

Fig. 2 Map of the Ken–Betwa link project (source: national water development authority, feasibility report), showing the proposed plan for construction of the dams, reservoirs, hydroelectricity projects, and link canal

Geological study of the area

Geologically, the area is covered by three major groups of rocks with high uncertain ages (1) Bundelkhand complex (older than 2.6 billion years) (2) Bijawar group (2.6–2.4 billion years), and (3) Vindhayan super group (1.4–0.9 billion years) as shown in Fig. 3. About half of the area is predominantly made up of Bundelkhand Granite complex belonging to Bundelkhand Group. Sometimes pegmatites and quartz reefs are present in Bundelkhand granites, which provide hardness to the rocks (Ahmad 1984). Above Bundelkhand gneissic complex newer alluvium, older alluvium, gravel, sand, and clay of recent origin are present, which in some places are termed as buried pediment plains (Mukherjee 1991). Bijawar consists of limestone, dolomite, quartzite, shale, sandstone, banded hematite quartzite, basic dikes, and lavas belonging to Bijawar group are exposed in a narrow zone in the south of the granitoid complex. Bijawar group lies in Chattarpur district of Madhya Pradesh. Vindhayan super group have been divided into four major groups namely the Semri (lower), Kaimur, Rewa, and Bhander (upper) based on lithological similarities and into Lower and Upper Vindhayans on the basis of major tectonic (major unconformity) evidences. (a) Bhander group is formed by alternating sequence of sandstone, shale, and limestone. (b) Rewa group is formed by alternating sequence of sandstone and shale. (c) Kaimur group is formed by arnaceous rocks with prominent carbonaceous shale/intrusive kimberlites. (d) Semri group is formed by thick limestone and sandstone (Mathur 1982).

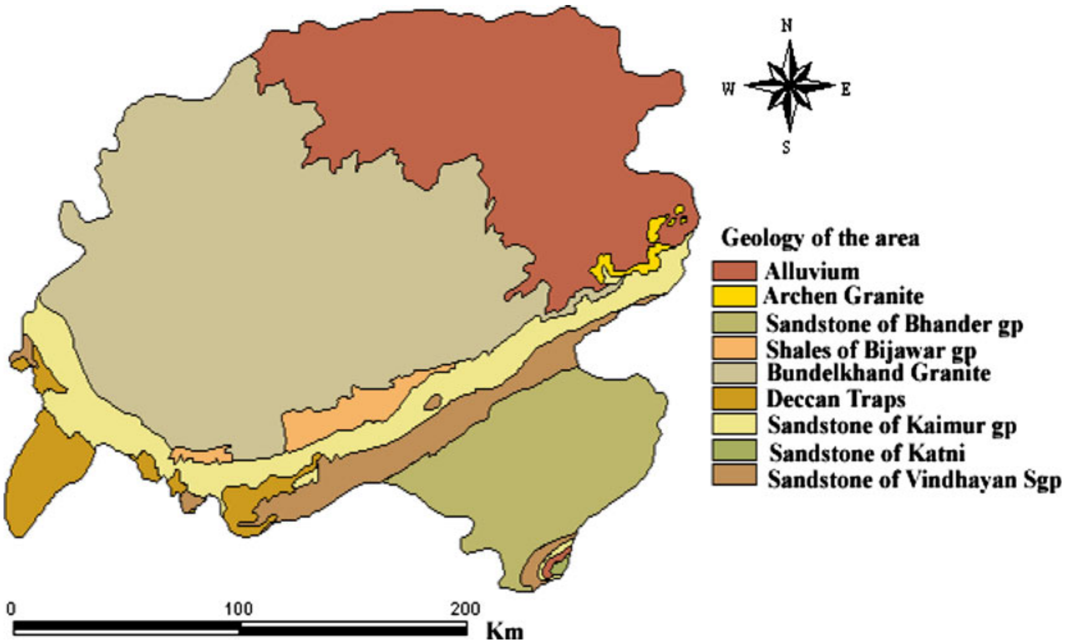

Fig. 3 Represents geological map of the area (Avtar et al. 2010)

Methodology

The methodology used in this study has fallowing steps:

1. In the first step, all the data have been converted to digital format and geo-referenced into Universal Transverse Mercator, spheroid and datum WGS-1984. After geo-referencing the maps are digitized using ArcGIS 9.1. Digitization is one of the prime and vital step for geographic information system (GIS)-based analysis. Remote sensing data are already in digital format so they are used directly for thematic map generation.
2. The second step involves generation of thematic layers of information from different sources. It involves digital image processing of remote sensing data and further processing of existing maps and field data for extraction of pertinent information.

   a. Digital image processing: an image contains different types of information about objects. Digital image processing provides information from raw data, which can be integrated in GIS for proper understanding of surface processes. Pre- processing of Landsat data includes three major steps for further analysis: geometric correction, radiometric correction, and noise removal.
   b. Geometric correction: raw satellite data contain geometric distortion due to instability of satellite platforms, altitude, and earth rotation. Geometric correction involves transformation of satellite data according to the referenced topographic map so that the image and map has the same scale and projection properties. Nearest neighborhood re-sampling techniques are used in ERDAS imagine8.5 to correct satellite imagery for geometric distortions. After the geometric correction mosaicking of the six scenes of Landsat data (Path/row: 145/42, 145/43, 145/44, 144/42, 144/43, 144/44) was done (Mukherjee et al. 2007; Lillesand and Keifer 2006).
   c. Radiometric correction: image normalization is used to reduce pixel brightness value variation caused by non-surface factors, such as sun angle, earth–sun distance,

atmospheric conditions, and sun target sensor geometry. The radiance measured by Landsat satellite over an object is influenced by some factors like scene illumination, atmospheric conditions, viewing geometry, and instrument response characteristics (Lillesand and Keifer 2006). The radiometric corrections were applied to the Landsat image.

d. Noise removal: image noise is the undesirable disturbance in the image data due to limitation in sensing, signal digitization, or data recording processes. Noise corrections are carried out using de-striping and line dropout (Lillesand and Keifer 2006).
e. Various image enhancement techniques have been applied to Landsat data to extract information on geology, geomorphology, land use, structural features, and vegetation cover (Jenson and Domingue 1988). Contrast stretching of individual bands is used to improve interpretability of different features. This is further enhanced by generating false color composite from bands 4, 3, and 2 coded in red, green, and blue color scheme which highlights the geomorphic features, land use, and vegetation cover. The normalized difference vegetation index (NDVI) image has been generated by band ratioing, which helps in visualizing the vegetation distribution in the area. It can be computed as the ratio of (NIR band − Red band)/(NIR band + Red band). In the present work, Landsat data were used; hence, NDVI was computed as function of bands 3 and 4 and defined as (band 4 − band 3)/(band 4 + band 3). The NDVI value varies from −1 to +1. The higher values indicate vegetated areas, because of high infrared reflectance (band 4) as compared to visible reflectance (band 3) (Jensen 2000). NDVI map was classified into the four classes as (a) barren (< -0.2), (b) low vegetation (−0.2 to −0.8), (c) medium vegetation (−0.8 to +0.4), and dense vegetation (+0.4 to +1.0).
f. Digital elevation model (DEM) is important for hydrological modeling. DEM is digital representation of topography (Heywood et al. 2000). Shuttle Radar Topographic Mission (SRTM) DEM data is used for generation of elevation and slope map. Slope is defined as change in elevation.

3. The third step involves generation of the GIS database. A base map has been generated from survey of India (SOI) topographic maps at 1:50,000 scale. The drainage map of the area was generated from the topographic maps. Drainage density is important parameter for hydrological study therefore drainage density map was generated using Horton's formula which is defined as,

$$D_{\mathrm{d}} = L/A$$

Where D_d is drainage density, L is total length of streams, and A is total area (Hortan 1945). Soil map was generated from digitization of existing soil map of National Bureau of soil survey and Land Use Planning (NBSS&LUP, Nagpur).

