ASSESSMENT OF WATER RESOURCES OF KEN-BETWA RIVER LINKING AREA – A GIS APPROACH.

Dissertation submitted to Jawaharlal Nehru University
in partial fulfillment of the requirements for
the award of the degree of

MASTER OF PHILOSOPHY

RAM AVTAR

SCHOOL OF ENVIRONMENTAL SCIENCES
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI-110067
INDIA
2008

जवाहरलाल नेहरू विश्वविद्यालय
JAWAHARLAL NEHRU UNIVERSITY
SCHOOL OF ENVIRONMENTAL SCIENCES
New Delhi- 110 067, INDIA

July 1, 2008

CERTIFICATE

This is to certify that the research work embodied in this dissertation entitled **'Assessment of Water Resources of Ken-Betwa River Linking Area – A GIS Approach'.** has been carried out in School of Environmental Sciences, Jawaharlal Nehru University for the partial fulfillment of the award of degree of MASTER OF PHILOSOPHY. This work is original and has not been submitted in part or full for any degree or diploma in any university.

Ram Avtar
Ram avtar

(Candidate)

Prof. V. K. Jain
(Dean, SES)

Prof. Saumitra Mukherjee
(Supervisor)

Gram : JAYENU TEL : 26741557, 26742575, 26742676
SES : 26741538 (Direct) 26704302, 4303, 4304 Fax : 26741502

Acknowledgment

I wish to take this opportunity to express my deep sense of gratitude to my supervisor, Prof. Saumitra Mukherjee, (School of Environmental Sciences, J.N.U., New Delhi) for his untiring supervision, valuable suggestions and inspiring guidance, which enabled me to bring this work into the present shape.

I am thankful to Prof. V. K. Jain, Dean of School of Environmental Sciences, J.N.U. for his multidirectional support and academic suggestions. I am also thankful to CIF Staff who helped me to access Center's instrument facility to complete my research work.

I would like to express my thanks to CGWB (Central Ground Water Board), IMD (Indian Meteorological Department), NWDA (National Water Development Authority), CWC (Central Water Commission),

I would like to give my thanks to ICMR (Indian Council of Medical Research) and CSIR (Central Scientific and Industrial Research) for giving me financial assistance to carry my research work.

I express my special regard to Chander sir who continuously helped me with brotherhood feelings and even provided his much needed support from dawn to dusk in the crucial hours in analytical part in JNU.

I would also like to give special thanks to S. Shastri sir, Prabir sir, Azeem sir, Vijay Veer sir, Sudhir sir, Manoj Pant sir, Abhimanyu sir, Bhuiyan sir & Reena ma'm who really gave me technical support (to run various water related software's) for my dissertation work.

I also express my gratitude to my seniors Sachin sir, Sandeep sir, Umesh sir, Ashwani sir, Gurmeet sir, Deepak Chaudhary sir, Parijat sir, Rajesh sir, Kushagra sir, Jaya ma'm, Shivaji sir, Chandrasekhar sir, Dharmendra sir, Durgesh sir, Pathak sir, Vivek Misra sir, Baba sir, Ashutosh sir, Hemant sir, Atul sir, Pavin sir & Linda sir who made me to explore various dimensions regarding my dissertation. I am also thankful to Dayaram Yadavji (lab assistant) for the timely help I received during samples analysis.

I am very thankful to my friends Pankaj, Naren, Satish, Abhijeet, Naseer, Manika, Prashant, Rajdeo, Moonish, Shweta, Nilendu, Bane, Aarif, Rajesh, Meghna, Ramratan, *OP, Dinu, Divyaprakash, Jagjit, Sandy, Anurag, Shiv, Amit, Joylata, Madhuri, Garima, Monika, Poonam, Tonuka, Shruti, Ratnesh, Gopal, Pintu, Dinesh, Samved who provided me with important feedbacks, and helped me in encapsulating some tricky aspects related with this work.*

I also express my hearty feelings to my juniors especially Alok, Bindu, Palden, Amit Singh, Amit Mishra, Mukesh, Radhey Shyam, Shailnder, Bhupi, Sandeep, Sasmita, Deepak, Ravi, Ram Pravesh, Nitya, Shyam, Naba, Fanish, Amit, Vinit, Vikas, Virender for their chirpy faces and morale boosting attitudes.

I also thankful to office staff SDS Rawat sir, DL Sachdeva sir, Amrik sir, Bhatia ma'm, Pant ma'm, Kusum ma'm, Anju kapoor ma'm, Chand narayan sir, Balvir sir, Anil, Om Prakash, Ashwani who helped me in administrative, financial and official work.

No matter acknowledgement can express my feelings for my family members, who deserve more than a written acknowledgement.

Thanks a lot to the Almighty BHAGWANJI

Ram avtar

Dedicated To,

MY PARENTS

CONTENTS

Acknowledgements.. *i-ii*

1. INTRODUCTION.. *1-11*

2. LITERATURE REVIEW.. *12-29*

3. STUDY AREA.. *30-40*

4. MATERIALS AND METHODS.. *41-54*

5. RESULT AND DISCUSSIONS.. *55-93*

6. CONCLUSION.. *94-96*

References.. *97-105*

Field Photographs.. *106-107*

CHAPTER I

INTRODUCTION

1.1. GENERAL

There is a water crisis today. But the crisis is not having too little water to satisfy our needs. It is a crises of managing water so badly that billions of people and environment suffering badly (World Water Council, 2000). Water is the elixir of life and is essential for sustainable development of human civilization. It is the most powerful agent in shaping the Earth's surface features through the processes of rivers, ground water, glaciers, mass movement and oceans. Water as an element has over the years played an essential role in the development of the world's civilization. Since the dawn of Human civilization, water has been harnessed in ways more than that can be listed for the very physical existence of human being. Human being has over the years devised numerous ways of capturing, storing, purifying and diverting fresh water resources to reduce their vulnerability to highly variable river flows and precipitation (Mirza, 2004). With the growing compulsion of industrialization as result of increase in demand for finished goods and thereby, increase in demand for food grains in the past few centuries there has been a greater escalation in the global fresh water requirements therefore, the per capita availability of fresh water has declined drastically. Presently the availability of water per season per annum has come down from 6500 cubic meters to 2500 cubic meters (NWDA, 2006).

Due to the importance of this resource, it is likely that water will be one of the most critical issues of the 21st century both in terms of quantity and quality. International institutions such as various United Nations agencies and the World Bank have claimed that these scarcities will escalate in the future, creating serious problems for humankind and the environment. This situation is largely due to the present unhealthy management and development practices. As a result of ballooning population and subsequent development coupled with climate-change, management of water resources is a great concern. In addition to the above cited reasons, the degradation of water quality due to rampant pollution makes the situation even worse and is leading towards global water crisis. Thus, interlinking of rivers becomes an issue at the top of the agenda for water authorities and river managers throughout the world.

In Europe the water framework directive (2000/16/EEC), aims at improving the status of fluvial ecosystem in broad integrated ecological perspectives. At the same time river restoration is an important tool as well as a challenging topic, for planning strategy and project appraisal for a number of different types of river system including-

- Upland rivers
- Lowland rivers
- Urban rivers

For the conservation of rivers, the interlinking of rivers studies should focus on hydrology, geomorphology, ecology and economics. In the last decade the river interlinking project which aimed at enhancing degraded river habitat and improving the wider river landscapes has increased. Each such project increases the extent of our knowledge regarding river interlinking and restoration process, whether it is planning from an ecological, hydrological or engineering point of view. Moreover, several experiences claimed that ILR and river restoration could be the current and rhetoric approach to face the increasing challenges of flood hazards and associated land-sliding phenomenon.

1.2. WATER SCENARIO

The current population of India is about 1.37 billion and it is projected that by the year 2025 it will be about 1.4 billion (FAO, 2005). The galloping rise of population density and as result the rapid urbanization of villages, the process of industrialization has increased the water-demand for domestic, irrigation and industrial purposes. In view of the water-demand it is said that the "Next World War Will Be Over Water" (Howard, 2003). In the present scenario, increasing water demand poses new challenges for water resources planners and managers to keep pace with the increasing population as well as agricultural production, which need to be increased along with irrigation. This is possible through development of new water resources projects (supply management) or efficient water management of available resources. Conjunctive use of surface and groundwater is one of the most effective water management alternatives, to deal with increasing irrigation demand and inadequate surface supplies.

In the Indian context, the distribution of water is extremely uneven both temporally as well as spatially. The precipitation over the country is primarily orographic, associated with tropical depressions originating in the Arabian Sea and the Bay of Bengal; this causes higher annual rainfall in the Indian subcontinent compared to other major continental areas. The resource potential of the country, which occurs as the natural run-off in the rivers is about 1869 km^3, considering both surface and ground water as one system (CGWB, 2004). Due to various constraints of topography and uneven distribution of resources over space and time, it has been estimated that presently only about 1122 km^3 of the estimated average runoff of 1869 km^3 is utilizable (CGWB, 2004). But the uncertainty in the average rainfall and seasonal fluctuations (means annual rainfall varies from 100 mm in western Rajasthan to over 1100 mm in Meghalaya) lead to prolonged dry space, causing droughts in the larger parts of Rajasthan, Haryana, Maharashtra, Andhra Pradesh, Tamil Nadu, Gujarat, Madhya Pradesh and Chhatishgarh as a results enormous loss to the nation (Indian Water Resources Society, 1994). The water availability even for drinking purposes become critical, particularly in the summer months when the rivers dry up and the ground water recedes (National Water Development agency, 2002).

On the other hand, some regions (e.g. states of Assam, Bihar, West Bengal and Eastern Uttar Pradesh) get excess rainfall causing floods thus; the entire scenario creates an imbalance in the water availability. The adequate rainfall during monsoon months serves the need for the period of non precipitation and sustaining the growth of crops. In the last couple of years, floods and droughts have occurred consistently, causing enormous loss to the nation. The flood damages which were 52 crores in 1953 have gone up to almost 7500 crores in 2004, with annual average being 2000 crores (National Water Development Agency, 2005). Floods are probably the most reccurring, wide spread feature, particularly in the Brahamputra and the Ganga river basins where 60% of the annual floods occurr. In India at present, 40 million hectares of area is flood affected.

1.3. INTERLINKING OF RIVERS IN INDIA

The basic objective of the Inter Linking of River (ILR) 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. So it will provide national water security and alleviate poverty with a broad measure of regional and social equity. Interlinking of rivers, although primarily aimed to mitigate problems of floods and droughts in different regions of the country, is also correlated with positive implications to energy and transport related industry, as well as with the agriculture and human health sectors. It is essential to study the feasibility before any river linking project (Mukherjee S., 2003).

It envisages creation of storage dams and link-canals to transfer water from areas of absolute or seasonal plenty to water stressed basins this leads to the development of new or augmentation of existing irrigation commands, water supply and sanitation schemes. Transfer of water from one river basin to another has been practiced as an exemplary engineering response for meeting the growing water requirements. But when we are discussing about linking of different river systems with different catchments characteristics, an engineering perspective cannot be sufficient. An intensive knowledge about landscape properties, which includes fluvial geomorphology, land use/land cover pattern, vegetation and population density with detailed assessment analysis is also required. Under the proposed ILR project, 14 probable links of the Himalayan Rivers and 16 probable links of the peninsular rivers were proposed (NWDA 1982).

A) **Himalayan River link:** The Himalayan river component holds the idea of transferring water from the eastern part that is the Ganga–Brahmaputra system to the westwards covering the parts of southern Uttar Pradesh, Haryana, Punjab and Rajasthan and finally proceeding towards south meeting the peninsular component (as shown in figure1.1). It includes the construction of large storage tanks on main tributaries of the Ganga and the Brahmaputra in India and Nepal. It calls for interlinking canal systems to transfer surplus flows of the eastern tributaries of the Ganga to the West. It also proposes to link the main Brahmaputra and its tributaries with the Ganga, and the Ganga with Mahanadi. Dasgupta (2004) has proposed that this component would provide an additional irrigation of about 22 million hectares and would raise the ultimate irrigation potential from 113 million hectares to 148– 150 million hectares facilitating the generation of about 30,000 MW of hydropower, besides providing flood control in the Ganga–Brahmaputra basin. The proposed Himalayan river links are:

1. *Kosi–Mechi link,* 2.*Kosi–Ghaghra link,* 3.*Gandak–Ganga link,* 4.*Ghaghra–Yamuna link,* 5.*Sarda–Yamuna link,* 6.*Yamuna–Rajasthan link,* 7.*Rajasthan–Sabarmati link,* 8.*Chunar–Sone, Barrage link,* 9.*Sone Dam–Southern Tributaries of Ganga link,* 10.*Brahmaputra–Ganga link (Manas–Sankosh Tista–Ganga),* 11.*Brahmaputra–Ganga link (Jogighopa Tista–Farakka),* 12.*Farakka–Sunderbans link,* 13.*Ganga–Damodar–Subernarekha link, and* 14. *Subernarekha–Mahanadi link*

B) Peninsular River link: The peninsular river project is more vital and crucial because in the peninsular part no river is glacially fed. The water budget strongly depends upon the rainfall (both South West as well as North West monsoon) and groundwater regime. The project has been divided into four major parts. (1) Interlinking of the Mahanadi –Godavari – Krishna – Cauvery Rivers and building storages at potential sites in these basins. This part involves major interlinking of the river systems where surpluses from the Mahanadi and the Godavari Rivers are intended to be transferred to the more interior parts of the peninsula. (2) Interlinking of west-flowing rivers, originating on the Western Ghats, North of Bombay and South of Tapi. This part will be supplemented by the construction of storage basins. The scheme incorporates water supply by canal to the metropolitan areas of Mumbai; it also provides irrigation to the coastal areas in Maharashtra. (3) Interlinking of Ken–Chambal. The scheme provides for a water grid for Madhya Pradesh and Uttar Pradesh and interlinking canals backed by as much storage as possible. (4) Diversion of other west flowing rivers to the east. The plan includes the construction of an interlinking canal system backed up by adequate storage spaces to transfer water to meet the needs of drought affected areas. The Peninsular development is expected to provide additional irrigation of about 13 million hectares and is expected to generate about 4,000 MW of power. The proposed probable links of Peninsular Rivers are: (as shown in figure 1.2)

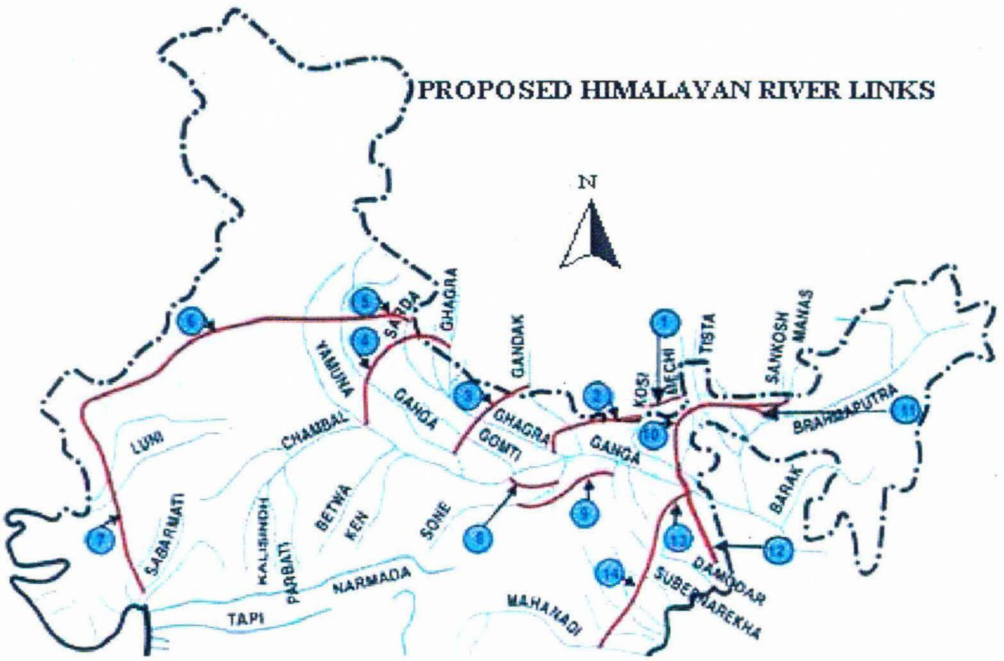


Fig.1.1. Showing proposed inter river linking in India in Himalayan component (Source: NWDA).