4. Erosion can be used as predictive tool for assessing soil loss for conservation planning and project planning. Universal soil loss equation is mostly used for erosion study (Ozhan et al. 2005; Morgan and Davidson 1991). This model has some limitations like it cannot simulate deposition, channel or gully erosion, and not good for hillside erosion. Some other models like ANSWERS, CREAMS, and MODANSW are basically conceptual and event based (Fistikoglu and Harmancioglu 2002). Therefore, in the present study, we used GIS-based model for erosional and inundation hazard zonation. According to De Roo (1996) GIS-based erosional model is more powerful because it has a spatially distributed character. The study of the factors that influence erosion and inundation is necessary. Therefore, field investigation and previous studies are useful for the determination of factors causing erosion and inundation. Geomorphology, drainage density, rainfall, soil, vegetation, elevation, slope, and land use/land cover were considered important factors for erosion and inundation study.

5. The fourth step consists of integration of multi-disciplinary datasets into a composite information set. Thematic maps for various factors controlling inundation and erosion in the KBLP command area were prepared for the study area. These factors include geomorphology, land use/land cover, normalized difference vegetation index, elevation, slope, drainage density, rainfall, and soil texture. These factors are more important for erosion and inundation hazard zonation study. These thematic data contain spatial information derived from satellite data along with existing map and field data. Each thematic map was assigned a weight and rankings depending on its influence on erosion and inundation hazard. Considering their behavior with respect to erosion and inundation, the different classes were given suitable values according to their importance to other classes in the same thematic layer. The weighting and rating system is based on the relative importance of a variety of causative factors derived from field knowledge and previous studies (Jasrotia et al. 2002; Jasrotia and Singh 2006; Pandey et al. 2007). Various thematic layers are arranged in hierarchical order of importance.

In this study, we used multiple criteria decision-making techniques. GIS is an ideal tool to analyze and solve multiple criteria problems (Belton and Stewart 2002). Relative score of each thematic unit in a theme were calculated by multiplying the weight of the theme with the rank of the respective thematic unit. The weight and rank of each layer is given in the Tables 2 and 3. The ideal tool for multi-criteria decision making is the spatial analyst of ArcGIS9.1. Weighted overlay tool of spatial analysis is a technique for applying a common scale of values to diverse and dissimilar

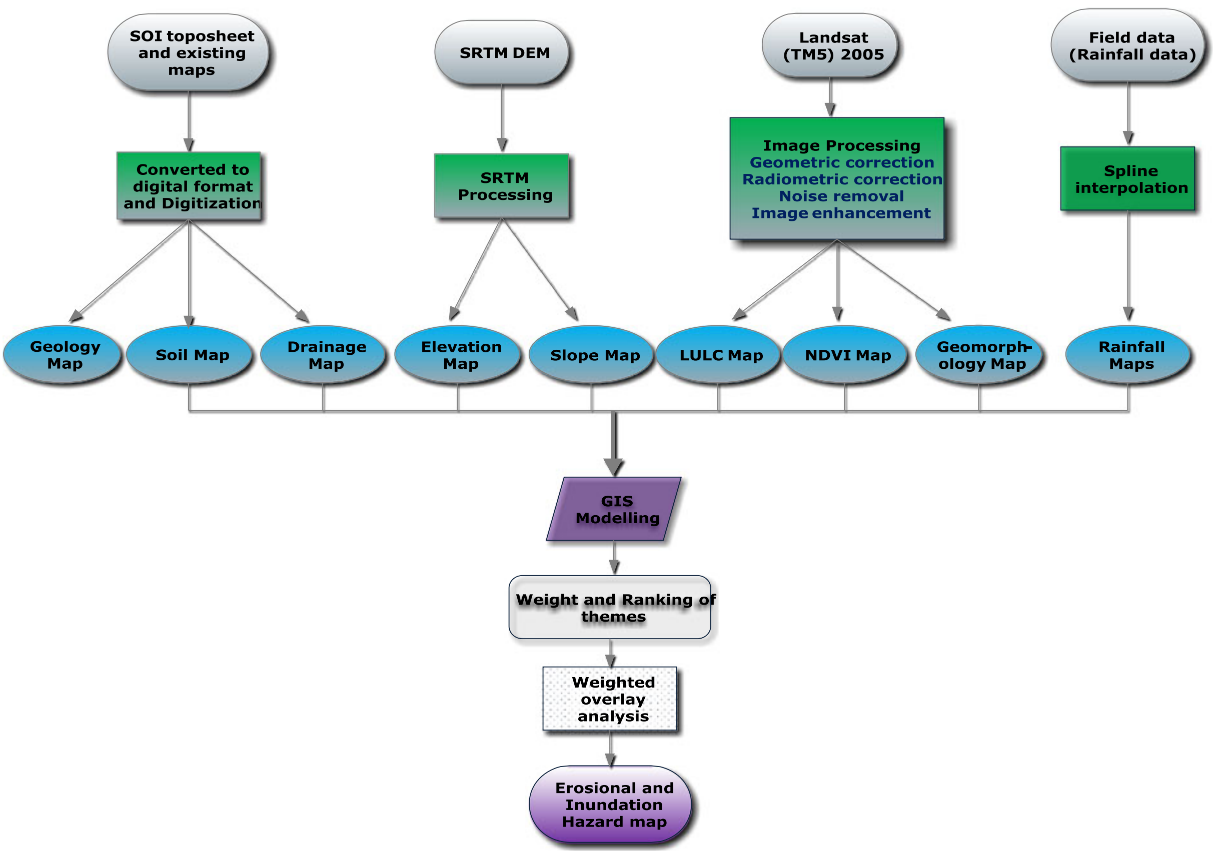

Fig. 4 Methodology flow chart

input to create an integrated analysis (ESRI 2006). It is based on the fact that each theme is not equally important for erosional and inundation study therefore the priority of theme depends on their importance by assigning the weight to theme. In this study, numeric evaluation scale 1 to 5 was selected for ranking the subclasses of themes. The higher value 5 represents higher impact and 1 lowest impact. This ranking system is made to perform arithmetic operations on raster data. The methodology adopted in this study is shown as a flow chart (Fig. 4). The following equation was used for erosional and inundation mapping using multi-criteria decision-making technique.

$$\text{EHPZ or IHPZ} = \sum [(Wt_1)*(Rt_1)+(Wt_2)*(Rt_2)+(Wt_3)*(Rt_3) + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (Wt_8) \times (Rt_8)]$$

Where EHPZ is erosional hazard potential zonation and IHPZ is inundation hazard potential zonation, W is weight of the theme, R is rank of the theme, and t_1, t_2, $t_3 \ldots\ldots t_8$ is theme number. The weight value of the particular theme was multiplied by rank, then added together to get the final output map.

Result and discussion

Generation of thematic layers

Geomorphological structures

Visual interpretation of enhanced satellite images is useful for identification of the geomorphological features. Various geomorphological features produce different signatures in different spectral bands. Figure 5 shows the geomorphological map of the area.

- Erosional/denudational hills: This represents the remnants of oldest planation surface marked by domes and ridges of Bundelkhand granites. Erosional hills were identified on the satellite data by location, low reflectance, and irregular topography. The low reflectance is characteristic of hard rocks and the reason why they look dark. These occupy the south-

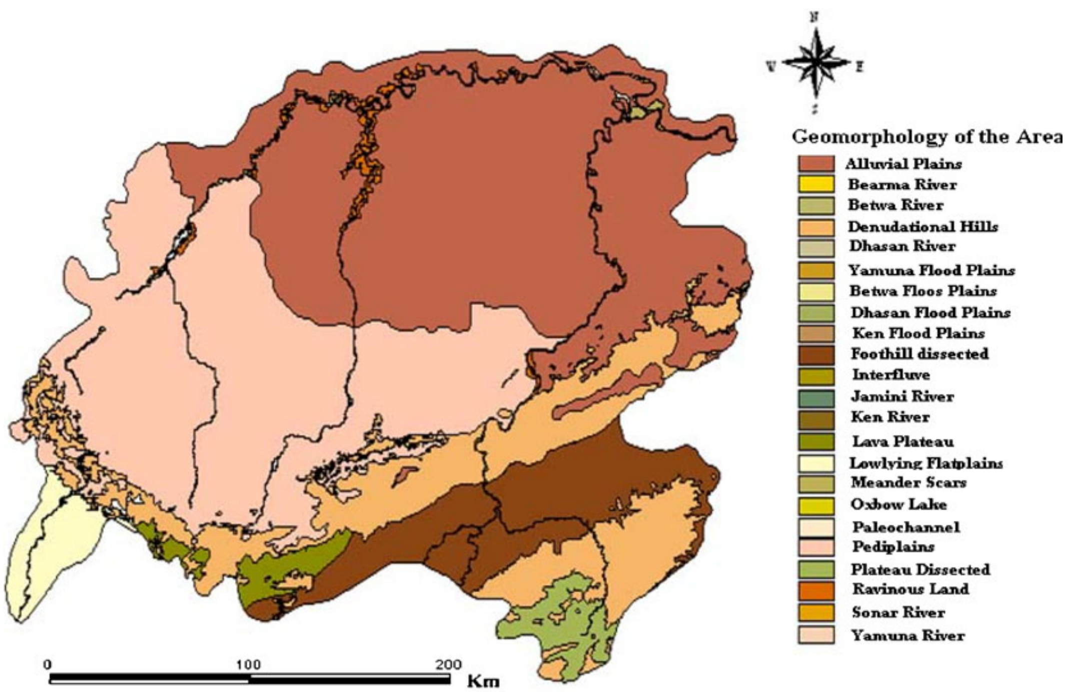

Fig. 5 Geomorphological map of the study area

western alignment of the area. Denudational hills were given higher rank for erosional hazard because they are more susceptible to erosion due to high weathering rate.

- River channel: The area is covered by Ken, Betwa, and Yamuna rivers along with a number of tributaries. This river system transports a heavy amount of silt, clay, and sand. Meandering of rivers is very prominent. Meandering of river causes formation of various geomorphological structures.
- Flood plain deposits: These areas are present along the stream or rivers and covered by sand, clay, and silt, directly deposited at the time of floods. These are comparatively low-lying area, close to the river or stream (Bhatt et al. 2008). Flood plain areas are very good for agricultural and groundwater point of view. These areas are more prone to inundation because of the vicinity with river; therefore, it was given a higher rank as compared to other geomorphological features.
- Alluvial plains: These are relatively flat landform created by the deposition of soil or sediment over a long period of time by river. Alluvial plains are more productive land and erosion of these areas causes land degradation. Most of the northern part of the study area is covered by alluvial plains.
- Ravines: It is highly rugged and ravenous topography. In aerial photographs, they are recognized by their light tone, gullied landform, running parallel to river courses and sharp pinnate river drainage, and fine gradient texture of soil materials (Sharma 1979). Groundwater possibilities in these areas become vey less because of high run off and its impermeable nature, therefore these areas are more prone to gully erosion.
- Pediments: A pediment is a gently inclined erosional surface carved in bedrock and developed at the base of mountain. Pediments are most prevalent in very arid environments. Pediments are identified by their lighter tone with sharp outline. These are indicator of the erosion prone area (Raghavendra Reddy et al. 2003). Buried pediment can be discriminated from pediments by their relatively darker tone.
- Meander scar and oxbow lake: Meanders exhibit symmetrical to asymmetrical, narrow to wide, and simple to compound loops along the rivers. The meandering pattern of rivers has been greatly influenced by the structure of the basement rocks and major tectonic trends. The clay and silt filling within the sloughs of meander scar areas supports vegetation. Channel migration has sometimes resulted in the formation of abandoned channels (Hooke 2007). The abandoned channels which are partly or entirely cut-off from the main channels is called as oxbow lake.

Soil map of the study area

The soil of the area is divided into clayed loam, sandy loam, loamy, and loamy sand on the basis of soil texture. Most of the part of study area is covered by loamy soil. Loamy sand soil is present in most of the Betwa basin, while Ken basin is covered by loamy sand in upper part and sandy clay in lower part. Linking canal is covered by loamy soil (Fig. 6). Soil erodibility is a function of several soil properties such as the particle size distribution, organic matter, moisture, top soil shear strength, infiltration capacity, etc. (Lal 1994). Soil particle size plays important role in erodibility, like clay particles that cannot be detached easily but can be easily transported, while sand particles are opposite. Loamy sand soil is more predominant in the northwestern region of the study area with poor moisture retention causing extensive erosion. On the other hand, clay loam and loamy soils, which are present mostly in the south region have higher water retention capacity and therefore are less prone to erosion. Clayed loam soil has given higher rank for inundation because of high storage capacity of soil and loamy sand has given higher rank for erosion because of low storage capacity.

Elevation map

The general topography of the catchments was studied through the digital elevation model generated from SRTM data. Elevation was considered as one of the important variables for the assessing runoff. During the monsoon season, the

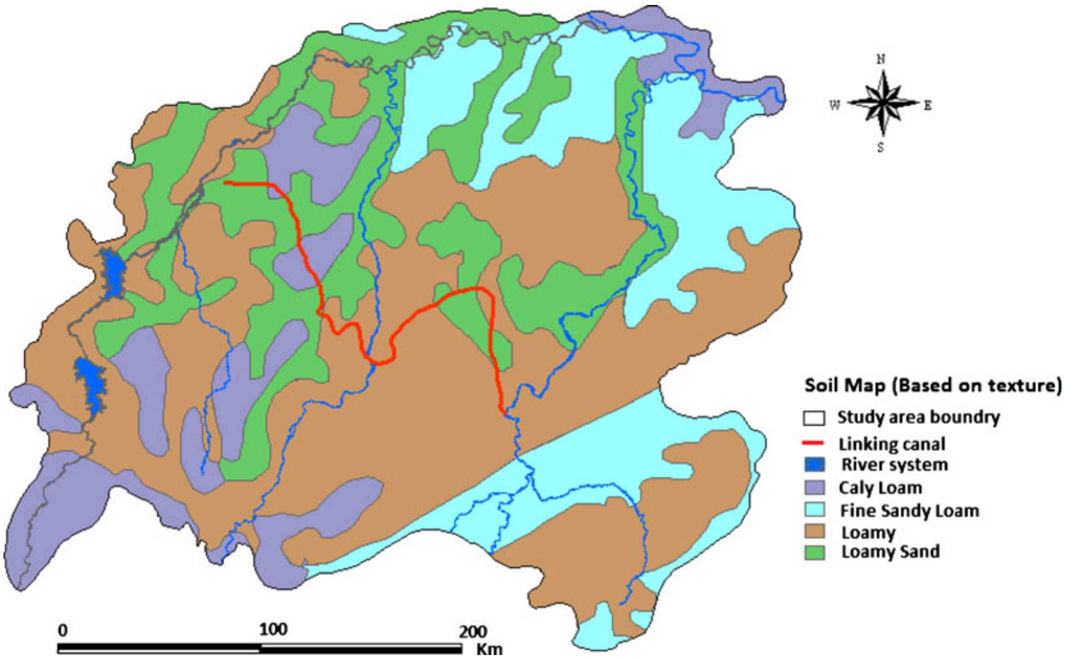

Fig. 6 Soil map of the study area

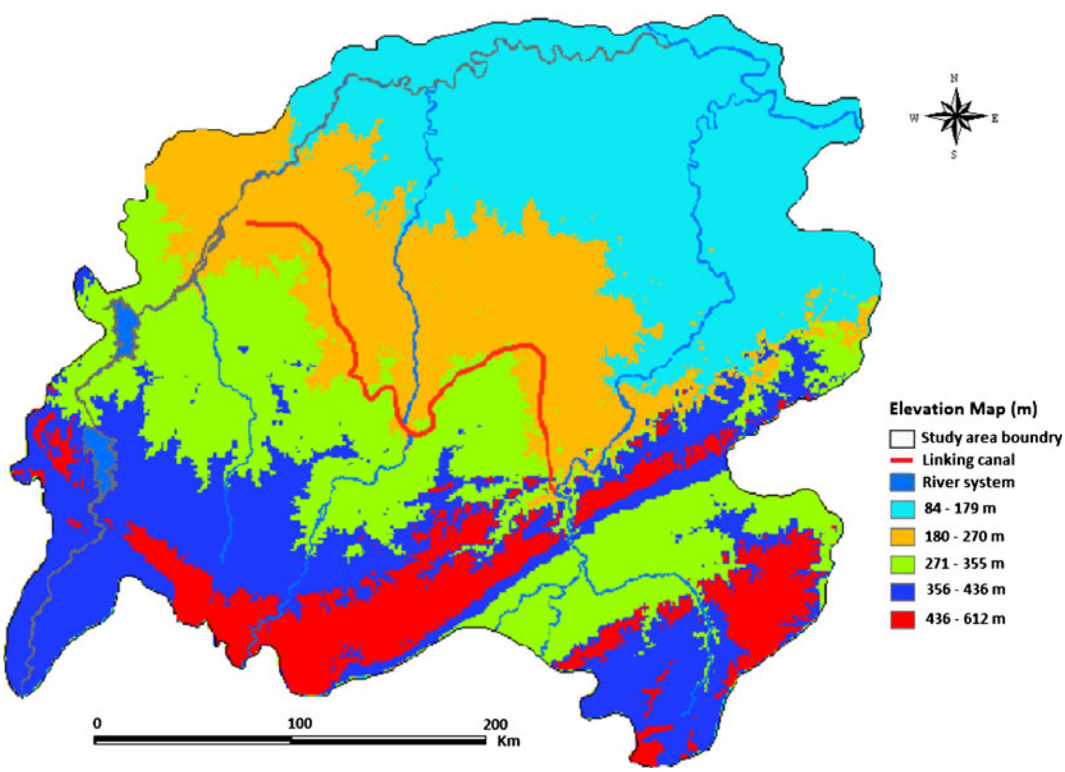

Fig. 7 Elevation map of the study area (SRTM classified)