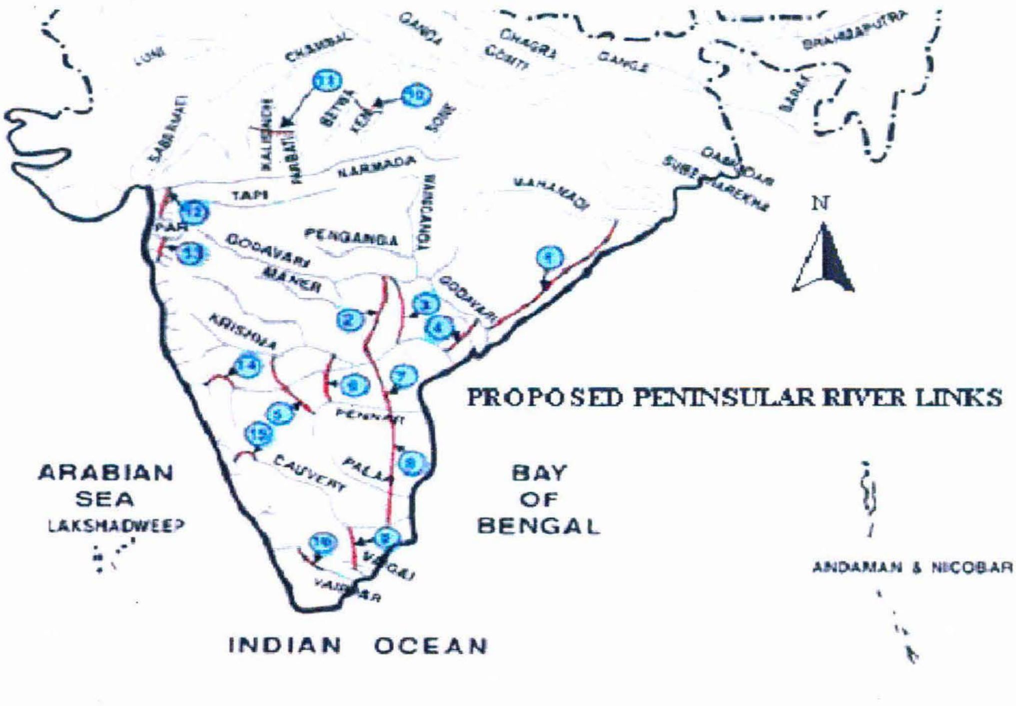


Fig.1.2. Showing proposed inter river linking in India in Peninsular component (Source: NWDA).

1.*Mahanadi (Manibhadra)–Godavari (Dowlaiswaram) link,* 2.*Godavari (Polavarm)–Krishna (Vijayawada) link,* 3.*Godavari (Inchamaplli)–Krishna (Nagarjunasagar) link,* 4.*Godavari (Inchampally Low Dam)–Krishna(Nagarjunasagar Tail Pond) link,* 5.*Krishna (Nagarjunasagar)–Pennar (Somasila) link,* 6.*Krishna (Srisailam)–Pennar link,* 7.*Krishna (Almatti)–Pennar link,* 8.*Pennar (Somasila)–Cauvery (Grand Anicut) link,* 9.*Cauvery (Kattalai)–Vaigai (Gundar) link,* 10.*Parbati–Kalishindh–Chambal link,* 11.*Damanganga–Pinjal link,* 12.*Par-Tapi–Narmada link,* 13.*Ken–Betwa link,* 14.*Pamba–Achankovil–Vaippar link,* 15. *Netrreavati–Hemavati link, and* 16. *Bedti–Varda link.*

1.4. KEN-BETWA RIVER LINKING

The growing global scarcity of water is fast becoming a major social and economic crisis and as a result generating resource development projects such as the Ken-Betwa Link Project (KBLP) in India. The KBLP involves connecting the Ken and Betwa rivers through the creation of a dam, reservoir, and canal to provide storage for excess rainfall during the monsoon season in the upper Ken basin and deliver this water for consumption and irrigation purposes to the upper Betwa basin.

The main aim of the Ken-Betwa link project is to make available water to water deficit areas of Upper Betwa sub basin from the surplus waters of Ken basin. 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. While no links have been built to date, the KBLP is being pursued as the pilot project of the national program to serve as a "litmus test" for the national ILR plan. Critics suggest that the KBLP has been chosen as the premiere project as a result of its remote location, which minimizes opportunity for controversy. Additionally, the physical construction required for the KBLP is relatively minimal as a result of the close proximity of the Ken and Betwa Rivers to each other. The outcome of this pilot link will set the tone for river interlinking nationwide. Therefore, both supporters and opponents of the project are eager to use the KBLP as an example to either continue or defeat the national water management plan. The Detailed Project Report (DPR) study is going on; however it is unknown when the report will be completed.

The Ken-Betwa link project, which is a diversion cum storage scheme, envisaging the transfer of 1020 mm^3 surplus water from Ken river basin to water deficit Betwa basin which comprises of:

- A 73.80 m high and 1468 m long earth dam across river Ken near Daudhan village having gross storage capacity of 2775 mm^3.
- Two power houses one was under ground power house with 3x20 MW installed capacity and second one was a surface power house at the end of the tunnel with 2x6 MW installed capacity.
- A 231.45 km long canal for transferring water from river Ken to river Betwa having design discharge of 72 cusecs.
- A 326 m long side channel spillway on left flank
- Diversion of 659 mm^3 of water (using existing outlet of Barwa sagar) to Betwa basin upstream of Parichha weir to be utilized by way of substitution to provide annual irrigation to 1.27 lakh hectare of drought-prone area of upper Betwa basin.
- Annual irrigation to an area of 47,000 hectare enroute of the Ken-Betwa link
- Annual irrigation of 3.23 lakh hectares under the Ken multipurpose project earlier proposed by the Madhya Pradesh Government
- Provision of 11.75 mm^3 for drinking water supply to villages and towns enroute of the link canal

A) Ken-Betwa Basins

The Ken River has its origin from the Ahirgawan village on the north-west slopes of the Kaimur hills in the Jabalpur district of Madhya Pradesh at an elevation of about 550 meters above mean sea level. The Ken is an interstate river between Uttar Pradesh and Madhya Pradesh. The total length of the river from its origin to confluence with the river Yamuna is 427 km, out of which 292 km lies in Madhya Pradesh, 84 km in Uttar Pradesh and 51 km forms the common boundary between Uttar Pradesh and Madhya Pradesh. The river joins the Yamuna River near village Chilla in Uttar Pradesh at an elevation of about 95 m. The river is the last tributary of Yamuna before the Yamuna joins the Ganga. The river basin lies between the latitudes of $23^0 12'$ N and $25^0 54'$ N and the longitudes of

$78^0 30'$ E and $80^0 36'$ E. The total catchment area of the basin is 28058 sqkm, out of which 24472 sqkm lies in Madhya Pradesh and the remaining 3586 sqkm in Uttar Pradesh.

The basin covers the areas of Jabalpur, Sagar, Damoh, Panna, Satna, Chhatarpur and Raisen districts of Madhya Pradesh and Hamirpur and Banda districts of Uttar Pradesh. It is bounded by Vindhyan range in the south, Betwa basin on west, free catchment of Yamuna below Ken on east, the river Yamuna on north. The important tributaries of Ken are Alona, Bearma, Sonar, Mirhasan, Shyamari, Banne, Kutri, Urmil, Kail and Chandrawal. Out of these, Alona, Bearma, Sonar, Mirhasan and Shyamari join Ken River upstream of the project site.

The Betwa River originates in the Raisen district of Madhya Pradesh near Barkhera village south-west of Bhopal at an elevation of about 576 metres above mean sea level. The Betwa River is also an interstate river between the two states viz. Madhya Pradesh and Uttar Pradesh. It flows in a northeasterly direction. The total length of the river from its origin to confluence with the Yamuna is 590 km, out of which 232 km lies in Madhya Pradesh and the balance 358 km in Uttar Pradesh. The river joins the Yamuna near Hamirpur in Uttar Pradesh at an elevation of about 106 m. The river basin lies between the latitudes of $22^0 54'$ N and $25^0 00'$ N and the longitudes of $77^0 10'$ E and $80^0 20'$ E. The total catchment area of the basin is 43895 sqkm, out of which 30217 sqkm lies in Madhya Pradesh and the remaining 13678 sqkm lies in Uttar Pradesh.

It covers the areas of Bundelkhand uplands, the Malwa plateau and the Vindhyan scrap lands in the districts of Tikamgarh, Sagar, Vidisha, Raisen, Bhopal, Guna, Shivpuri and Chhatarpur of Madhya Pradesh and Hamirpur, Jalaun and Jhansi districts of Uttar Pradesh. During its course from the source up to the confluence with the Yamuna, the river is joined by a number of sub-tributaries, the important among them being Bina, Jamini, Dhasan and Birma on the right bank and Kaliasote, Halali, Bah, Saga, Narain and Kaithan on the left bank. In addition, there is a large hydropower and irrigation multipurpose project proposed on a portion of the Betwa in MP.

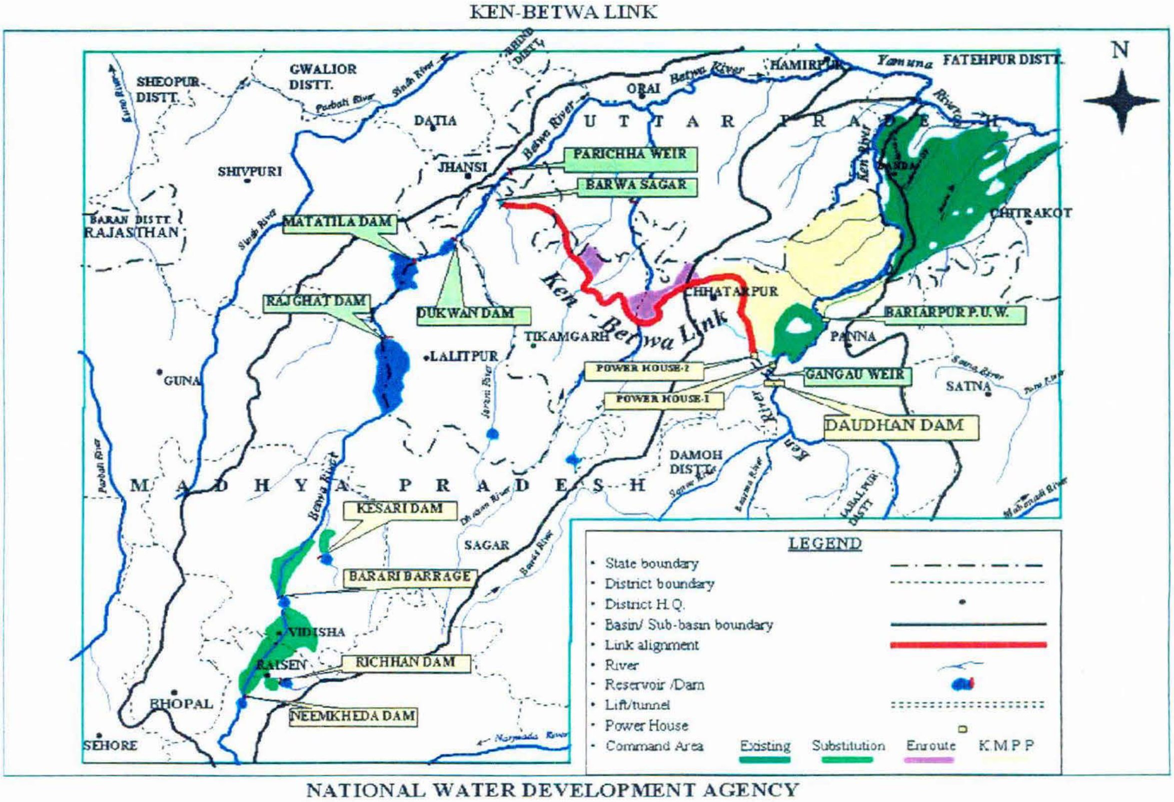


Fig.1.3. Map of the Ken-Betwa Link Project (Source: NWDA), showing the proposed plan for construction of the dams, reservoirs, hydroelectricity projects and link canal.

B) Canal Details

The proposed link canal will take off on the left bank of the Ken River at 245.5 m from the tail race of power house-1. The proposed link canal will run in almost northly direction for a distance of 81 km in Madhya Pradesh, thereby passing through the Bhusor and Bandari protected forest area of Chattarpur district. Thereafter, it will run in westerly direction for a distance of 131.4 km within the vicinity of the state boundary between Madhya Pradesh and Uttar Pradesh. The canal will cross on its way the Dhasan River, a major tributary of Betwa, many other minor streams, state highways, railway line and Pabra and Magarwara reserve forest till it terminates in a reservoir across the kainau nadi near village Jobra. This terminal reservoir will have a storage capacity of 60 MCM.

1.5. SCOPE AND OBJECTIVES

The scope of this research is to develop a water resource assessment map of Ken-Betwa River linking area by using Remote Sensing and GIS techniques. The main aim of my research is to find out the impacts of river linking on land and water resources of the area as we well as drought in the Bundelkhand area. By using recent mapping technology and spatial modeling tools we can study impact assessment. The water is a scare resource in Bundelkhand. The overall aim of this study is to contribute towards systematic groundwater studies utilizing remote sensing, field studies, Digital Elevation Models (DEM) and Geographic Information Systems (GIS) in the assessment of groundwater resources of Bundelkhand.

In order to obtain a meaningful assessment of impacts on regional hydrology, a detailed geomorphic and hydrological assessment of project affected and influenced area on the catchments is necessary. This will serve as a baseline survey and suggest the socio-economic goals that must be realized with the model changes in geomorphology, development of agricultural activities, thus leading to hydrologically beneficial land use planning and cropping patterns.

The major objectives are:

- To study ground water and surface water quality of Ken-Betwa River linking area.
- To study ground water level and rainfall pattern in Ken-Betwa River linking area.
- To identify areas within the Ken-Betwa watersheds those are at risk of being impacted by the Ken-Betwa River linking.
- To identify fluctuation in water level and drought condition of Ken-Betwa River linking area.
- To prepare and integrate various thematic layers pertaining to land system.
- To identify probable impacts of river linking on land use/land cover.