area with high elevation having steep slope causes more discharge in lowland areas (Reddy 2007). The value of elevation varies from 84–612 m in the study area. The elevation value of the study area, where construction of Greater Gangau weir is going on, is equal to 261 m and where the link will finish, near Barua Sagar, is equal to 218 m. So this shows the alignment of link canal is appropriate (Fig. 7). Low elevated areas are the places to be inundated first during flood, therefore, were given higher rank. Higher elevation and steep slope cause quicker depletion of storage, which results as larger peak discharge in the downstream reaches, especially close to the proposed dam; therefore, high elevated area was given higher rank for erosional hazard.

Slope map

Regional topography and slope data gives important information about the nature of geologic and geodynamic processes occurring in the area (James 1999). Most parts of the study area has slope ranging from 39° to 57°. Southern part of the area (hilly region) exhibits steeper slope, whereas the northern parts (alluvial region) are associated with lower slopes (Fig. 8). The intensity of erosion in the sloping areas was higher due to small streams, gullies, and denudational processes. High elevation area in the basin causes high runoff (Collins 1998). The steeper the slope, the higher the slope gradient. Slope steepness plays an important role in soil erosion activity. By increasing slope steepness, the velocity of runoff increases which in turn increases the flow that causes more erosion; therefore, area with higher slope was given higher rank for erosional hazard. Steep slope with short slope length causes less erosion as compared to gentle slope with long slope length (Wischmeier and Smith 1978). During monsoon, the elevated area having steep slope causes quicker depletion that results in peak discharges in the lowland areas that causes less inundation; therefore, was given lower rank for inundation zonation (Pandey et al. 2010). The general slope of the Ken–Betwa link command

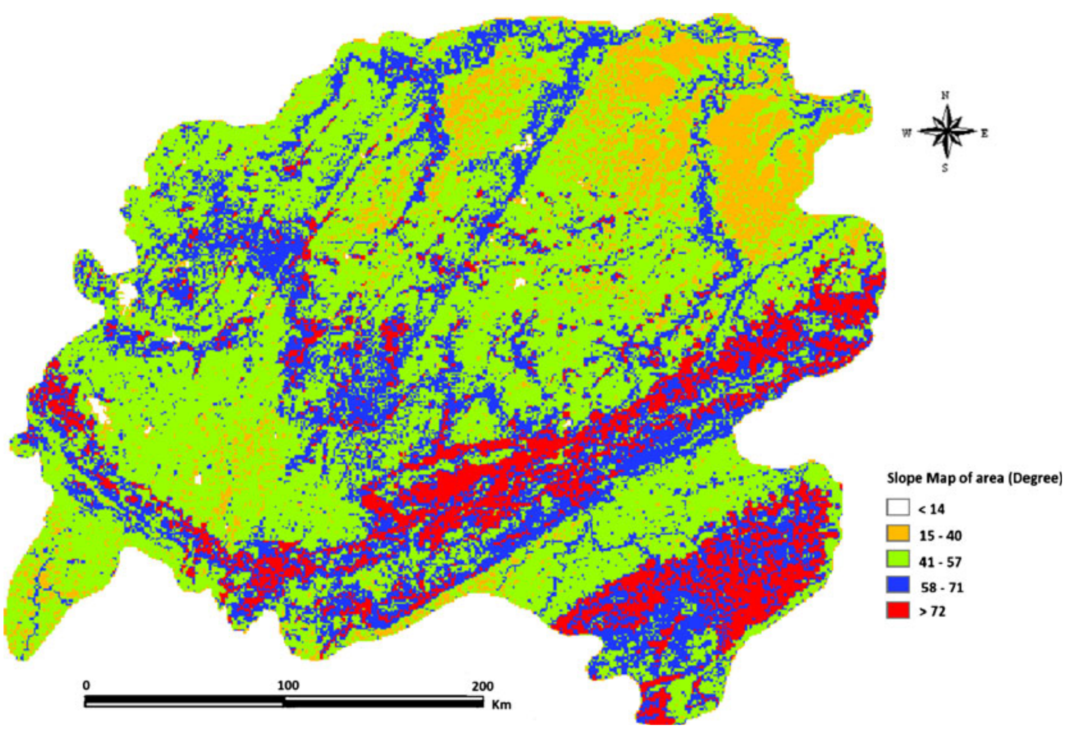

Fig. 8 Slope map of the study area

near the proposed dam site is, in the southeast direction parallel to the flow direction of river. The Ken River flows at a slightly higher topographic level as compared to Betwa River.

Drainage map

Evaluation of the characteristics of the drainage pattern of a river basin using quantitative morphometric analysis provides information about the hydrological nature of the rocks exposed within the drainage area (Pakhmode et al. 2003). A drainage map of a river basin provides a reliable index of the permeability of the rocks and also gives information about basin yield (Wisler and Brater 1959). Drainage map of the study area represents the network of main streams in the catchments, followed by the tributaries up to the last order. The drainage map shows the major rivers Yamuna, Ken, Betwa, Dhasan, Jamni, and a large number of other streams draining this study area (Avtar et al. 2010). The drainage pattern in the area was dendritic, pinnate type (Fig. 9). The southern part of the area, where proposed Gangau dam exists falls into the high drainage density. About 40% of the area upstream of the proposed dam shows medium drainage density (Fig. 10). The area having higher drainage density causes low infiltration and the movement of the surface run-off is faster therefore it causes more erosion hence was given a higher rank for erosion zonation (Pachauri et al. 1998; Cevik and Topal 2003).

Normalized difference vegetation index map

The nature and extent of vegetation has a strong control on runoff characteristics and sediment production of Ken and Betwa river basins (Molina et al. 2008). For this study, vegetation map was generated using Landsat Thematic Mapper (TM5) data of the year 2005. Higher value of NDVI shows dense vegetation so this area is less prone to inundation and erosion because plants anchor the soil in their root system therefore high NDVI area is given low rank for erosion as well as

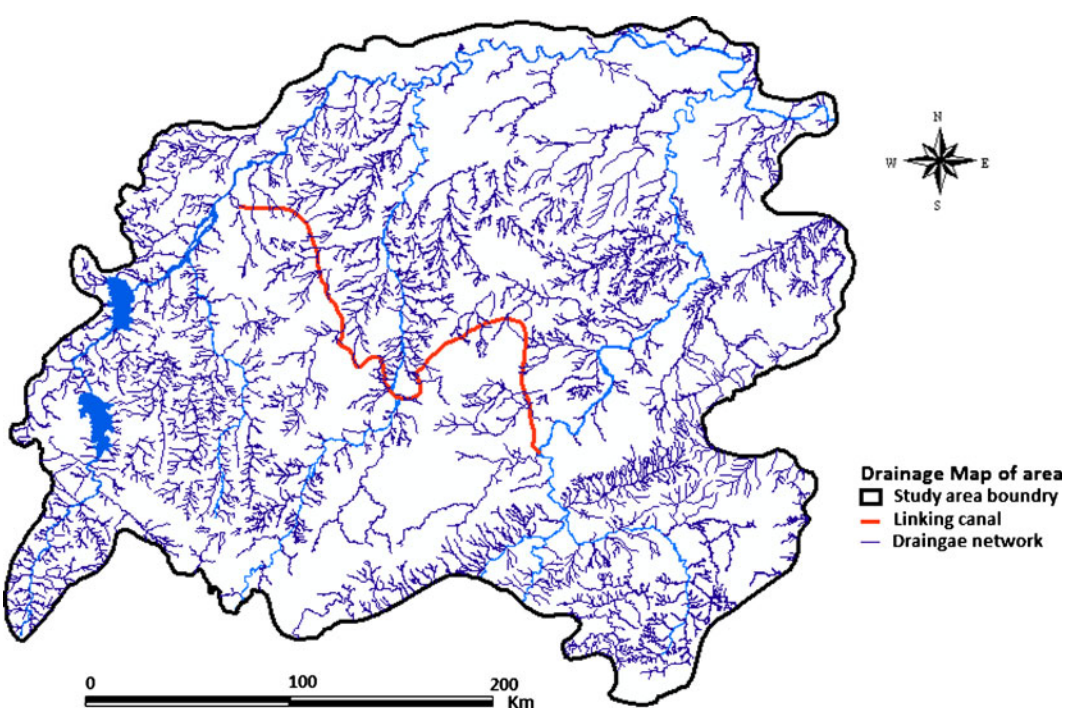

Fig. 9 Drainage map of the study area

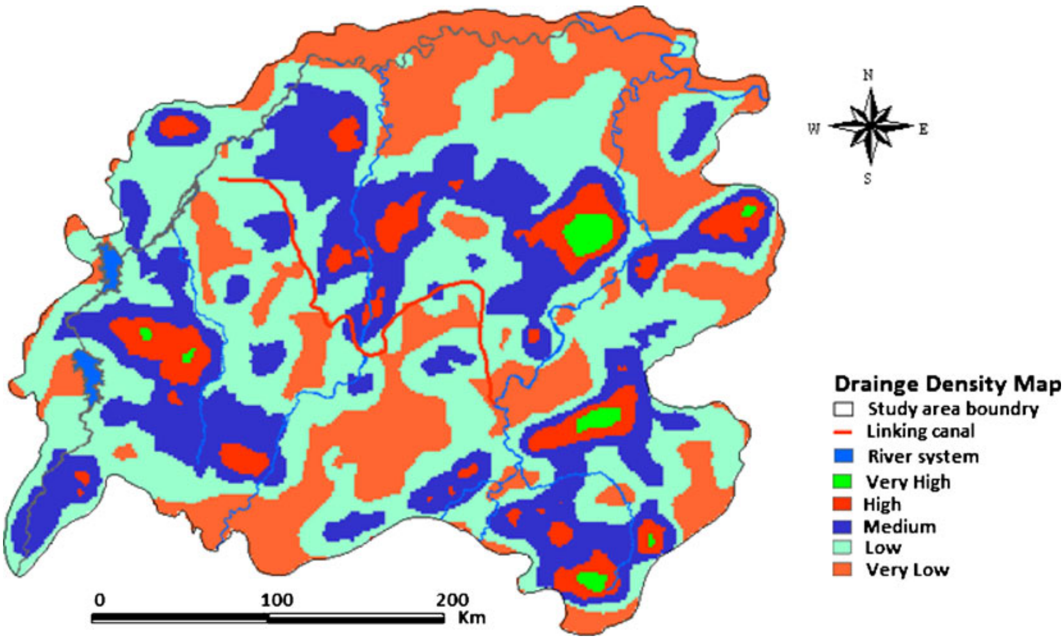

Fig. 10 Drainage density map of the study area

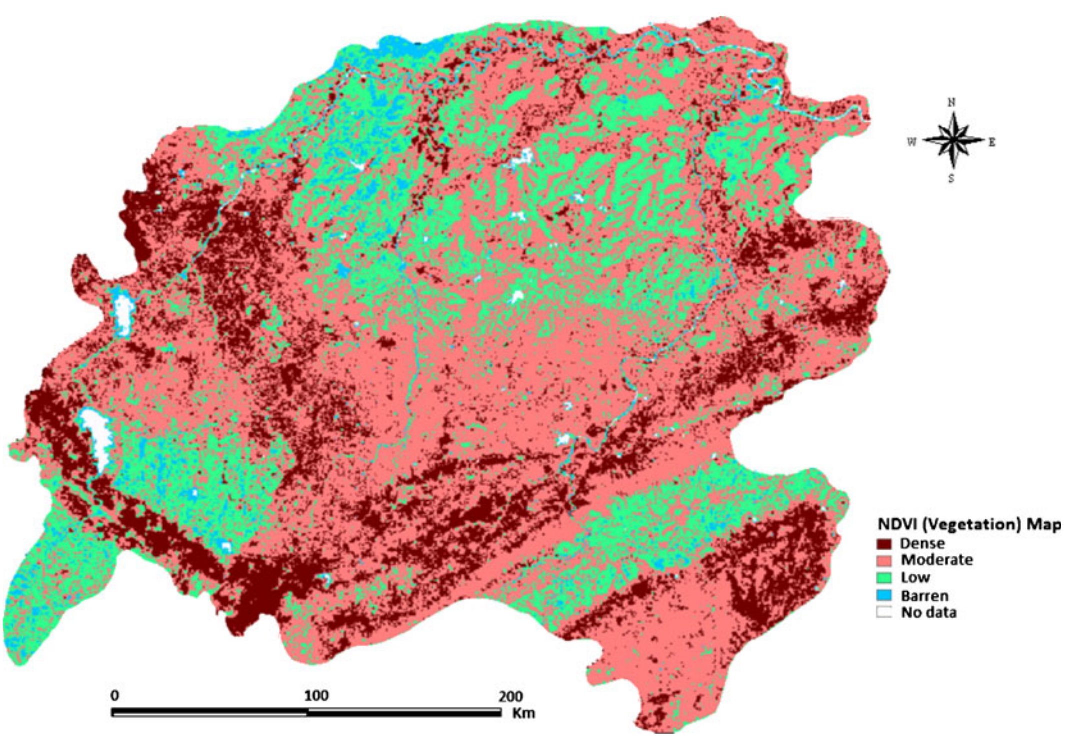

Fig. 11 NDVI map of the study area

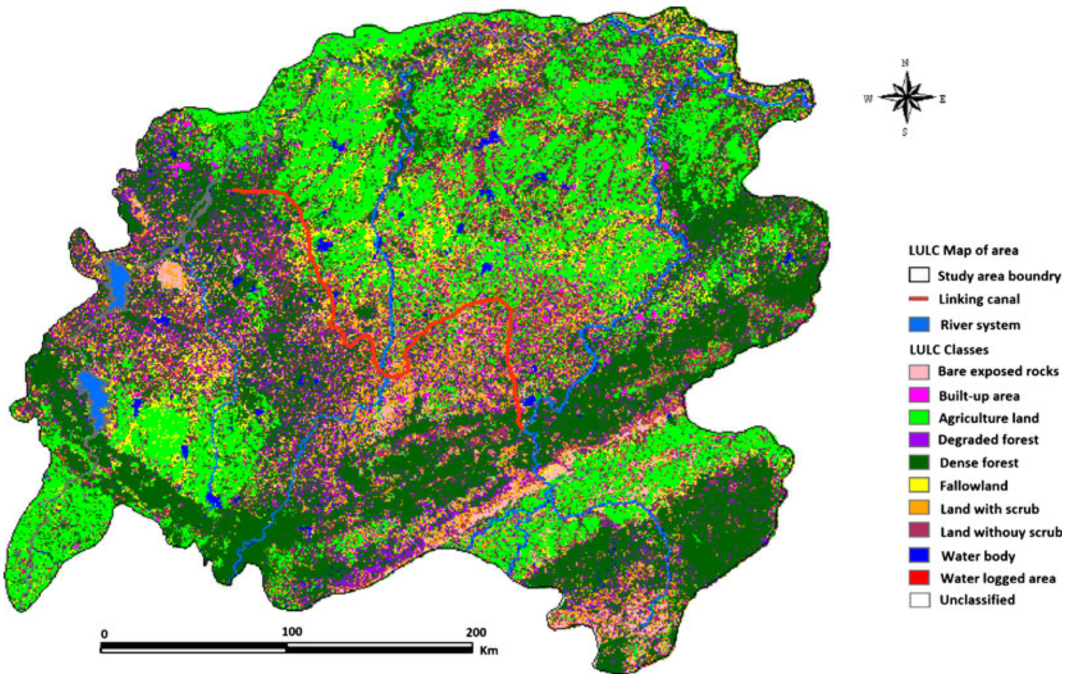

Fig. 12 Land use/land cover map of study area (based on unsupervised classification of Landsat Data 2005 data)

inundation hazard. Vegetation cover is protective against soil erosion. It affects soil detachment and transport capacity of runoff. Plants root increase the mechanical strength of the soil and also infiltration rate (Morgon 2005). High vegetation causes high infiltration therefore less inundations hazard (Reddy 2007). The higher value of NDVI in southern region shows dense forest of Panna tiger reserve (Fig. 11).