CHAPTER -II

LITERATURE REVIEW

2.1 RIVER LINKING PROJECT: AN OVERVIEW

The basic idea behind river linking project is to transfer the water from "surplus" river basins to "deficit" basins in order to reduce imbalances arising due to non-availability of water. It is not a concept, as has been fixed on providing supply augmentation as the solutions, ignoring the 'soft' demand-side management options (Biswas, 1979). This has resulted in plans for several inter-regional water transfers (IWT) in many parts of the world. Some of the prominent examples are from Canada where, 16 inter basin water transfer schemes have been implemented for hydropower development. In the USA the longest and best known schemes implemented so far is the California State Water Project, which envisages transfer of water from the Sacramento river in North California towards the south through a 715 km-long aqueduct with a lift of about 1,000 m to meet domestic, industrial and irrigation demands (NWDA 1982). Similarly, in China, there are schemes existing since time immemorial, which have now been supplemented by modern construction techniques. Now China is also planning for a transfer of 45 BCM of water from the Yangtze River to the North China Plain. In grandiose North American Water and Power Alliance (NAWAPA) scheme, it includes numerous plans for the distribution of water from areas with high precipitation in the north-western part of North America to less water endowed areas of Canada, United States and Mexico (Biswas, 1978). But due to high cost and environmental problems associated with the project components the project was abandoned. Similarly, engineering proposals were put forward for large transfer of water from humid to the less humid regions of Soviet Union (Micklin, 1977). The results obtained varied from country to country. Russia's ambitious project of diverting the waters of Amudariya and Syrdariya, which drained into Aral Sea, turned out to be a great success when the cotton production was top in the world. But the success soon turned into a curse as the cotton production declined slowly because of soil degradation by salinization (Kumar and Srinivasa, 2004). As a result, the climate became too hostile and hundreds of livelihood was displaced; the area became one of the sickest places on the earth due to pollutants blowing with winds from dry bed.

The Inter-regional water transfers are appealing because of the great amount of water produced, which drastically changes the water scenario in the implemented region (Golubev and Vasiliev, 1978). As per Okamoto's, (1983) study on Japan's water transfer programme specification has been given to the importance of technical, economical and environmental aspects involved in the study of IWT. He stated that all small scale inter basin transfer was economical rather than mega water transfer projects and thus, proposed step wise procedure for the planning and execution of the IWT.

As per the study undertaken by Hermann (1981) on environmental implications of sustainable water transfer from the Chang Jiang to the North China Plain in China. The most important implications from this study were:

(i) The combination of seepage and deep percolation losses would cause a rise of ground water table. This meant severe water logging;

(ii) Because of the aridity in the North China plain, a soil water potential gradient developed in such a way that water moved upward which resulted in salinization of the root-zone in soil horizons as well as in the upper soil. This process of salinization resulted in severe deterioration of agriculture, and thus expensive relief measures would have been taken into account before water transfer among the regions.

Alternatives to linking of rivers, namely rain and rooftop water-harvesting, conventional water-conservation techniques, re-use and recycle of wastewater, irrigation return flow and artificial groundwater recharge, dynamic recharge by over-exploitation of groundwater, etc. have been examined quantitatively, all these approaches have been discouraged not only on technical and economic viability grounds but also because of pollution threats to subsurface aquifers (Biyani A. K, 2004). There is a need to revaluate all the secondary information which may includes new technology like detailed terrain analysis, digital terrain model, conducting high precision survey using fly map techniques, laser mapping, collection of baseline environmental information, and use of remote sensing & GIS for further analysis (Mukherjee S., 2003).

The socio economic study and collection of environmental baseline data will form a key component of the river-linking project. The success of this project has to be taken on the basis of proper mass awareness through mass media and involvement of NGO's (Mukherjee S., 2003).

In India too, the idea of inter-basin transfer is not a new concept. The projects such as, the Periyar-Vaigai system, Indira Gandhi Canal and Telugu Ganga Canal are some classic examples of IWT. The idea of networking the rivers in India was originally conceived by Sir Arthur Cotton for inland navigation. On the basis of his planning, the Ganga-Mahanadi connection was implemented and operated till 1930's. Later in 1975 it was Dr. K. L. Rao, an engineer and a Central minister in 1972 Government of India had revised and proposed a plan in which, Dr. Rao had divided the whole country into four zones and calculated both the water potential and cultivable area falling in each zone (as shown in figure 2.1) . His analysis had revealed that Zone-I (the Himalayan rivers zone comprising the Brahmaputra and Ganga Basins) had 64 percent of total water of the country and 44 percent of the total cultivable area, whereas, Zone-II and Zone-III barely had 9 percent and 19 percent of the total water, but had 19 and 35 percent cultivable area respectively; Zone-IV was negligible in water supply and cultivable area (Krueger et al., 2007). As a result of his analysis, Dr. Rao had emphasized the necessity of transferring surplus water through the construction of 2640 kms long canal between Ganga and Cauvery, having total estimation of 1,50,000 crores rupees. This link drawing nearly 60,000 cusecs of flood flows of the Ganga River near Patna for about 150 days in a year and linking it up with the river Cauvery in the south (Radhakrishna, 2003). It proposed to irrigation an additional area of 4 million hectares. But the proposal involved large scale pumping over a head of 550 m, which eventually would have utilized 5000 to 7000 MW power and also the proposal did not have any flood control benefits. Based on these drawbacks, the Central Water Commission (CWC), which examined the proposal, found it to be grossly underestimated and economically prohibitive.

Fig.2.1 Dr. K. L. Rao's Proposal for river linking in India (Source:NWDA)

In 1977, Captain Dastur proposed another project known as Garland Canal Plan. He suggested garland canals, in which Himalayan rivers could be linked individually through 4200 km long canals and peninsular rivers were proposed to be linked individually through 9300 km long canals. Two canals were proposed, one running at the foothills of Himalaya from Ravi river to Brahmaputra river and the second running through Central and Southern part of India (as shown in figure 2.2). Both these were to be linked at Patna and Delhi pipelines. The total cost estimate was 70 million crores rupees (As per 2002 estimates). Even though the proposal received very good response from all sectors of communities but the two committees comprising of experts of Senior Engineers from CWC, state Governments, Professors from IIT, Delhi and Roorkee University and Scientists from Geological Survey of India and Indian Meteorological Department had opined that the proposal was technically infeasible (NWDA, 2002).

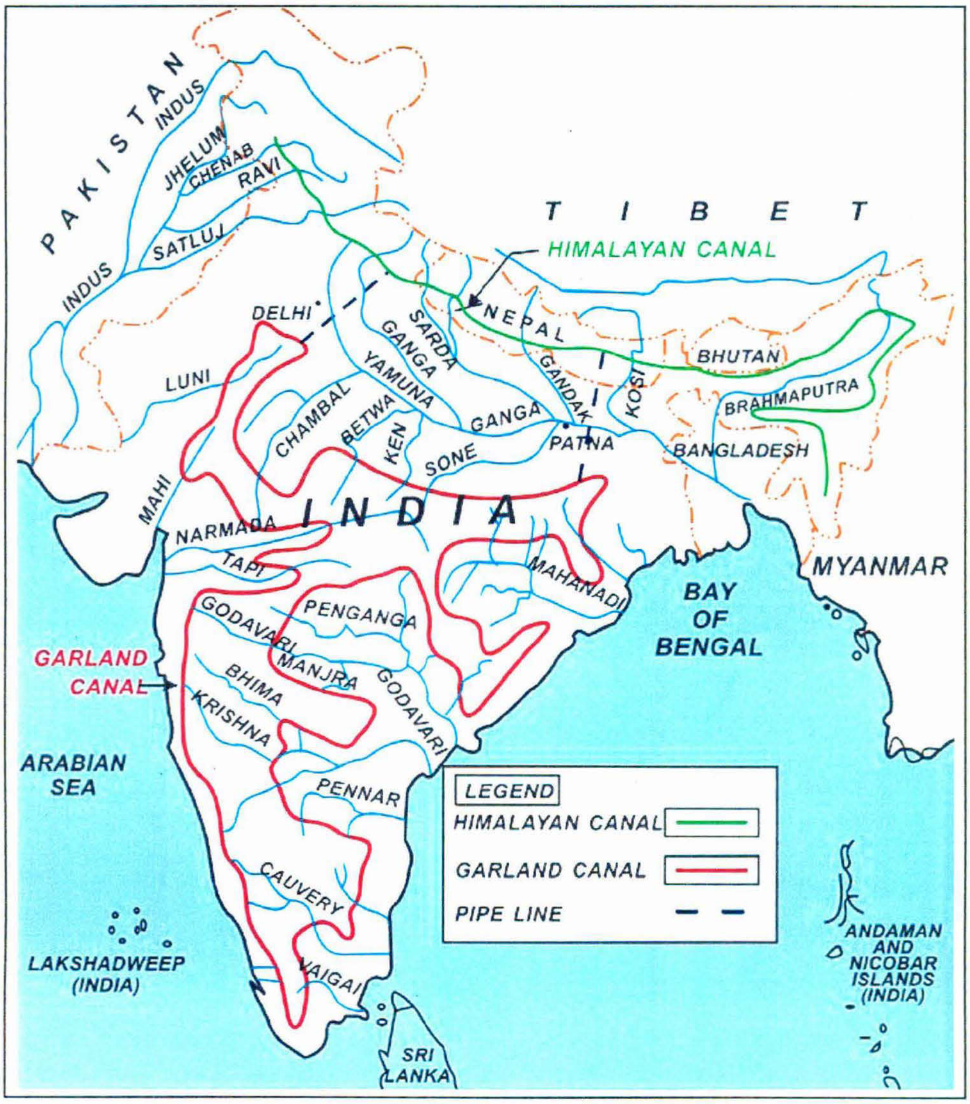


Fig.2.2 Captain Dastur's proposal for river linking in India (Source:NWDA)

2.1.1 The present perspective plan

The continued interest shown by people engaged in Water Resources Development gave further impetus to study inter-basin water transfer proposals in more details. In 1980, the Ministry of Irrigation (now Ministry of Water Resources) and Central Water Commission formulated a National Perspective Plan (NPP) for Water Resources Development. As per this plan, the transfer of water has been proposed mostly by gravity; lifts are to be kept minimal and confined to around 120m only, surplus flood after meeting all in-basin requirements in foreseeable future have been planned for transfer to water deficit areas. This proposal aims to identify the surplus, marginal surplus, deficit and marginal deficit regions based on the water availability, water consumption and basin characteristics (as shown in figure 2.3). This project plan mainly comprises of components viz. (a) Himalayan river development component, and (b) Peninsular river development component. The Himalayan component involves linking of tributaries of Ganga, the Brahmaputra with Mahanadi River using 14 links and peninsular component proposes 16 links. The entire project therefore involves a total of 30 links joining 37 rivers across the country. The projected cost of this project is 5, 60,000 crores rupee (2002 estimate) which is likely to go up to 10, 00,000 crores rupees.

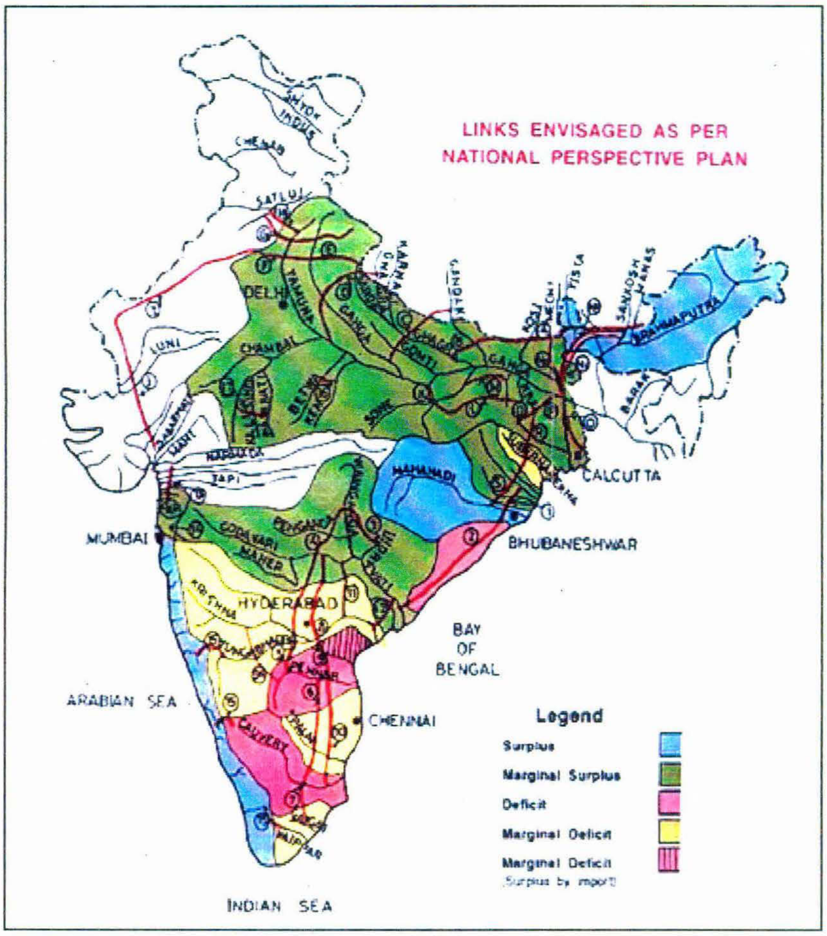


Fig.2.3 Map showing surplus, marginal surplus, deficit and marginal deficit are of India (Source: NWDA).

2.1.2 Expected benefits from inter-linking of Rivers (ILR):

(i) Minimization of damage due to floods and droughts may be via minimizing the natural imbalance.

(ii) 5 metropolitan cities and 101 districts all over India will be benefited through drinking water facility that may be provided as an outcome of ILR.

(iii) Additional 34,000 MW electricity may be produced which would be used in industrial, pharmaceutical and IT sectors for economic growth.

(iv) The project may generate employment for 3.4 crores people.

(v) As result of increase in water availability, almost 3.4 million hectares of land may be additionally irrigated every year.

(vi) Many of the river links will also constitute national waterways. The Brahamputra-Mahanadi link will be a major step in augmenting inland water transport. An inland waterway Authority of India has developed various important waterways such as Allahabad to Haldia of Ganga River, and Sadiya to Dhubri of Brahamputra River. So will use for navigation purposes.

2.2 PROBLEM ENVISAGED AND KNOWLEDGE GAPS:

(A) Environmental issues: The Ganga and Brahamputra Rivers pass through number of industrial cities and rural areas; there may be issues related to water quality of these rivers passing through respective areas. One major threat is the serious contamination of river water bodies in many ways if they are connected with each other through canals and water grids. Mixing of this water with water of the peninsular rivers may result in unwarranted changes in the chemistry causing serious environmental hazards (Suresh Reddy, 2007).

(B) Change in river course: Most of the rivers change their course (the flow direction) every 70 to 100 years in response to tectonic features, aggregation process and climate of the region. Large alluvial rivers that flow across wide alluvial plains can avulse as a result of faulting and earthquakes. Recent investigations revealed that Himalayan front has more severe fault movements and major changes in the course of the Ganga, the

Brahamputra and their tributaries have occurred in the last about 200 years. These issues have not been taken into consideration while planning for ILR.

Rivers, the natural channels for water, carry various nutrients and minerals. They modify local microclimates, including temperature and humidity. Any large scale change in their course will eventually change the patterns in which these environmental entities flow and give shape to the existing local and regional scale climate systems. It cannot be denied that environmental assets, e.g. air and water quality, soil fertility, nutrient cycles, and climate have real values (Gurjar, B. R., 2003).