Land use/land cover

Various land use/land cover classes were mapped from Landsat data through unsupervised classification (Lillesand and Keifer 2006). Land use/land cover study is useful in assessing impacts of river linking on land resources. Landsat TM5 satellite data of year 2005 and topographic maps were used to prepare the land use/land cover map of the area through hybrid image classification technique. The study area was classified into 10 categories viz. water, dense forest, built up, current fallow/agricultural land, water logged, degraded forest, land with scrub, bare exposed rock, fallow land, and land without scrub. The classified image depicting various land use/land cover classes of the study area is shown in Fig. 12. The land use/land cover statistics of the study area presented in Table 1. Due to seasonal variability in water quantity, some area that was submerged during monsoon season may not have been present on the date the images were taken and therefore not identified as water in the classification. The characteristics of forested areas also changed dramatically depending on season.

Table 1 Percentage of various land use/land cover classes in the study area

Class	Area in km^2	Percentage
Water body	1,333.38	2.58
Dense forest	18,634.05	36.11
Built-up	606.72	1.18
Current fallow/ agriculture land	12,657.22	24.53
Waterlogged	219.91	0.43
Degraded forest	4,035.82	7.82
Land with scrub	3,929.60	7.62
Bare exposed rock	1,471.42	2.85
Fallow land	2,704.16	5.24
Land without scrub	6,011.10	11.65
Total	51,603.39	100

Land cover units such as dense forest are very less prone to erosional process whereas other units such as barren lands (fallow land) have relatively high susceptibility to erosion therefore fallow land has given higher rank for erosion as well as inundation hazard. Project development activities will affect change in land use/land cover pattern therefore it will impact erosion and inundation in the area.

Rainfall map

Annual rainfall maps were generated through an inverse distance weight interpolation in a GIS environment using annual rainfall data of Indian Meteorology Department (IMD). The interpolated maps show that rainfall in this region varies both spatially and temporally. The rainfall distribution in the study area is not uniform due to the changes in the topography (Athavale et al. 1980).

The annual rainfall in the year 1999 varied between 700 and 1,850 mm. But in the year 2004 annual rainfall of the study area was less (minimum 250 mm and maximum 1,375 mm) in comparison to 1999 and 2003. Figure 13 (A to F) shows spatial and temporal variation of rainfall data. The year 2002 was a drought year and annual rainfall was less in comparison to normal monsoon years. In 2002, annual rainfall varied between 500 and 1,150 mm (Fig. 13 (D)). In this study, average annual rainfall data from year 1999 to 2004 was used to generate thematic map for GIS modeling.

From the above study, it is observed that the spatial pattern of rainfall varies from northeast to southwest direction, i.e., from Jhansi region towards Panna region. So the Panna region from where the links start (Gangau weir) has high annual rainfall in most of the year as compared to the region where links end near Barua Sagar (Jhansi District). The early monsoon rains, coming after a relatively long dry period, can cause excessive erosion considering that at this time the land becomes more vulnerable to erosion due to low vegetation cover (Joshi and Tambe 2010). High-intensity rainfall always intensifies the inundation as well as erosion hazard, therefore high-intensity rainfall was given a higher rank for both erosional and inundation hazard zonation (Tables 2 and 3).

GIS integration and modeling

All the thematic maps (geomorphology, NDVI, land use/land cover, drainage density, soil, elevation, slope, and rainfall maps) with their individual

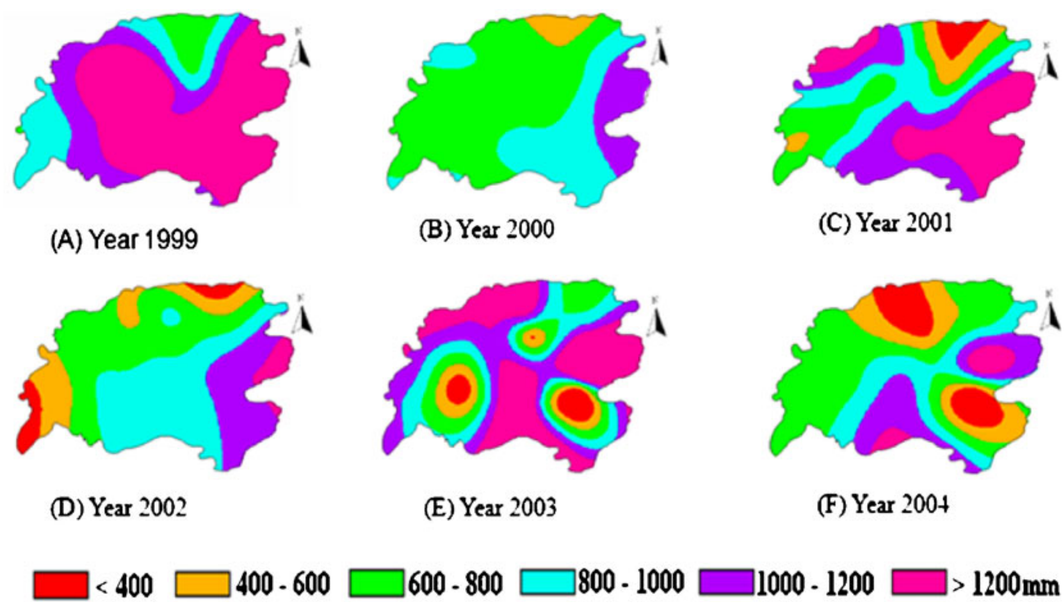

Fig. 13 Maps of annual rainfall (mm) on temporal scale from 1999 to 2004

Table 2 Thematic map weight, feature, and ranking for inundation hazard zonation

Theme	Weight	Features	Rank
Annual rainfall	8	>1,200	5
		1,000–1,200	4
		800–1,000	3
		600–800	2
		<400	1
Geomorphology	7	Flood plain	5
		Ravines	3
		Pediment	2
		Denudational hills	1
		Alluvial plain	2
Elevation	6	>436	1
		355–436	2
		270–355	3
		179–270	4
		<179	5
Slope	5	>72	1
		57–72	2
		39–57	3
		14–39	4
		<14	5
Drainage density	4	Very high	1
		High	2
		Medium	3
		Low	4
		Very low	5
Soil cover	3	Clayed loam	5
		Sandy loam	4
		Loamy	3
		Loamy sand	2
NDVI (vegetation)	2	Dense	1
		Moderate	2
		Low	3
		Barren	5
Land use/ land cover	1	Dense forest	1
		Land with scrub	2
		Agricultural land	3
		Degraded forest	3
		Land without scrub	4
		Fallow land	4

classes were prepared from different datasets and field verification. Within a layer, each class is rated on a scale based on its suitability or risk. The ideal tool for the modeling analysis is "Weighted Overlay Function" of spatial analyst tools in Arc GIS 9.1. To perform overlay analysis, all the thematic layers were converted into ESRI GRID format and chosen scale was '1 to 5 by 1'. The unequal weight represents better the relative importance of the features in the erosion and inundation process. The weight and rank of different classes are as shown in the attached Tables 2 and 3.