(C) Effect on Bay of Bengal: Result of river linking under ILR very little water would reach the oceans which will affect the coastal environment. Marine life in Bay of Bengal would be deprived of nutrient supply due to obstruction of river flow. Although wind can transport mineral dust from land, which contain nutrients but they are not readily used for aquatic life cycle (biodiversity). If nutrient-rich river water is not mixed in proper ratio, sea water salinity would increase and would threaten the marine life in the Bay of Bengal. Further, the Bay of Bengal contains less dense and less saline layer of water due to large river flow. Low salinity water layer helps in the maintenance of the high sea surface temperatures responsible for the intensification of summer monsoon in the Bay of Bengal (Rajamani, 2005).

(D) Effect of river flooding: River flooding is not a disaster; it is constructive geological processes that create fertile plains, by depositing nutrient-rich sediments. Further, it had acquired the textures, mineralogy to hold enormous quantities of water and nutrients. Annual flooding helps in the removal of agricultural waste/toxins, deposits nutrient-rich sediments, recharges the groundwater in the farmland, and sustains various riparian habitats. Low frequency and high magnitude flooding makes new cultivable farmland, in addition to all the above parameters involved. River flooding, in lowland areas particularly, is good for agriculture and ecology. If all human civilization and development are due to sustainability of agriculture then there is no earth process that is more beneficial to mankind than Natural River flooding. Flooding becomes a hazard from human perspective, only when the floodplains are taken over for human habitation. Dams in the upstream part of river not only deprive the downstream region of its natural supply of sediments but also increase the hydraulic gradient locally. Both these factors increase the erosive power of water leading to bank erosion provided water is allowed to flow downstream. Curtailing floods in the lower reaches amounts to virtual stoppage of natural recharging of groundwater in the cultivated floodplains and deltas (Rajamani, 2005).

(E) Effects on global climate: Plants act as carbon sinks by sequestering carbon dioxide from the atmosphere through the process of photosynthesis. Better agricultural practices can also contribute in carbon sequestration. So, increase of area under agriculture can act as carbon sink. But agriculture is itself a greenhouse gas emission (GHG) source due to the emissions of N_2O and Methane. It has also been found that Nitrogen compounds and methane may change the ozone budget that have the potential to further intervene in the oxidizing capacity of the atmosphere through hydroxyl chemistry (Gurjar, 2003).

Interestingly, the overall impact of interlinking of rivers on regional climate may be constructive, because this project is estimated to produce substantial amount (up to 34 gigawatts) of non-GHG emission hydroelectric power and allows the substitution of a great number of fossil fuel-based transportation systems that currently have considerable share in air pollution. The reduced particulate pollution might improve the regional air quality while saved GHG emissions could impart benefits from the, global climate change perspective. Thus, the interlinking of rivers is likely to play a significant and at least partially environment-friendly role in meeting the increasing energy demand of an expanding population and economy of India (Gurjar, 2003).

(F) Geo-Political issues: most of the states are not interested for sharing surplus amount of water. Further, India shares almost 17 rivers with Nepal, Bangladesh, Bhutan and Pakistan and has treaties with Bangladesh, Nepal and Pakistan. Within the Ganga and Brahmaputra rivers 60% of the surplus available water was shared with Nepal and Bangladesh. They are strongly opposing Indian river linking programme. It is also believed that China has a proposal to link Yangtze with north Indian rivers, and if it happens there may be no excess water in Brahamputra basin.

(G) Submergence of land and forest cover: Result of river linking almost 75000hectares forest land may be submerged, and several national parks and bird sanctuaries may be affected. For example, the Panna Tiger Natioanla Park in Madhya Pradesh that falls in the vicinity of the linking of Ken and Betwa rivers is going to suffer major damages. Over 50 square kilometers of land, which is a habitat to many endangered species that fall under the wild life protection act 1972, will get submerged. Similarly in Uttar Pradesh the Jim Corbett National Park that falls under Shadra-Sahayak Canal Link will bear irreparable losses with the submergence of the elephant reserve area (Krueger et al., 2007).

(H) Human resettlement and rehabilitation: The districts covered under this link project are heavily populated and there may be serious issues of human resettlements involved. About 5000 villages would need relocation and 4, 50,000 people have to be rehabilitated as consequences of the implementation of this project. The present feasibility report of KBLP prepared by NDWA does not address any of these issues and there is no rehabilitation program formulated as yet. Although, it is important to recognize that this project has been proposed to address issues related to water inequality in India that currently prevails, it is equally important to address other influencing factors in an in-depth manner. Taking into account the unprecedented size, sensitivity of this project, and its influencing parameters it is not possible to discuss here, all affecting parameters with all proposed links. The focus of this study is mainly on assessment of water resources and impacts of Ken-Betwa River Linking area on land and water resources (Suresh Reddy, 2007).

2.3 ALTERNATIVES FOR RIVER LINKING

a) Rain water harvesting and conservation of water resources

It would be more sensible to encourage the traditional practice of conserving rainwater where it falls instead of indulging in schemes with disastrous consequences. This is the only measure which will mitigate the ill-effects of droughts over a major part of India. The most obvious way to preserve as much rain water as possible is to impound it where it falls. This is what our ancestors tried to do and succeeded, as is evidenced by the numerous bunds, tanks and ducts that are characteristic features of the Indian landscape. Instead of promoting such efforts and keeping the structures in good condition we have allowed them to fall into disuse. These structures once full with water have now disappeared, becoming victims of rapacious estate builders and cities have been allowed to expand without limit creating pockets of enormous water consumption. Extensive deforestation of hill slopes has allowed rain water to run-off and disappears in no time. Before indulging in implementation of such projects which cost enormous amounts of money, it would be far safer and prudent to examine whether we have used available resources wisely. In major dams that have been constructed, loss by evaporation is nearly 30%. In the open system of channels we have adopted for transporting water over long distances, loss through seepage and evaporation is enormous and the alternative of conveying through pipes has apparently not been considered as the cost may over run. Major dams are no doubt constructed at enormous expense but these structures can at best store only one year's requirement and no more and benefit only a small section of the population living in river valleys.

b) Reduce water consumption by the affluent in cities

The actual requirement of water for drinking and keeping alive per person is just two litres a day. This is what a large majority of poor people are subsisting on today. It is to be noted that in USA per capita consumption per person is 1300 gallons m (~ 5910 litres) per day. In the present global scenario, we are changing our life style and waste this amount of water. If this is the aim, the entire water resources of the country will not be able to meet such extravagant demands even for the next five decades. India is not badly off when compared to many other parts of the world with respect to water availability. The average amount of rainfall received over the plains of India is 117 cm as against the global average of only 70 cm. This annual precipitation amounts to as much as 370 million hectare metres of water which is adequate for our requirement. It is for us to manage these resources wisely and well.

c) Prevent wastage of water

Judicious usage of water is a practice which our farmers have failed to adopt due to lack of proper awareness, especially in the fields supplied with canal water. Although water is literally allowed to flood their fields, the yields are less compared to farmers who use the resource judiciously. Many modern gadgets are now available like sprinklers and drip irrigation pipes which can further economize the use of water (Radhakrisna, B. P., 2003). Droughts are caused not due to lack of rains but due to the adoption of wrong agricultural practises and irresponsible usage of water.

d) Large-scale utilization of groundwater in deltas

If the farmers are reluctant, the State should take the initiative to develop a system of bore wells and supply water for irrigation. Large-scale utilization of groundwater especially in the delta region is particularly feasible. In areas away from river valleys, groundwater is the only source of drinking water. Over-exploitation of this precious resource has gone to such an extent that the water table has steadily declined from 10 m to 100 m. Wells have been drilled to 300 m depth and beyond to strike water. Despite these clear danger signals, our politicians and administrators have continued to support the drilling of more and more bore wells without taking effective measures for recharge and proper usage. If this process continues, all the easily available groundwater near the surface will be exhausted, making it dry as dust.

e) Groundwater escaping into the sea

A certain amount of precipitated rainwater flows from the coastal region into the sea through porous rocks and sediments, this component being designated as Submarine Ground Water Discharge (SGWD). If we minimize this discharge and utilize than it may be useful for water management.

f) Controlling the excessive withdrawal of ground water

The continuously falling water table is posing a great risk of low yields of water. All over the country people are using the boreholes, and dug wells causing the over drafting of water. The result of overdraft is complete depletion of groundwater reserve. Shallow wells go dry and springs and streams lose their water. This excessive withdrawal often causes the encroachment of the saline water in the coastal areas Therefore, a detailed and systematic study of the behavior of water table in the well fields its relation to rainfall, extraction and regulation is necessary to overcome and regulate this problem.

g) Recycling and reuse of wastewater

The natural water cycle or hydrological cycle is the best example of recycling and reuse of water for millions of years. Water used for bathing, washing and toilets as well as that used by industries and power generation plants return to the hydrological system as wastewater and effluents. This water can be recycled and reused for beneficial purposes such as agricultural and landscape irrigation, industrial processes, toilet flushing and recharge of groundwater; further it will substantially reduce the volume of fresh water needed to meet the growing demand. More promising is the recycling of water in industrial and thermal power units. The potential contribution would be much more if large public and commercial building complexes are converted to install recycling plants for their wastewater in situ and to use the output for toilets, gardens and other nonpotable consumption (Mishra A. K. 2007).

h) Use of natural geomorphology for recharging ground water reservoirs

India is blessed with numerous and varied type of water bodies. Many of these features such as small channels, lakes and ponds have become abandoned, and remain dry during most part of the year, except during monsoon when they behave as active channels. The water flowing/captured in these abandoned water bodies has great potential for recharging. Afforestation of catchment areas, contouring, leveling of land, creation of farm ponds and check dams across small streams and gully-plugging are measures aimed at arresting the flow of water on the surface and directing its infiltration and percolation (Radhakrishna, B. P., 2003). There is no dearth of easily and economically feasible artificial groundwater recharge techniques. By the use of these techniques the recharge of groundwater reservoir is possible both in consolidated and unconsolidated formations. Furthermore, emphasis would be given on the formation of small watersheds, as it can be initiated at low cost.

i) Efficient management of floods

In Eastern India especially the parts of Assam, Bihar, West Bengal and Uttar Pradesh have experienced the extensive flooding almost every year during the monsoon periods. The Brahmaputra, Ganga, Rapti and Kosi are some of the major rivers responsible for flooding in these states. According to an estimation of the Planning Commission, about 50 million hectares of land is flood prone. The efficient control of the flood in these areas will solve the problem of water scarcity in the other areas. These can be achieved by constructing the diversion canals, check dams and storage reservoirs. Encourage and educate the common man (Mishra A. K., 2007).

2.4 REMOTE SENSING AND GIS BASED STUDIES FOR ASSESSMENT OF WATER RESOURCES:

Remote sensing consists of interpretation, in terms of spectral reflectance emitted by a target from a vantage point that is distant from the target (Mather, P., 1999). The sensors of the satellite normally operate between the wavelengths 0.4μm (visible) to the 0.25μm (microwave) to collect information about the earth, atmosphere, ocean, land and the surfaces. The main function of the remote sensing is to provide spatial information about the surface and near surface feature of the earth in the form of aerial photographs and satellite imagery for analysis, interpretation and mapping (Mukherjee, S., 2005, Mukherjee S. et al, 2007). Satellite data provides quick and useful baseline information about the parameters controlling the occurrence and movement of groundwater e.g. geology, geomorphology, soil, land, lineaments. In order to predict groundwater potential zone different thematic maps are prepared. These include annual rainfall distribution, land use, geology, and lineament density. Integrated assessment of thematic maps using a model based on GIS technique gave a suitable method for predicating groundwater potential (Mukherjee, S., Jaisawal R. K., et al., 2003, Mukherjee et al, 2007). Remote sensing techniques have been widely used in the past decade to help in the assessment of water quality studies in different places of the world (Mukherjee et al, 2005 and Mukherjee, S. 2007).

Geographical Information System (GIS) integrated with remote sensing offer many advantages which make them suitable for assessment of water resources. It includes ability to store spatial data and attribute information's, to perform spatial overlay analysis through powerful visual abilities. The GIS Model builder facilitates to predict the future changes by pairing up with multi-criteria analysis. Van Dijck (2001), proposed a method for the assessment and the evaluation of impacts on landforms and soil erosion on ski-trials in the Vosges (France) using GIS, Remote sensing and multi-criteria analysis. Their study analyzes the geomorphic impacts caused due to land cover changes, soil loss through forest clearance for the construction. The impacts assessed through decrease in the scientific quality. Patrono et al. (2001) analyzed geomorphic characterization as important elements for environmental impacts, due to a motorway project, located in a typical alpine environment in northern Italy. They used GIS and multi-criteria method for the evaluation of impacts, where they converted impacts into a computational form that suited spatial data analysis and decision-making. Goudji et al. (2005) carried studies on watershed hydrological modeling on Ganga basin using GIS and HEC-HMS model for preliminary evaluation on interlinking rivers.

Krueger et al. (2007) done similar type of study on potential hydrological impacts and social impacts caused by Ken-Betwa projects. They took into consideration and integrated GIS with multi criteria analysis. Suresh Reddy et al. (2007) also had done study on hydro-geological impact assessment of Ken-Betwa River Interlinking Project. As of now limited technical studies have been done on the assessment of river linking. In the developed countries of the world mapping of impacts and hazards from specific projects are not new endeavours. However, the present work involving assessment of water resources of Ken-Betwa River linking area using GIS will help in understanding and sharing the information to the public at large and other researchers.

2.4.1 Digital Elevation Models (DEM) for hydrological study

The hydrogeomorphological units play a very important role in groundwater prospect (Horton 1945; Thornbury, 1985). In ground water studies DEM are extremely valuable in understanding the properties of terrain (e.g. – Slope, aspect curvature, flow accumulation, stream ordering etc). DEM provides a number of information about the geomorphic and hydrological properties of an area. DEM not only represents ground elevation but also other variables such as ground water level, chemical properties of soil and water are also represented. DEM is useful for extracting drainage, river gradient, elevation and slope maps. To create stream network and sub basin flow direction, filling of sink, flow accumulation, stream network, stream ordering and watershed algorithms were used (Strahler, 1952; Jenson and Tarboton et al., 1991). The most common use of DEM data is the generation of slope values. Slope is an important factor in understanding the groundwater movement and also in suggesting artificial recharges sites (Saraf and Choudhury, 1997, 1998; Saraf, 1999; Saraf et al., 1999). Slope values are also used as input to models. Slope comprises two components namely gradient, the maximum rate of change of altitude, and aspect, the compass direction of this maximum rate of change (Burrough, 1986).

The flow direction dataset is used to create a flow accumulation dataset where each cell is assigned a value equal to the number of cells that flow to it. It is defined flow accumulation as an operator which, given the drainage direction matrix and a weight matrix, determines a resulting matrix such that each element represents the sum of the weights of all elements in the matrix which drain to that element'. If the weight matrix is set to one, the flow accumulation matrix will contain the contributing drainage area of every cell. Finally, the DEM could be used successfully to extract hydrologically relevant information such as altitude, slope, aspect, curvature, and drainage network, etc., which are important to improve distributed hydrological model applications (Flugel, 1996).