The maps (inundation and erosion) were classified into different hazard zones. Inundation map was classified into high, moderate, and low hazard zone (Fig. 14). In inundation map, most of the area falls into moderate hazard zone but southern part of the area falls into high hazard zone and the linking canal path also falls into high and moder-

Table 3 Thematic map weight, feature, and ranking for erosion hazard zonation

Theme	Weight	Features	Rank
Annual rainfall	8	>1,200	5
		1,000–1,200	4
		800–1,000	3
		600–800	2
		<400	1
Elevation	7	>436	5
		355–436	4
		270–355	3
		179–270	2
		<179	1
Slope	6	>72	5
		57–72	4
		39–57	3
		14–39	2
		<14	1
Drainage density	5	Very high	5
		High	4
		Medium	3
		Low	2
		Very low	1
Soil cover	4	Clayed loam	2
		Sandy loam	3
		Loamy	4
		Loamy sand	5
Geomorphology	3	Flood plain	3
		Ravines	4
		Pediment	2
		Denudational hills	5
		Alluvial plain	1
NDVI (vegetation)	2	Dense	1
		Moderate	2
		Low	3
		Barren	5
Land use/land cover	1	Dense forest	1
		Land with scrub	2
		Agricultural land	3
		Degraded forest	3
		Land without scrub	4
		Fallow land	5

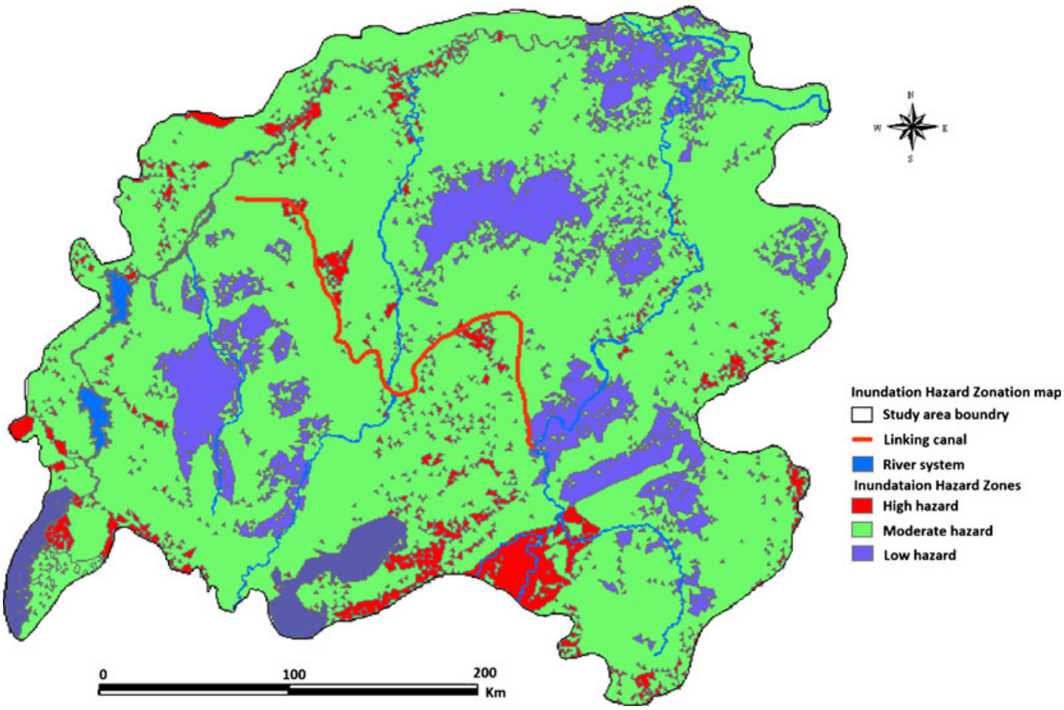

Fig. 14 Map showing Inundation hazard zones of the study area

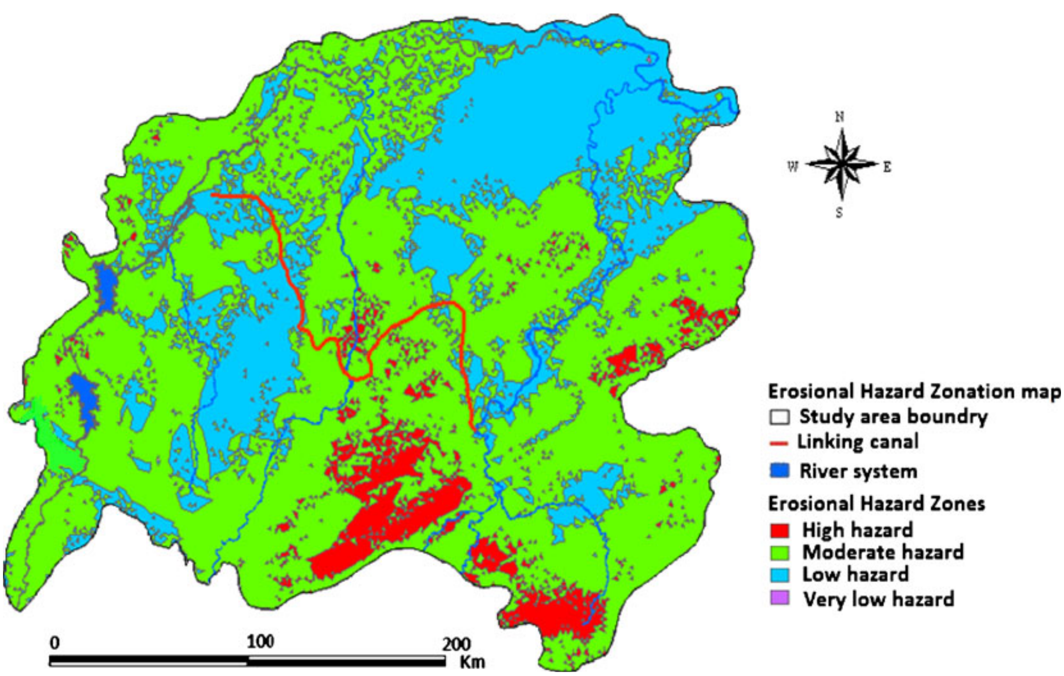

Fig. 15 Map showing erosion hazard zones of the study area

ate hazard zone. Erosion map was also classified into high, moderate, low, and very low hazard zones (Fig. 15).

The inundation hazard map was classified into high, medium, and low hazard zones on the basis of cumulative inundation hazard index. A high hazard zone indicates the area is more vulnerable to inundation. The erosion hazard map was classified into high, medium, low, and very low hazard zones on the basis of cumulative erosional hazard index. In erosion map, most of the area falls into moderate and low hazard zone. The southern part of the study area falls into high hazard zone. So from both maps it is clear that southern part of the study area which lies in Panna district of Madhya Pradesh is more vulnerable than the other areas. This area has Panna Tiger reserve forest which is the most vulnerable site. The construction of Greater Gangau dam as proposed at Panna tiger reserve will cause tremendous environmental impacts. Therefore, during project development activity the developers must consider these vulnerable sites to minimize the environmental impacts of Ken–Betwa river linking.

Conclusion

Water is essential for sustaining life and all kind of socio-economic development. Growing global scarcity of water is fast becoming a major threat against socio-economic progress. Rapidly developing countries like India, already suffering from increasing population and shortage of natural resources, especially water, need mammoth projects such as the Ken–Betwa link project to combat the water scarcity and related issues.

While the KBLP might provide benefits by developing water resources, it is equally important to consider the potentially negative environmental impacts, including those that could have long-term consequences. There are many well-documented examples of such unanticipated environmental consequences associated with dams including loss of habitat, changes in downstream morphology (increased erosion), changes in downstream water quality, and the reduction of biodiversity as in Sardar Sarovar dam area.

In KBLP, the reservoir (Greater Gangau Weir) would affect the land around the reservoir rim. The introduction of a huge reservoir will disturb the delicate balance between soil, water, and plants due to the rise in groundwater table (water logging), and further agitating the natural salt distribution in the soil. Construction of the dam and transferring the water through the catchments will accelerate the changes on the land system resulting in changes in cropping pattern of Bundelkhand region.

The impacts of Ken–Betwa linking will be more near the Dam site as well as downstream of the Ken River. Most of the affected area falls into medium intensity of impact in terms of inundation or erosion; however, the Panna region, which contains the Panna tiger reserve forest, comes under high impact zone. The Betwa basin comes under low impact zone.

The above study demonstrate without doubt that a complete feasibility study of the area using the most advanced scientific methods (including remote sensing and GIS) is a must if unforeseen disastrous consequences of such a mammoth task are to be averted and full benefits of this landmark initiative are to be reaped. Spatial modeling, for identification of impacts in affected regions, with the help of remote sensing and GIS environment can prove to be a major tool in such feasibility studies and help us to achieve environment conscious approach to socio-economic problems.

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References

Ahmad, S. M. (1984). Hydrogeological investigations for augmenting water supply in drought affected areas of Banda District, Uttar Pradesh, Central Ground Water Board. Unpublished report, Lucknow, India.

Athavale, R. N., Murti, C. S., & Chand, R. (1980). Estimation of recharge to the phreiatic aquifers of lower

Maner Basin, India by using tritium injection method. *Journal of Hydrology, 45*, 185–202.

Avtar, R., Singh, C. K., Shashtri, S., Singh, A., & Mukherjee, S. (2010). Identification and analysis of groundwater potential zones in Ken–Betwa river linking area using remote sensing and geographic information system. *Geocarto International, 25*, 379–396.

Belton, V., & Stewart, T. J. (2002). *Multiple criteria decision analysis: An integrated approach*. Dordrecht: Kluwer.

Bhatt, C. M., Litoria, P. K., & Sharma, P. K. (2008). Geomorphic signatures of active tectonics in Bist Doab interfluvial tract of Punjab, NW India. *Journal of the Indian society of remote sensing, 36*(4), 361–373.

Cevik, E., & Topal, T. (2003). GIS-based landslide susceptibility mapping for a problematic segment of the natural pipeline, Hendek (Turkey). *Environmental Geology, 44*(8), 949–962.

Collins, D. N. (1998). Rainfall-induced high-magnitude runoff events in highly-glacierized Alpine basins. Hydrology, water resources and ecology in headwaters. *IAHS Publication, 248*, 69–79.

De Roo, A. P. J. (1996). *Soil erosion assessment using GIS. Geographical information systems in hydrology* (Vol. 26, pp. 339–356). Dordrecht: Kluwer Academic Publishers.

ESRI (2006). ArcMap version9.1. Environmental Systems Research Institute (ESRI), Redlands, CA.

Fistikoglu, O., & Harmancioglu, N. B. (2002). Integration of GIS with USLE in assessment of soil erosion. *Water Resources Management, 16*, 447–467.

Gurjar, B. R. (2003). Interlinking of rivers: A climatic viewpoint. *Current Science, 84*(11), 1381–1382.

Heywood, I., Cornelius, S., & Carver, S. (2000). *An introduction to geographical information systems*. Reading: Addison Wesley Longman.

Hooke, J. M. (2007). Complexity, self-organisation and variation in behavious in meandering rivers. *Geomorphology, 91*(3–4), 236–258.

Hortan, R. E. (1945). Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. *Bulletin of the Geological Society of America, 56*, 275–375.

James, W. (1999). Analysis of global and regional slope distributions for Venus. In *30th Lunar and planetary science conference*. Houston, Texas.

Jasrotia, A. S., Dhiman, S. D., & Aggarwal, S. P. (2002). Rainfall–runoff and soil erosion modeling using remote sensing and GIS technique—A case study of Tons watershed. *Journal of the Indian Society of Remote Sensing, 30*(3), 167–179.

Jasrotia, A. S., & Singh, R. (2006). Modeling runoff and soil erosion in a catchments using GIS, in Himalayan region. *Environmental Geology, International Journal of Geosciences, 51*(1), 143–150.

Jensen, J. R. (2000). *Remote sensing of the environment*. New Jersey: Prentice Hall Publication.

Jenson, S. K., & Domingue, J. O. (1988). Extracting topographic structures from digital elevation data for geographic information system analysis. *Photogrammetric Engineering and Remote Sensing, 54*, 1593–1600.

Joshi, V. U., & Tambe, D. T. (2010). Estimation of infiltration rate, run-off and sediment yield under simulated rainfall experiments in upper Pravara basin, India: Effect of slope angle and grass-cover. *Journal of Earth System Science, 119*(6), 763–773.

Khare, D., Jat, M. K., & Sunder, J. D. (2007). Assessment of water resources allocation options: Conjunctive use planning in a link canal command. *Resources, Conservation and Cycling, 51*(2), 487–506.

Krueger, K. (2007). Assessment of the India river linking plan: A closer look at the Ken–Betwa pilot link. M.Sc. Dissertation, University of Michigan.

Lal, R. (1994). Soil erosion by wind and water: Problems and prospects. In R. Lal (Ed.), *Soil erosion research methods* (2nd Edn.). Ankeny: Soil and Water Conservation Society and St. Lucie Press.

Lillesand, T. M., & Keifer, R. W. (2006). *Remote sensing and image interpretation*. New York: Wiley.

Mathur, S. M. (1982). Prrecambrian sedimentary sequences of India: Their geochronology and correlation. *Precambrian Research, 18*, 139–144.

Morgon, R. P. C. (2005). *Soil erosion and conservation*. Harlow: Longman.

Morgan, R. P. C., & Davidson, D. A. (1991). *Soil erosion and conservation*. U.K.: Longman Group.

Millward, A. A., & Mersey, J. E. (1999). Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. *Catena, 38*, 109–129.

Mishra, A. K., Saxena, A., Yaduvanshi, M., Mishra, A., Bhadauriya, Y., & Thakur, A. (2007). Proposed river-linking project of India: A boon or bane to nature. *Environmental Geology, 51*, 1361–1376.

Molina, A., Govers, G., Poesen, J., Hemelryck, H. V., Bievre, B. D., & Vanacker, V. (2008). Environmental factors controlling spatial variation in sediment yield in a central Andean mountain area. *Geomorphology, 98*, 176–186.

Mukherjee, S. (1991). Ground water appraisal report Hamirpur District Uttar Pradesh, remote sensing applications centre (pp. 4–9). Unpublished Technical report no. RSAC; GED91: 02, UPRSAC: Lucknow, Uttar Pradesh, India.

Mukherjee, S., Veer, V., Tyagi, S. K., & Sharma, V. (2007). Sedimentation study of Hirakund reservoir through remote sensing techniques. *Journal of Spatial Hydrology, 7*(1), 122–130.

National Water Development Agency (NWDA) (2005). Environmental effects on linking of Rivers.

National Water Development Agency (NWDA) (2007). Ken–Betwa link project feasibility report.

Ozhan, S., Balci, A. N., Ozyuvaci, N., Hizal, A., Gokbulak, F., & Serengil, Y. (2005). Cover and management factors for the universal soil-loss equation for forest ecosystems in the Maramara region, Turkey. *Forest Ecology and Management, 1–3*, 118–123.

Pachauri, A. K., Gupta, P. V., & Chander, R. (1998). Landslide zoning in a part of the Garwal Himalayas. *Environmental Geology, 36*(3–4), 325–334.

Pandey, A., Chowdary, V. M., & Mal, B. C. (2007). Identification of critical prone areas in the small agricultural watershed suing USLE, GIS and remote sensing. *Water Resource Management, 21*, 729–746.

Pandey, A., Chowdary, V. M., Mal, B. C., & Dabral, P. P. (2010). Remote sensing and GIS for identification of suitable sites for soil and water conservation structures. *Land Degradation and Development*. doi:10.1002/ldr.1012.

Pakhmode, V., Kulkarni, H., & Deolankar, S. B. (2003). Hydrological-drainage analysis in watershed-programme planning: A case from Deccan basalt, India. *Hydrogeology Journal, 11*, 595–604.

Raghavendra Reddy, M. G., Reddy, G. P. O., Maji, A. K., & Rao, K. N. (2003). Landscape analysis for pedogeomorphological characterization in basaltic terrain, central India using remote sensing and GIS. *Journal of the Indian Society of Remote Sensing, 31*(2), 271–282.

Reddy, S. (2007). Hydro-Geomorphic impact assessment of Ken–Betwa interlinking project. M.Tech. Dissertation, Indian Institute of Technology, Kanpur.

Reusing, M., Schneider, T., & Ammer, U. (2000). Modelling soil loss rates in the Ethiopian highlands by integration of high resolution MOMS-02/D2-stereo-data in a GIS. *Journal of Remote Sensing, 21*, 1885–1896.

Sharma, H. S. (1979). *The physiography of lower Chambal valley and its agricultural development*. New Delhi: Concept Publication.

Singh, R., & Phadke, V. S. (2007). Assessing soil loss by water erosion in Jamni River Basin, Bundelkhand region, India, adopting universal soil loss equation using GIS. *Current Science, 90*(10), 1431–1435.

Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion losses. USDA agricultural research service handbook, 537.

Wisler, C. O., & Brater, B. F. (1959). *Hydrology*. Wiley: New York.

World Water Council (2000). *A water secure world; vision for water, life, and the environment*. Marseille: World Water Council.