2.4.2 Geomorphologic Mapping

Geomorphology deals with the study of landforms and landscapes, including their description, types and genesis. However, the sole attention is diverted by the landforms, which are the end products of actions and reactions between natural surface agencies and the rock types. The overall process of landform formation is controlled by: (a) climatic setting and its variations throughout time, (b) lithology and structure of the terrain, and (c) the time span involved. The hydrogeomorphological units play a very important role in groundwater prospects (Horton, 1945; Thornbury, 1985) and hence it is given the highest weightage for finding groundwater potential zones. Drainage pattern is one of the most important indicators of hydrogeological features, because drainage pattern, texture, and density are controlled in a fundamental way by the underlying lithology (Charon, 1974). In addition, the stream pattern is a reflection of the rate that precipitation infiltrates compared with the surface runoff. The infiltration/runoff relationship is controlled largely by permeability, which in turn is function of the rock type and fracturing of the underlying rock or surface bedrock. Tropical weathering in a humid climate is the principal requirement for the production of a thick regolith. According to Thomas (1966) and Greenbaum (1985), other factors being equal, the formation of a thick regolith is also favoured by structural anisotropy, such as the presence of faults, joints, and fissures in the crystalline basement. These fractures tend to increase the permeability of thick regolith. In addition, most of the structurally controlled streams occur in valleys filled with thick sand and gravel, which are potentially excellent aquifers. Moreover, the channels can act as conduits for the migration of groundwater from deep aquifers to shallow aquifers (Greenbaum, 1985). Some of these are variously named as low-sinuosity, meandering, oxbow lake, and overbank aquifers (Edet, 1993).

2.5 GIS IN GEOHYDROLOGY

Interpolation in GIS (water level, rainfall)

The objective of interpolation is to estimate values at unsampled sites using known values of existing observations at neighbouring locations. Interpolation involves points and lines with values. The preference and selection of interpolation method over others depends on the level of accuracy, number of points or lines, their distance and distribution, compatibility and applicability of the interpolation function to represent the spatial distribution of the concerned parameter (Meijerink, et al., 1994). Different interpolation techniques have their strong and weak points, which are based on the applications. Hydrological, hydrometeorological and hydrogeological point data provide information and idea of discrete points only. Regional overview about any such parameter cannot be obtained until unless these point data are interpolated.

Rainfall in humid regions is more or less homogeneous throughout the area unlike arid zones where rainfall varies widely within small regions. In certain arid and semi-arid zones where rainfall is controlled by particular air mass such as the monsoon, rainfall amount varies gradually with distance. In such zones rainfall vary greatly from place to place since the intensity of the water bearing air mass diminishes with distance. Therefore, for interpolation of point values of rainfall, if widely separated small number of rain-gauge stations should be considered. If the rain-gauge stations are well distributed, the interpolated surface map will well represent the actual rainfall distribution over the region irrespective of interpolation technique. While at some places simple interpolation technique generates better rainfall surface, at other places a more sophisticated interpolation technique is required. In Arc view software, an inverse distance weight (IDW) interpolation will generate a more general surface through weighted moving average operation, whereas a spline interpolation technique will move the polynomial function through the actual points depending upon the tension factor applied. Groundwater surface and its fluctuation are governed by many geological, hydrological and meteorological factors. While temporal variation of water-table depth is governed principally by meteorological and hydrological parameters, spatial heterogeneity of water-table depth is mainly controlled by spatial hydrogeological variations. In spite of hydrogeological inhomogeneity, a static groundwater level in an isotropic aquifer exhibits a smooth and gradual variation of heads. Since groundwater surface in an aquifer exhibits a high degree of spatial continuity, an interpolator that results smooth surface is desirable (Meijerink et al., 1994). Regional gradients with topographic control are often observed but presence of a complex fracture system, dyke or stream channel might influence the aquifer heads locally. Interpolation of hydrological surface requires precautions and prior study of parameter influence over aquifers in hard rock areas. A hard-rock area with high degree of spatial variability in weathered-zone thickness, soil thickness, sub-surface fracture depth and lithology, groundwater levels varies greatly from well to well within near vicinity. Interpolation of groundwater surface in such terrains is difficult and may require help of tricks like part-by-part interpolation within aquifer boundary followed by joining in a GIS environment. Construction of synthetic points along aquifer boundaries, faults or dykes or other influential parameters might help in this regard depending upon situation.

CHAPTER III

STUDY AREA

3.1. GENERAL

Most of the part of the study area lies in Bundelkhand. Historically Bundelkhand till 16th century (during the rule of Chandelas) known as (Jaijak bhukti). But after 16th century it was ruled by Bundelas (Rajput) so its name becomes Bundelkhand. It is a geographic region of central India. The region is divided between the states of Uttar Pradesh and Madhya Pradesh, with the larger portion lying in Madhya Pradesh. The major districts are Jhansi, Banda, Hamirpur, Lalitpur, Orai, Mahoba of Uttar Pradesh and Datia, Sagar, Tikamgarh, Damoh, Panna, Narsinghpur and Chhatarpur of Madhya Pradesh.

3.2. LOCATION AND CLIMATE

The Ken-Betwa link project (KBLP) is one of the links proposed by the National Water Development Authority (NWDA). It involves the linking of the Ken and Betwa Rivers through a 231.45 Km long canal covering the states of Madhya Pradesh (MP) and Uttar Pradesh (UP). The commend area of this link is bound between latitude $24^0$40' E-$78^0$60'N, $25^0$65'E and longitude $78^0$40'N, $25^0$30'E to $80^0$00'N as shown in the figure 3.1. It covers approximately 51700 km^2 of area spread in 17 administrative blocks. The study area is surrounded by low-lying mountains varying in elevation from 72m to 648m. It comprises of undulating and ridges and valleys forming a hard rock hilly terrain. The Bundelkhand generally experiences a semi-arid climate, though this is highly variable depending on the region and the time of year. Indeed, the area is notorious for experiencing droughts in summer and disastrous floods during the monsoon.

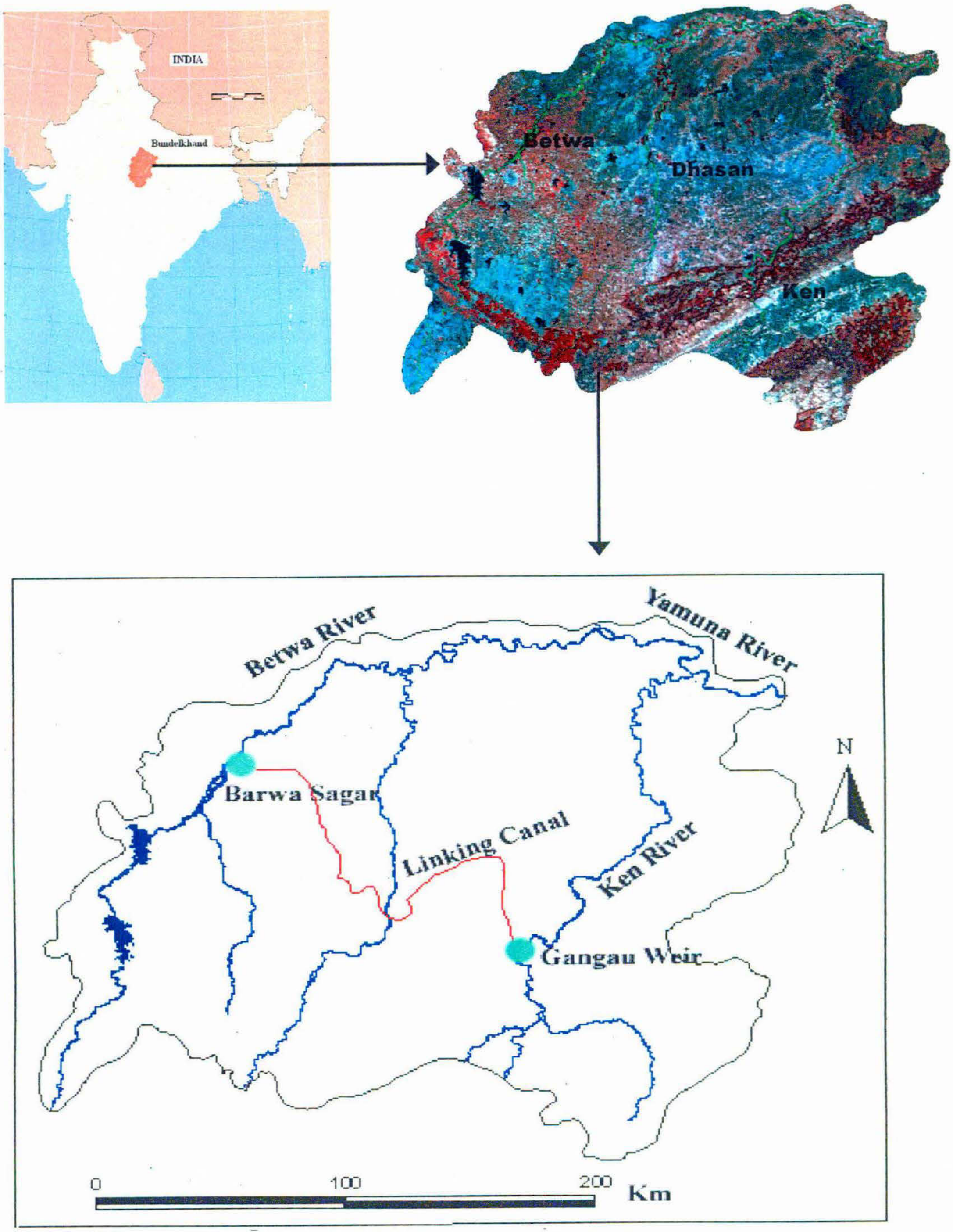


Fig.3.1 Location of the study area

As with the rest of the Indian sub-continent, the Bundelkhand sees two main seasons: monsoon and dry. The monsoon brings over 90% of the annual rainfall between the months of June to September, with the highest precipitation occurring in July and August. On average, the region receives anywhere from 75 cm to 125 cm of rain each year. The dry plains in the north usually receive less while the southeast benefits from more water. The area has average maximum and minimum temperature of 44.2^{0}C and 6.7^{0}C. The temperature ranges from minimum of 6°C in winter to 44 °C in summer. May and June are generally hottest months and December and January are the coldest months. The maximum and minimum values of humidity are 95% and 9% during monsoon and summer seasons respectively.

3.3. GEOLOGY OF THE AREA

The area contains three major groups of rocks with high uncertain ages: the Bundelkhand complex (older than 2600 my) the Bijawar group (2600-2400 my), Vindhayan super group (1400-900 my) as shown in figure 3.2. The study area is predominantly made up of Bundelkhand Granite complex belonging to Bundelkhand Group. This group of rocks includes pink, white and dark coloured fine, coarse to porphyritic granites, magmatites, diorites, synenites and some intrusive basics and metabasics. These granites are frequently associated with pegmatites and quartz reefs. The granite is often traversed by pegmatite veins and well-marked quartz reefs of various dimensions (Ahmad, 1984). The Bundelkhand granites are considered to represent the oldest granite in India. In addition to granites, other intrusive rocks in the Bundelkhand complex include young, mafic to silicic dikes and the ultrabasic rocks, which consist of metamorphosed peridotites, pyroxenites and gabbros (Sharma, R. P. 1982). Foliation is rarely found in them and they have been metamorphosed into grey slabby gneisses in some of the places. Bundelkhand granites have been formed by replacement from hornblende-biotite schists (Misra and Saxena 1956). The Bundelkhand granite is traversed by prominent quartz reefs, which contains veins of pyrophyllite along the joint planes and along the junction with granite. Above Bundelkhand gneissic complex newer alluvium, older alluvium, gravel, sand and clay of recent origin lie uncomfortably which in some places are also termed as buried pediment plains depending upon their mode of formation (Mukherjee S. 1991). On weathering, the granite gives rise to a coarse residual material comprising fragments of quartz, feldspar and other rock fragments. This serves as a good aquifer material specially where covered under thick mantle of alluvium and yields good amount of water to dug wells (Bhattacharya, 1976). The Bijawar group of the area consists of terrigenous sequence of basal carbonates and shales with greenschists or pillow basalts, chloritic shales, ferruginous quartzites and banded iron formations. The group is intruded by gabbros and granites older than the overlying Vindhayan sediments. Vindhayan supergroup have been broadly divided into four major groups namely the Semri (lower), Kaimur, Rewa and Bhander (upper) based on lithological similarities (Auden 1933) and into Lower and Upper Vindhyans on the basis of major tectonic (major unconformity) evidences (Mallet 1869). Vindhayan were further confirmed by magnetic anomaly (Mukherjee S. 1999). The upper Kaimur group rocks of the Vindhayan supergroup are represented by sandstones all over the Vindhayan basin. The sandstones are red to greyish-white, medium to fine grained, compact and highly jointed (Bhattacharya, 1983). Lower Vindhayan formations are represented by Tirohan limestone, Baghain sandstone; diamond-bearing conglomerate of Kaimur group is present in Panna district. The Kaimur sandstones in the area consist of two distinct litho-facies, one red sandstone or sub grey-wakes and the other white sandstone or quartzite. Bedding planes and joint planes are exhibited by both the varieties. The sandstones are medium to fine grained, white to fawn in colour and are well jointed. They have gentle dip upto 15-20^0 north and north-east. These joints are open at surface, with a tendency to close down at depth. The middle protereozoic formations have been deposited over Bundelkhand massif along its southeastern margin are known as Bijawar Group (Medlicott, 1860). The Bijawar Group comprises a succession of a basal conglomerate and quartzite overlain by limestone, breccia, phillitic shale, red jaspers and dioritic traps. These rocks are again well exposed along the southeastern edges of the Vindhayan syncline. Structural geology of the upper renches of Ken River is flanked by undulating plateau with sandstone, shale and limestone (Geological survey of India, 1985). In the plains, recent alluvium engrosses the River upto the Gangau dam. Alluvial deposits of clay, silt and sand of sub-aerial and fluviatile origin are the most recent geologic deposits in the Bundelkhand and are more predominant near the Yamuna River and its tributaries. The upper horizon of alluvium comprises mainly clay and Kankar with lenticular bodies of silt and fine to medium sand. The stratigraphy in the region consists of alluvium soil, Deccan traps, Lameta beds and Vindhayan system (Prakash and Dalela et al. 1981) belonging to protereozoic period (Chakrobarty et al. 2006). The Betwa basin covers area of Bundelkhand uplands, Malwa plateau, and Vindhayan scrap lands. The stratigraphy of rock formations found in the region is mostly alluvial soil, Deccan traps, Lameta beds and Vindhyan system, whereas Betwa basin covers areas of Bundelkhand uplands, Malwa plateau and Vindhyan scarp lands. Among it diverse geologic clusters, the region hosts a variety of economically valuable minerals that have inspired mining activities. Minerals such as limestone, granites, gneisses, basalt, sandstones, diamond, pyrophylite, diaspore, ochre, River sands and silica sands are the major types being mined in various locations throughout Bundelkhand.

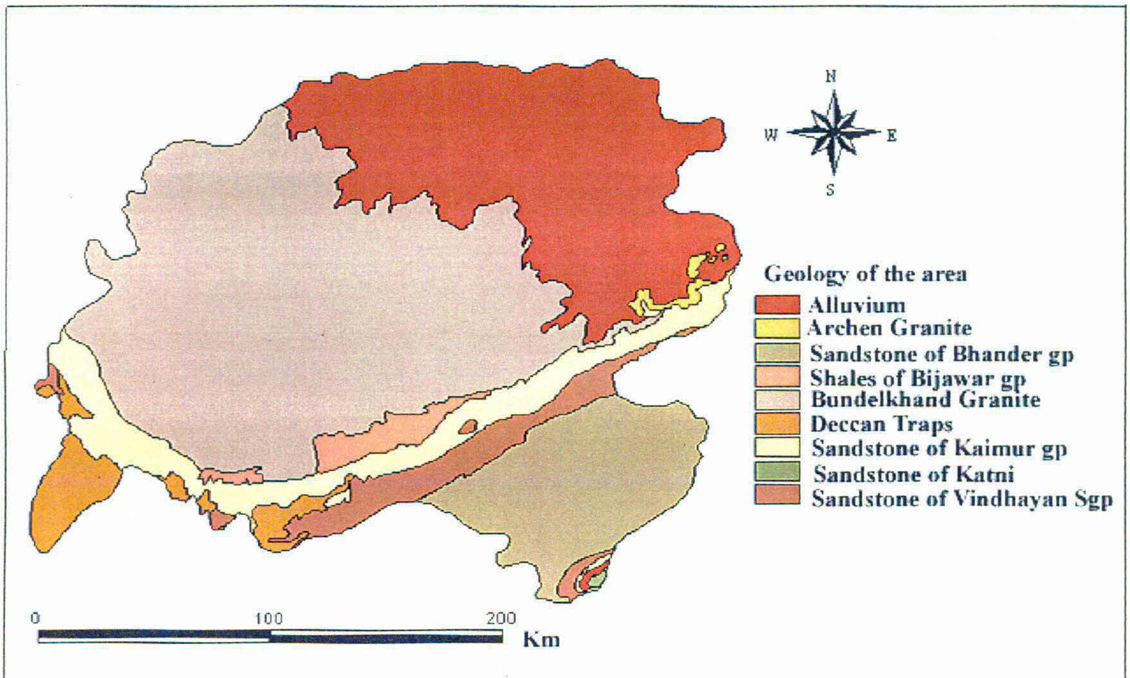


Fig: 3.2 Geology of the Study Area

If we see the geological setup of different districts of the study area than we find that; Banda district is covered by 5-10 m thick alluvium. Granite and Gneisses are the main rock formations. At some places doleritic and diabasic dykes cut across the Bundelkhand Granitoid complex. NE-SW running quartz reefs are also present. Jhansi district is covered by Bundelkhand Gneissic complex with distinct features of NE-SW trending quartz reefs and NW-SE trending dolerite dykes.

Geology and Stratigraphy of Bundelkhand:

AGE	GROUP	SERIES	UNIT
Quaternary (Sub-Recent To Recent)		....	Alluvium-gravels, and silt and clay
Pre-Cambrian	Upper Vidhayan	Kaimur Series	Kaimur sandstone and quartzite
		UNCONFORMITY	
	Lower Vindhayan	Semri Series	Tirohan Breccia Tirohan Limestone Upper Gluconite Sandstone Pallet Limestone Lower Gluconite Sandstone and Conglomerate
		UNCONFORMITY	
Archens		Bundelkhand Group of Rocks	Basic Dykes Schist, Quartz reef etc. Pegmatite, Apatites Bundelkhand Granites

3.4 GEOMORPHOLOGY OF THE AREA

The study area has very dynamic geomorphology manifested as dissected land, flood plain, denudational hills, pediments, paleochannels, valley fills, meander scars, oxbow lake, ravenous land, alluvium, and barren slopes (Mukherjee S., 1996). Landforms are the result of erosion and deposition. The Ken River is flanked by mountains in the proposed reservoirs and hence no distinct fluvial dynamics is observed. The other important morphological units are pediments and buried pediments, which are present all along the terrain (Mukherjee S., 2004). Pediments are broad gently sloping erosional surfaces of low relief situated in between hills and valleys. Valley fills and alluvium plains are mostly confirmed around the streams and channels. Spectacular ravine lands in the north and deep gorges in the south result from the active erosion of the unconsolidated alluvial material deposited by the main streams in the region, namely the Betwa, Dhasan and the Ken. These ravines and gorges are uncultivable and pose an increasing threat to nearby farmland as they continue to expand.

3.5 GEOLOMORPHOLOGICAL STRUCTURES

Geomorphologically, the area depicts both erosional and depositional landforms as shown in figure 3.3. The following geomorphic zones have been identified and mapped in the study area based on remote sensing studies.

A) **Erosional hills:** This represents the remnants of oldest planation surface marked by domes and ridges of Bundelkhand granites, gneiss quartzites and dolerites.

B) **Inselbergs:** Prominent steep-sided hill of resistant solid rock, such as granite, rising out of a plain, usually in a tropical area. Its rounded appearance is caused by so-called onion-skin weathering (exfoliation), in which the surface is eroded in successive layers.

C) **River channel:** Ken, Betwa and Yamuna are main Rivers along with number of tributaries, transporting a heavy amount of silt, clay and sand. Meandering of Rivers is very prominent. The Ken-Betwa Rivers follow meandering path, V-shaped asymmetric valley having very less gradient. The channel material seems to be sand and silt.

D) **Point Bars:** These are fluvial deposits, comprises of mainly sand. They are formed on the inner side of the meander. Their upper surface is not flat forming ridge and swale topography. Point bar are the loci on the convex side of the River curves. This geomorphic feature can be recognized on the images from a characteristic depressed and swell topography arranged in the arc shape. Point bar deposit constitutes highly permeable unconsolidated deposits of fluvial origin. The depressed area between ridges is filled with silty material, some times clay.

E) **Flood Plain Deposits:** Generally area bordering a stream is covered by coarse fine sand, clay and silt, directly deposited at the time of floods. This is comparatively low-lying area, close to the River. The flood plain deposits are developed at the constructive side of River channels. Flood plain areas are very good for agricultural and ground water point of view.

F) **Channel Bar:** The features consist of coarse to fine sand, slit and clay deposits in the channel and are formed due to braiding of River channel, when velocity of River decreases due to fall in gradient. These landforms are good for agriculture point of view, but ground water cannot be explored here.

G) **Area of Badlands:** It is highly rugged and ravenous topography. In aerial photographs, they are recognised by their light tone, gullied landform, parallel to River courses, and sharp pinnate River drainage and fine gradient texture of soil materials. Ground water possibilities become less due to high run off and its impermeable nature. Most of the area of River Betwa, Dhasan and some area of Ken is covered by ravines

H) **Pediments:** A pediment is gently inclined erosional surface carved in bedrock, thinly veneered with gravel, and developed at the base of mountain. Pediments are most prevalent in very arid environments. A pediment may look like alluvial fan on an image, but it is dramatically different. A pediment is an erosional surface, while an alluvial fan is a depositional surface.

I) **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. Typical meanders are composed of depressions and rises on the convex side of the meander loops with the channel migrating towards the concave bank. The clay and silt filling within the sloughs of meander scar areas support vegetation. Channel migration has sometimes resulted in the formation of abandoned channels. The abandoned channels which are partly or entirely cut-off from the main channels is called as oxbow lake.

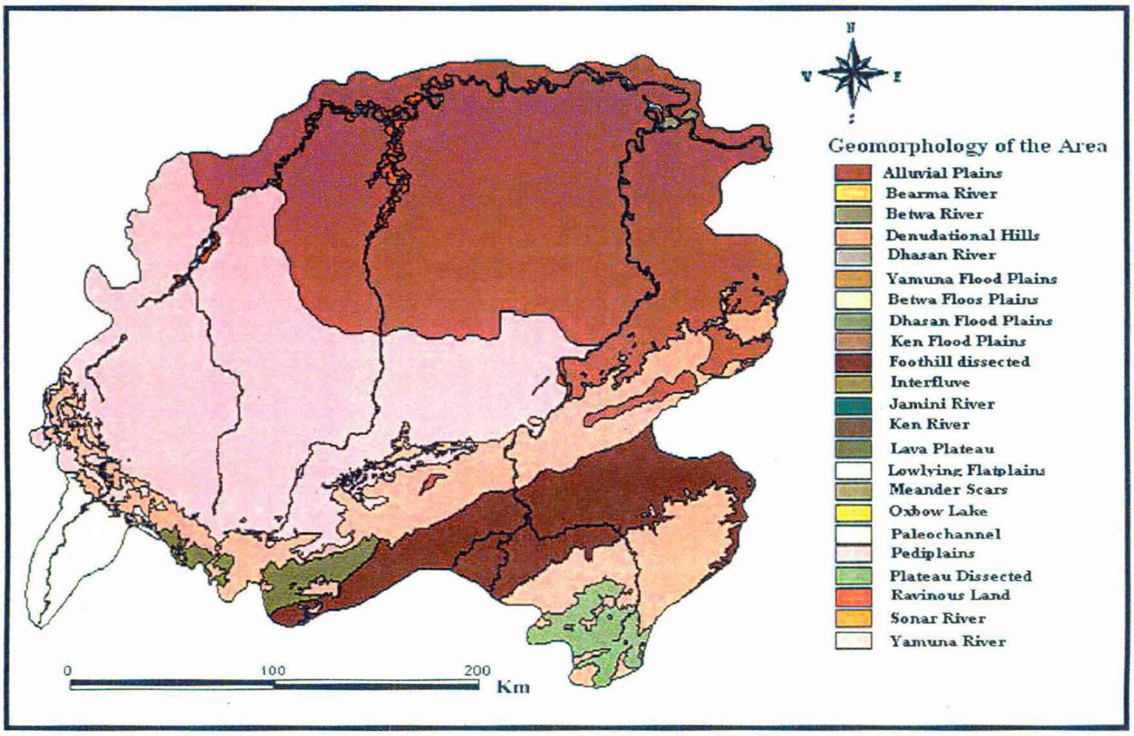


Fig: 3.3 Geomorphology of the Study Area

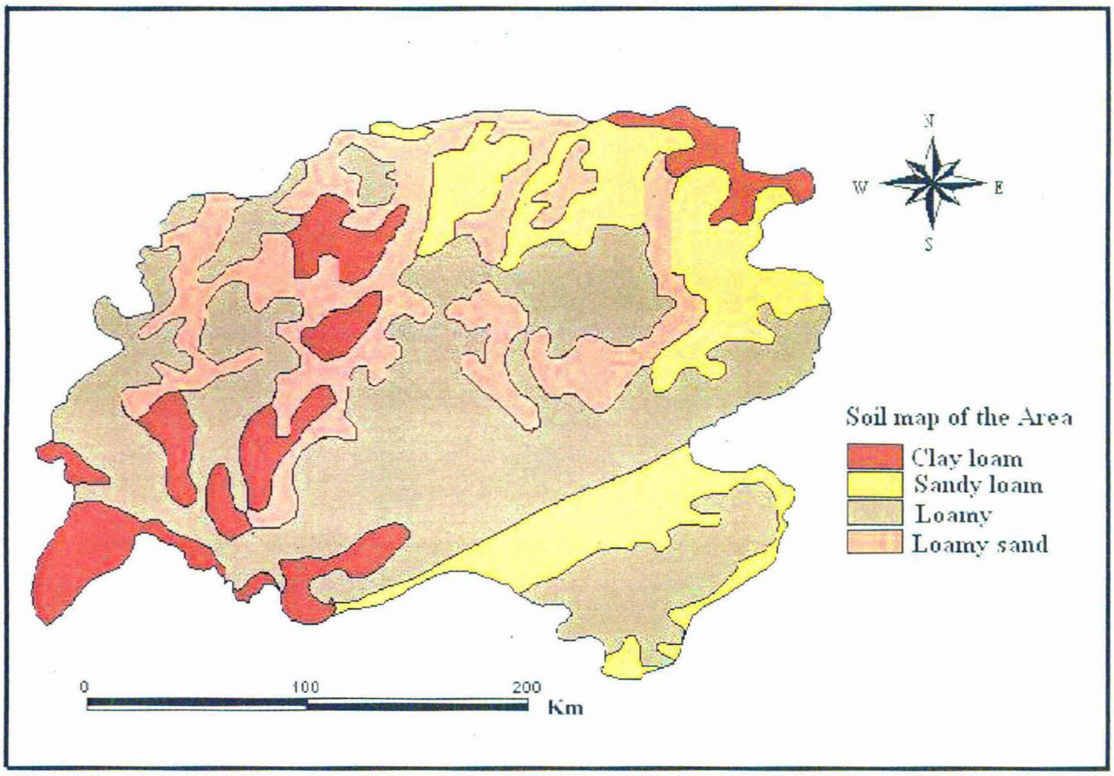


Fig: 3.4 Soil map of the Study Area

Drainage morphometry, using satellite data and GIS has great potential in water resource management (Mukherjee S., and Das, A. K. 2005). If the gradient is sufficient, the stream or River may continue to deepen and widen the River bottom to the point that the River loses velocity and beings to deposit some of its suspended sediment load. This can be the beginning of a River valley with flood plains, wide meander, and occasional oxbow lakes. There are a number of factors that can cause the River or stream to have a reduced gradient including land subsidence. Sometimes a stream or River loses a substantial amount of its source water or their gradient is diminished greatly. When this occurs, even more sediment may be deposited. This can result in extremely broad and sallow valleys that have meanders, meander scars, cut- off meander, point bars, numerous ox bow lakes, and natural levees.

3.6 SOIL MAP OF THE STUDY AREA

The soil is a natural body of minerals and organic materials differentiated into horizons, which differ among themselves as well as from the underlying material in morphology, physical make-up, chemical composition and biological characteristics. Here are many different classifications of soils of the Ken-Betwa River link area by different sources. The simple texture based soil classification on the basis of the texture, the climate, and the topography and denudation process. In the study area mainly four types of soils are found on the basis of soil texture as shown in the figure 3.4, namely.

- Clay loam
- Sandy loam
- Loam
- Loamy sand

On the basis of soil texture, most of the part is covered by loamy soil and most of the Betwa basin covered by loamy sand and ken basin by loamy sand in upper part and sandy clay in lower part. Most of the part of the link canal covers loamy soil and in near Betwa basin it's mainly covered by loamy sand.

3.6 RIVER SYSTEM AND WATER RESOURCES

Main Rivers, Tributaries and Canals

The Bundelkhand is drained by the Yamuna River system, itself one of the principal tributaries of the Ganges. Due to this, drainage occurs principally from north to south, with some local variation depending on topography. The main tributaries of the Yamuna are the Betwa, Ken, Baghain, Pahuj and Dhasan Rivers, most of which are important sources of irrigation water. These Rivers are monsoon fed River. The monsoon brings heavy flooding and the highest flows in all the Rivers and tributaries and during the dry season often become dry and the flow in the major Rivers dwindles.

Tanks and reservoir

Both man-made and natural water bodies are present in the study area. These vary from lakes and reservoirs to tanks and other water harvesting structures, and play an important role in assuring water security in the region. The most well known are: Pahuj reservoir, Barwar sagar, Barwar lake, Siaori lake, Pachawara lake, Dakwan and Parichha reservoirs, Arthar tal, Manikput tal, Majhgawan tal, Bela tal, and Raipura sagar among others. These water bodies provide drinking water supply as well as for irrigation.

Irrigation

Bundelkhand region is predominantly rural and as a consequence, agriculture is the mainstay of most inhabitants. However, the generally semi-arid climate of the region has limited agricultural development and prevented it from reaching its full potential in many areas. Irrigation is generally prescribed as the means to achieve adequate agricultural production and improve the livelihoods of the people. The majority of the irrigated land receives water from later construction works such as the canals. These structures have done much to increase the irrigation potential of the region, but it only benefits one third of the cultivable area.

Groundwater extraction from wells is the primary source of irrigation water over most of the region. The rolling terrain and the variable depth of the soil mean that the groundwater table can be found at a depth anywhere between 3 m and 22 m and above. However, the relative accessibility of groundwater means that most farmers can obtain water from their own land regardless of their distance to a major surface water source. Mechanized pumping using gasoline or diesel powered pumps has greatly increased the use of groundwater for irrigation.

CHAPTER IV

MATERIAL AND METHODS

4.1 GENERAL

Quantitative data such as water level, discharge, sediment yield of Ken and Betwa Rivers are either unavailable to public or very difficult to assess because Ken-Betwa are tributaries of Yamuna River which is the part of classified river system of India so I was unable to access these data but I collect some secondary data for river water level from field survey as well as from the irrigation department. My study therefore, has utilized the readily available data to characterize the current environmental conditions of the area and to assess the area's vulnerability to inundation and erosion resulting from the construction of Ken-Betwa link using a GIS approach. In the GIS based study, which involved data acquisition followed by data analysis, interpretation, and hierarchical modeling algorithm and impact index development. The overall procedure involves retrieval of ground data and maps into digital format. Other components of analysis include selection of coordinate and projection system, extraction of information from satellite remote sensing data, generation of surface maps from point data, analytic hierarchical ranking, model builder and interpretation of the results.

4.2 SATELLITE DATA

4.2.1 Landsat Satellite:

The Landsat Program is a series of Earth-observing satellite missions jointly managed by NASA and the U.S. Geological Survey. Since 1972, Landsat satellites have collected information about Earth from space. Landsat satellites have taken specialized digital photographs of Earth's continents and surrounding coastal regions for over three decades, enabling people to study many aspects of our planet and to evaluate the dynamic changes caused by both natural processes and human practices. There are three different types of sensors have been flown in various combinations on the missions. These are return Vidicon (RBV) camera system, the multispectral scanner (MSS) system and the Thematic Mapper (TM). Landsat images have found a large number of applications, such as, agriculture, botany, cartography, civil engineering, environmental monitoring, forestry, geography, geology, land resources analysis, land use planning oceanography, and water quality analysis.

4.2.2 Characteristics of Landsat Satellites and Their Sensors

Satellite Capabilities	
Particulars	Landsat 6,7
Altitude	705 Km
Orbit	Near-polar, Sun-synchronous
Inclination	98.2 degrees
Period	99 Minutes
Equatorial crossing time	0945 Hours
Repeat cycle	16 days
Swath width	185 Km
Data rate	84.9 MBPS

Sensor Capabilities					
Sensor	Mission	Channel	Spectral spatial resolution (microns)	Spatial resolution	Radiometric resolution
TM	Landsat	1	0.45-0.52	30 m	8 bits
		2	0.52-0.60	30 m	(255 levels)
		3	0.63-0.69	30 m	
		4	0.76-0.90	30 m	
		5	1.55-1.75	30 m	
		6	2.08-2.35	30 m	
		7	10.4-12.6	120 m	

4.2.3 Digital Elevation Data

The Shuttle Radar Topographic Mission (SRTM) derived elevation data on a near-global scale was used to generate a regional digital topography of the study area. SRTM is an international project spearheaded by the National Geospatial-intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA) to map the world in two dimensions. These are available in both Arc Grid and Geo Tiff format to facilitate their ease of use in a variety of image processing and GIS applications. The SRTM data is available as 3 arcs second (approx. 90m resolution).

A large part of the study area is flat alluvial plain with some mountainous terrain and with varying slope from north-west to south-east. Therefore this data set has been used to extract topographic evolution, slope, aspect and relief of the study area and was also useful in identifying some of the geomorphic features of the study area.

4.3 THE PREPROCESSING OF SATELLITE IMAGES

(1) The Landsat Data for the year 2000 of the study area was acquired.

a) The image was downloaded for spectral bands1 to 7.
b) Layer Stacking: The image was stacked for bands 1, 2, 3, and 4.
c) Mosaicking and Clipping: the individual tiles were mosaicked and then clipped with district boundary
d) Projection: Finally the projection system of image was Universal Transverse Mercator, spheroid and datum WGS 84.

(2) The SRTM data were preprocessed to transform it into a product usable in GIS: -

a) Conversion of raw data: the image was converted from the DTED Level-2 format to the ESRI grid format (resolution 79.6x 79.6 meter).
b) Mosaicking: the individual tiles were mosaicked and then was clipped using district boundary.
c) Projection: the final output of step b was projected into Universal Transverse Mercator, spheroid and datum WGS 84.

4.4 ANCILLARY DATA

The following data has been acquired to supplement the Landsat, DEM and IRS data in the present study.

a) Survey of India Topographic Maps

Following topographic sheets cover the study area

Scale	Survey of India Topographic sheets reference
1:2,50,000	54 K, 54 L, 54 O, 54 P, 63 C and 63 D

b) District Planning Maps

Districts	Details	Data source
Panna	1:100000	National Atlas & Thematic Mapping Organization (NATMO), 2001
Charttarpur	1:100000	
Tikamgarh	1:100000	
Jhansi	1:100000	
Hamirpur	1:100000	
Banda	1:100000	
Lalitpur	1:100000	

c) Annual reports of Central Ground Water Board for the year 1999 to 2005

d) Climatic data of the study area for the year 1999 to 2005 from Indian Meteorological Department.

e) Census record book and Handbook of Basic Statistics of the State Uttar Pradesh and Madhya Pradesh for the year 2001 and 2004 respectively.

4.5 FIELD AND LABORATORY METHODS

4.5.1 Rock sampling

Rock samples were collected from different site of the study area by using geological hammer. Rock samples were collected on the basis of lithological formation. Analysis of rock samples was done by preparation of thin sections of the rock samples and these slides were analyzed by using ML 9000 series (Meiji, Japan) petrological microscope.

4.5.1.1 Introduction

Minerals are naturally occurring substances, usually crystalline, whose Compositions are either fixed or can only vary between certain fixed limits. Rocks, in contrast, are aggregates of mineral grains, usually belonging to more than one mineral species. Rarely one may find monomineralic aggregates, e.g. the igneous rock dunite, Composed entirely of olivine, but these are best referred to as monomineralic rocks (Cox, K. G.). Some minerals have a constant chemical composition and are definite chemical compounds, e.g. quartz (SiO_2), fluorite (CaF_2), and Barite ($BaSO_4$). Others, indeed the majority of the rock-forming Minerals, are solid-solution minerals, are solid-solution series between two or more compounds, termed end- members, of fixed composition. Thus the important group of plagioclase feldspars ranges in composition from the one end- member albite ($NaAlSi_3O_8$) to the other, anorthite ($CaAl_2SiO_8$) via all possible intermediate composition as calcium replaces sodium and aluminium replace silicon in the lattice.

4.5.1.2 Minerals in thin section

A thin section is made by grinding down a slice of rock, which has been gummed to a glass slide, until it reaches a standard thickness of 0.03 mm. At this thickness almost all mineral become more or less transparent and they can therefore be studied by microscopy using transmitted light. The instrument used in these studies is the polarizing microscope, in which the light is polarized before transmission through the crystal. Many properties of crystalline substance that are not apparent in ordinary (non-polarized) light may be observed.

4.5.1.3 The Polarizing Microscope

The normal non- polarizing microscope consists essentially of a light source, a sub- stage condenser, a stage to hold the specimen, an objective, and an eye-piece. The simple polarizing microscope carries in addition a device for producing polarized light, termed the polarizer, a graduated rotating stage as opposed to a fixed stage, and a second polarizing device termed the analyser. The analyser and polarizer are mounted sheets of Polaroid, a substance that allows the passage of light with only one vibration direction. The polarized is usually mounted below the stage and the analyser in the microscope tube where it can be slid into or out of position as required. The two devices are arranged so that the vibrations they transmit are mutually perpendicular. Photomicrographic documentation of microscope visual images was most conveniently achieved by using the trinocular (Photo-binocular) bodies for use with 35 mm SLR camera.

4.5.1.4 Properties of minerals in plane polarized light

a) Crystal morphology: The form of crystal and arrangement of cleavages within them are useful to determine dative characters. Angular relations between cleavages can be measured. This property can be studied on a non-polarized microscope since it doesn't depend on the illumination. It is, however, most easily studied on a petrological microscope where the rotating stage makes possible the measurement of angular relationships. The sub- stage diaphragm is used throughout the observation of morphological features to obtain the necessary image contrast.

b) Relief: Relief is a useful distinguishing property for the igneous rock-forming minerals, all the mafic minerals show high relief but all the felsic minerals (with the exception of muscovite) show low relief. Minerals which have refractive indices which differ markedly from that of the mounting medium (the glue used to stick the rock slice to the glass slide and the cover slip to the rock) show up clearly in thin section and are said to have high relief. Minerals with low relief have refractive indices close to that of the mounting medium.

c) Pleochrosim. The colour observed in a mineral grain in thin section is the result of selective absorption of certain of the wave lengths which make up the white light supplied by the light source. Not surprisingly, the anisotropies shown by crystal in their other physical properties absorbed and also the amount of light absorption, since the wavelengths absorbed and also the amount of light absorbed depends on the vibration direction of the light transmitted. The anistropy shown by non-cubic crystals in their physical properties can also be shown by their absorption - this phenomenon is called pleochroism and is apparent in thin sections when coloured minerals undergo a colour change as they are rotated in plane polarised light.

4.5.2 Water sampling

The study area was divided in several grids and a representative groundwater and surface water samples were taken from each grid. The grids were of 28 x 28 km^2 and samples were collected on the basis of spectral signature from each grid. Samples of ground water were collected in polypropylene bottles (of Tarsons) during month of June of the year 2007 (pre monsoonal) from Ken-Betwa river link site. Most of the groundwater samples were collected from open wells, dung wells, bore wells and hand pumps at various depth. Redox potential and pH were measured at the sampling site itself during the sampling. A part of each water sample was filtered and acidified by HNO_3 for metal analysis in laboratory. All these water samples were kept at 40°C after being brought to laboratory.

4.5.3 Chemical analysis of water samples

4.5.3.1 pH, conductivity (EC) and Total dissolved solids (TDS)

The pH of the water and soil samples were determined with a digital pH meter (Elico, model LI-120) using a double junction reference electrode. Buffers of pH 4.0, 7.0 and 9.2 were used to calibrate the instrument and pH was measured to an accuracy of + 0.01 pH units. The electrical conductivity of the samples was determined with a digital conductivity meter (Systronics, model 306) with automatic temperature compensation. 0.01 M KCI solutions were used for the calibration procedure.

4.5.3.2 Analysis of groundwater Total alkalinity

Alkalinity of the water is its acid-neutralizing capacity and is equal to the sum of all the titrable bases occurring in it. This can be determined by titration of the sample with 0.02 N H_2S0_4 using phenolphthalein indicators.

Reagents

Na_2C0_3 (0.05 N) - weighed 2.5±O.2g (dried at 250°C for 4h) and transferred to a 1litre volumetric flask.

H_2S0_4 (0.1 N) - Diluted 2.8ml conc. H_2S0_4 to 1litre. Standardized against 40 ml 0.05N Na_2C0_3 with 60 ml DDW.

H_2S0_4 (0.02N) - diluted 200 ml 0.1 N standard acid to 1litre.

Standardized by titration with 0.05 N Na_2C0_3.

1 ml = 1.00 mg $CaC0_3$.

Phenolphthalein indicator - dissolved 1 g phenolphthalein in 100ml. ethanol and added 100 ml DDW. Added sodium hydroxide solution (0.2272 N) in drops until the appearance of a faint pink color.

Methyl orange indicator - dissolved 0.1 g methyl orange in 200 ml DDW. Procedure

To 50 ml sample in a conical flask, added 2-3 drops of phenolphthalein indicator. The appearance of pink color indicated phenolphthalein alkalinity; titrated against 0.02N H_2S0_4 to an end point of pink to colorless (PA). Added 3 drops of methyl orange to the same sample and titrated further to an end point change from yellow to pink.

This was total alkalinity (T A).

PA as $CaC0_3$ mg/l = (A x N x 50 x 1000)/ml sample

T A as $CaC0_3$ mg/l = (B x N x 50 x 1000)/ml sample

Where A = ml of H_2SO_4 used with phenolphthalein

B = ml of H_2SO_4 used with phenolphthalein and methyl orange

N = normality of H_2SO_4

4.5.3.3 Total Hardness

Total hardness is defined as the sum of the calcium and magnesium concentrations, both expressed as calcium carbonate, in mg/l. Calcium and magnesium ions in the sample are sequestered upon the addition of disodium ethylenediamine tetraacetate at a pH of 10±0.1. The end point of the reaction is detected by means of Eriochrome black T indicator, which has a red color in the presence of Ca and Mg and a blue color when the ions are sequestered.

Reagents

Buffer solution - dissolved 1.179g disodium EDTA (AR) and 780 mg $MgSO_4 . 7H_2O$ in 50 ml distilled water. Added this solution to a 250ml volumetric flask containing 16.9 9 NH_4Cl and 143 ml. Conc. NH_4OH with mixing and diluted to the mark with DDW.

Indicator - mixed 0.5g Eriochrome black T with 4.5g hydroxylamine hydrochloride and dissolved in 100 ml 95 % ethyl alcohol.

Standard EDTA titrant, 0.02 N - Dissolved 3.723g disodium EDTA (AR), $NA_2H_2C_2H_{12}O_8N_2 . 2H_2O$ in 1 litre DDW.

Standard Calcium solution 0.02 N - Placed 1.000g anhydrous calcium carbonate in a 500 ml volumetric flask. Added 1 +1ml HCI, a little at a time, until all the $CaCO_3$ had dissolved. Added 200 ml DDW and boiled for a few minutes to expel CO_2. Cooled and added a few drops of methyl red indicator and adjusted to intermediate orange color by adding 3N NH_4OH. Quantitatively transferred to a 1litre volumetric flask and diluted to mark with DDW.

Methyl red indicator - dissolved 0.10g methyl red in DDW in a 100 ml volumetric flask and diluted to the mark.

Ammonium hydroxide solution, 3N - diluted 210 ml. Conc. NH_4OH to 1litre with DDW.

Procedure

Standardization - To 10.0 ml standard calcium solution added about 50 ml of DDW, 1 ml buffer solution and 1-2 drops of indicator. Titrated slowly with continuous stirring until the last reddish tinge disappeared and changed to blue at the end point. Care was taken that the total titration duration should be 5 minutes from the time of buffer addition.

N of EDT A = 0.2/ml of EDTA

Total hardness in the samples was determined by diluting 10.0 ml of the sample to 50 ml with DDW and following the same procedure as that for standardization.

Total hardness as mg/l $CaC0_3$ = (A x N x 50000)/ml sample Where

A = ml. EDTA titrant

N = normality of EDTA titrant.

4.5.3.4 Chloride

Chloride is one of the major inorganic anion in water and wastewater. In potable water, the salty taste produced by chloride concentrations is variable and dependent on the chemical composition of water. In a neutral or slightly alkaline solution, potassium chromate can indicate the endpoint of the silver nitrate titration of chloride. Silver chloride is precipitated quantitatively before red silver chromate is formed.

Reagents

Potassium chromate indicator solution - dissolved 50g K_2Cr0_4 in a little DDW. Added $AgN0_3$ until a definite red precipitate was formed. Let stand for 12 h, filtered, and diluted to 1litre.

Standard silver nitrate titrant, 0.0141 M - dissolved 2.395 g $AgN0_3$ in DDW and diluted to 1000 ml. Standardized against NaCl.

1.00 ml = 500:g Cl^-.

Standard sodium chloride, 0.0141 M - dissolved 824 mg NaCI (dried at 140°C) in DDW and diluted to 1000 ml

1.00 ml = 500:g Cl^-.

Procedure

To 100ml sample or a portion diluted to 100 ml, added 1.0 ml K_2Cr0_4 indicator solution. Titrated with standard $AgN0_3$ titrant to a pinkish yellow end point. The reagent blank was also established by the same method.

Cl^- mg /l= [(A-B) x N x 35450]/ml sample where

A = ml titration for sample

B = ml titration for blank

N = normality of $AgNO_3$

NaCl mg /l = (Cl^- mg/l) x 1.65

4.5.3.5 Sulphate

Sulphate is widely distributed in nature and may be present in natural waters in concentrations ranging from a few to several thousand milligrams per litre.

Sulphate ion is precipitated in an acetic acid medium with barium chloride so as to form barium sulphate crystals of uniform size. Light absorbance of the $BaSO_4$ suspension is measured by a photometer and the SO_4^{2-} concentration is determined by comparison of the reading of the standard curve.

Reagents

Buffer solution A - dissolved 30g $MgCl_2.6H_2O$, 5g $CH_3COONa.3H_2O$, 1.0g KNO_3 and 20 ml CH_3COOH (99%) in 500 ml DDW and made up to 1000 ml.

$BaCl_2$ crystals - 20 to 30 mesh.

Standard sulphate solution - 1.00 ml = 100 μg SO_4^{2-}

Dissolved 0.1479g anhydrous Na_2SO_4 in DDW and diluted to 1000 ml.

Procedure

To 100 ml sample or a portion diluted to 100 ml, added 20ml buffer solution and mixed in stirring apparatus. While stirring, added a spoonful of $BaCl_2$ crystals and began timing immediately. Stirred for 60s at constant speed. Poured solution into absorption cell of photometer and measured turbidity at 5min.Estimated SO_4^{2-} concentration in sample by comparing turbidity reading with a calibration curve prepared by carrying 0 to 40 mg/l SO_4^{2-} standards through the entire procedure.

4.5.3.6 Nitrate

Nitrate in groundwater was estimated by the colorimetric brucine method. This method is based upon the reaction of the nitrate ion with brucine sulphate in a 13N H_2SO_4 solution at a temperature of 100°C. The colour of resulting complex was measured at 410nm. Temperature control of the reaction is extremely critical.

Reagents

Distilled water free of nitrite and nitrate was used for the preparation of all reagents and standards.

NaCI solution, 30% - Dissolved 300g NaCI in DDW and diluted to 1litre. Sulphuric acid solution - carefully added 500ml conc. $H_2 SO_4$ to 125ml DDW. Cooled and tightly stoppered to prevent atmospheric moisture.

Brucine-sulphanilic acid reagent - dissolved 1g brucine sulphate and 0.1g sulphanilic acid in 70 ml hot distilled water. Added 3ml conc. HCI, cooled, mixed and diluted to 100 ml with DDW. Stored in a dark bottle at 5^0C.

Potassium nitrate stock solution - 1.0 ml = 0.1 mg $N0_3^-$.

Dissolved 0.72189 anhydrous $KN0_3$ in DDW and diluted to 1litre in a volumetric flask. Preserved with 2ml chloroform per litre.

Potassium nitrate standard solution - 1.0 ml = 0.001 mg $N0_3^-$.

Diluted 10.0 ml of the stock solution to 1 litre in a volumetric flask. This solution was prepared fresh weekly.

Acetic acid (1+3) - diluted 1 volume glacial acetic acid with 3 volumes of DDW.

NaOH (1 N) - dissolved 40 9 NaOH in DDW. Cooled and diluted to 1 litre.

Procedure

Adjusted the pH of the samples to approximately 7 with acetic acid or sodium hydroxide. Pipetted 10 ml of the standards and samples or an aliquot of the samples diluted to 10 ml into the sample tubes. For samples that were saline, added 2 ml of the 30% NaCI solution and mixed contents of the tubes by swirling and placed the sample rack in a cold water bath (0-10°C). Pipetted 10.0 ml of sulphuric acid solution into each tube and mixed by swirling. Allowed the tubes to come to thermal equilibrium in the cold bath. Care must be taken to ensure that temperatures have equilibrated in all the sample tubes. Added 0.5 ml of brucine-sulphanilic acid reagent to each tube and carefully mixed by swirling and placed the rack of tubes in the 100°C water bath for exactly 25 minutes. Removed the rack of tubes from the hot water bath and immersed in the cold water bath and allowed to reach thermal equilibrium (20-25°C). The absorbance was read against the reagent blank at 410 nm using a 1 cm or longer cell.

Obtained a standard curve by plotting the absorbance of standards run by the above procedure against $N0_3^-$ mg /l. Multiplied by an appropriate dilution factor if less than 10 ml of sample was taken.

4.5.3.6 Phosphate

Ammonium molybdate and potassium antimonyl tartrate react in acid medium with orthophosphate to form a heteropoly acid - phosphomolybdic acid that is reduced to intensely coloured molybdenum blue by ascorbic acid.

Reagents

Sulphuric acid, 5N - diluted 70 ml conc. $H_2 SO_4$ to 500 ml with DDW.

Potassium antimonyl tartrate solution - dissolved 1.3715g potassium antimonyl tartrate in 400 ml DDW in a 500 ml volumetric flask and diluted to volume. Stored in a glass stoppered bottle.

Ammonium molybdate solution - dissolved 20g ammonium molybdate in 500 ml DDW. Stored in a glass stoppered bottle.

Ascorbic acid, 0.01 M - dissolved 1.76g ascorbic acid in 100 ml DDW. Stored at 4°C.

Combined reagent - The above reagents were mixed in the following proportions for 100 ml of the combined reagent - 50 ml 5N H_2SO_4, 5 ml potassium antimonyl tartrate solution, 15 ml ammonium molybdate solution and 30 ml ascorbic acid solution. Throughly mixed after the addition of each reagent.

Stock phosphate solution - dissolved in DDW 219.5 mg anhydrous KH_2P0_4 and diluted to 1000 ml. 1.00 ml = 50.0 μg $P0_4{}^{3-}$.

Standard phospate solution - diluted 50.0 ml stock phosphate solution to 1000 ml with DDW.

1.0 ml = 2.50 μg $P0_4{}^{3-}$

Procedure

To 50 ml sample in a clean dry erlenmeyer flask, and added a drop of phenolphthalein indicator; if a red colour developed, added 5N H_2SO_4 solution dropwise to discharge the colour. Added 8.0 ml combined reagent and mixed thoroughly. After 10 min but not more than 30 min, measured absorbance at 660nm. using reagent blank as the reference solution.

Phosphate concentrations in the samples were then determined by comparison with a standard curve prepared for a series of six phosphate standards from 0.01 -0.25 mg/l. A DDW blank with the combined reagent was used for the photometric measurement of the calibration curve.

4.5.3.7 Fluoride

Fluoride in groundwater was determined by ion-selective electrometry using a fluoride selective electrode (Corning) and a standard calomel reference electrode.

The electrical potential of an ion selective electrode is a function of the logarithm of the activity of the ion to be measured, the relationship of which can be given by the simplified Nernst equation:

E_m = constant ± S log A_F.

Where;

E_m = measured potential,

S- is the slope of the calibration curve,

A_F = activity of the fluoride ion.

The measured potential E_m can be measured against the reference electrode, SCE, placed in the same solution. The electrode responds to uncomplexed fluoride ion activity over the range 10 to 10^{-5} M. The total ionic strength of all solutions was maintained constant by the addition of a concentrated (approximately 10^{-1} M) inert electrolyte such as TISAB in equal volumes as that of the standards and samples so that the electrode is calibrated directly in concentration units.

Reagents

Stock fluoride solution - dissolved 221.0 mg anhydrous NaF, in DDW and diluted to 1000 ml. 1.00 ml = 100 μg F^-.

Standard fluoride solution - diluted 100ml stock fluoride solution to 1000 ml with DDW. 1.00 ml = 10.0 μg F^-.

TISAB - The following solutions were prepared and equal volumes were then made upto 1 litre.

NaCl, 1M= dissolved 40 g NaCI in 1litre DDW.

Acetic acid, 0.25 M

Sodium acetate, 0.75 M

Sodium citrate, 0.001 M

Procedure

In suitable beakers, pipetted 10 ml of sample or standards and added an equal volume of buffer. Standards and samples should be brought to room temperature before the addition of buffer. The total volume should be sufficient to immerse the electrodes and permit operation of the stirring bar. Immersed electrodes in the samples and standards and measured developed potential while stirring on a magnetic stirrer. The electrodes were left in the solution at least 3 minutes before taking a final millivolt reading. A series of standards in the range of 0.05 to .2 mg F^{-}/l were prepared by appropriate dilution of the standard fluoride solution in 100 ml. Fluoride concentrations in the sample were directly in mg/l from the standard curve.

4.5.3.8 Sodium and Potassium

Na and K were analyzed in the emission mode of GBC-902 Atomic absorption Spectrophotometer using different concentrations of salt standards to calibrate the standards.

Calcium, Magnesium, Chromium, Cadmium, Lead, Zinc, Iron, Copper and Manganese were measured in AAS using mix standards of these elements.

CHAPTER V

RESULT AND DISCUSSIONS

5.1. GROUND WATER QUALITY OF THE STUDY AREA

Normalized inorganic charge balance, which is, defined as [Tz^+-Tz^- / Tz^++Tz^-] generally represents the fractional difference between the total cations and total anions. Major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-) are generally enough to give a charge balance. Most of the ground water samples showed a charge imbalance mainly in favour of positive charge. The observed charge balance between cations (Tz^+) and anions (Tz^-) support the quality of the data points, which is better than ± 5 percent. This imbalance of Δ Tz could be related to the fact that no analysis was made on organic matter, which is mainly produced by biological activities (Berner-Kay and Berner 1987; Huh et al. 1998). The pH of natural water is a useful index of the status of equilibrium reactions in which water participates. The ground water samples from the study area were mostly alkaline as evident from the range of pH values. The minimum value of pH was 6.91 and maximum value is 8.3. High values of pH have been found in some parts of Lalitpur, and Tikamgarh districts of Madhya Pradesh and Banda district of Uttar Pradesh. The pH values have been found to lie within permissible limit as per the WHO guidelines (WHO, 1984). The value of EC varied from 237 to 2314 µS/cm. The higher value of EC was found in Ramnagar of Banda District, Gursarai of Jhansi District, Charkhari of Mahoba District. This is mainly because of high concentration of dissolved solids and/or high ionic strength of ground water, local variation in soil type, multiple aquifer system and agricultural activities in the area (fig. 5.2). Bicarbonate represents the major source of alkalinity. In the study area, bicarbonate concentration ranged between 73 to 662 mg/L. The mean value was 248 mg/L. The higher value of HCO_3^- was present in Ramnagar, Bisanda, Pahari of Banda District, Charkhari of Mahoba District, Eairach of Jhansi District, Chattarpur District. High HCO_3^- concentration indicates the weathering of carbonaceous sandstones in the aquifer, while low concentration may be due to the precipitation of HCO_3^- along with other cations.

The primary source of chloride is halite (salt) and brines. Anthropogenic (human) sources of chloride include fertilizer, road salt, human and animal waste, and industrial applications. These sources can result in significant concentrations of chloride in shallow ground water because chloride is readily transported through the soil. The concentration of chloride ranged from 11mg/L to 419mg/L. The high values were observed in Ramnagar of Banda District, Charkhari of Mahoba District, Gursarai of Jhansi District, Panna District, Orchha and Prithvipur of Tikamgarh District. An increase in ground water chloride concentration may indicate that chloride was diluted near the surface due to recharge to the alluvium and/or chloride was upwelling in ground water from bedrock below the alluvium. The SO_4^{-2} concentration varied from 0.0 to 200 mg/L. The higher concentration of sulphate was observed in Ramnagar of Banda District, Amanganj of Panna District, Tikamgarh District. The high concentration of Sulphate attributed to breakdown of organic substances of weathered soils, sulphate leaching, from fertilizers and other anthropogenic activities. Low sulphate concentration may have resulted in ground water due to sulphate reduction. The NO_3^- varied significantly from 1.01 to 192 mg/L. The concentration of nitrate exceeding the permissible limit (50ppm, WHO) was observed in Ramnagar, Bisanda of Banda District, Charkhari and Pahari of Mahoba Disrtict, Chorgaon of Jhansi District, Bara of Lalitpur District, Chatarpur and Mankari of Chatarpur District, Ajaigarh of Panna District, Jatara, Palera, Daigura, Baragaon and Majna of Tikamgarh District. The excess of nitrate present in ground water is a serious health hazard resulting in symptoms of methaemoglobinemia in infants. The excess of nitrate can be attributed by farm animals produce considerable amounts of nitrogenous organic waste that tends to concentrate in places where large numbers of animals are confined. The excess amount of nitrogen fertilizers and biocides used on agricultural land may also result in increase in nitrate in Rivers and ground water. It seems probable that the occurrence of high nitrate concentrations in some of the areas would have resulted by leaching of irrigated soil. The F^- varied significantly from 0.00 to 3.20 mg/L. The higher concentration of fluoride was observed in Ramnagar of Banda District, Kabrai, Belatal, Terha and Kapsa of Hamirpur District, Charkhari of Mahoba District, Jakhaura of

Lalitpur District, Laundi and Kukrel of Chatarpur District, Beriyarpur of Panna District. The sources for the fluoride consist of fluorite, which occurs in sedimentary and igneous rocks. Amphiboles, such as hornblende and some of the micas, may contain fluoride, which has replaced part of the hydroxide. Finally among anions bicarbonate is the dominant species while average value trend found was $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > F^-$. The dominant cation was Ca^{2+} followed by Na^+, Mg^{2+} and K^+. The concentration of Ca^{2+} varied from 20.0 to 164 mg/L. The higher concentration of Ca^{2+} was observed in Gursarai of Jhansi District, Laundi, Tatampur and Chatarpur of Chatarpur District, Ajaigarh, Amanganj of Panna District, Tikamgarh, Majna of Tikamgarh District. The high concentration of Ca^{2+} may be due to weathering of carbonate mainly from limestone, gypsum and plagioclase feldspar minerals, which is abundant in some regions. The concentration of Mg^{2+} varied from 3.69 to 185 mg/L. The higher concentration of Mg^{2+} was observed higher in Jaspura of Banda District and Kurri of Chatarpur District. The high concentration of Mg^{2+} may be due to weathering of feldspar, dolomites. The concentration of Na^+ varied from 13 to 580 mg/L. The higher concentration of Na^+ was observed in Ramnagar, Bisanda, Pahari of Banda District, Kapsa of Hamirpur District, Charkhari of Mahoba District, Gursarai, Chirgaon, Garotha of Jhansi District, Bara of Lalitpur District. The most common sources of elevated sodium levels in ground water are:

- Erosion of salt deposits and sodium bearing rock minerals.
- Natural occurring brackish water of some aquifers.
- Irrigation and precipitation leaching through soils high in sodium.
- Infiltration of leachate from landfills or industrial sites.

The concentration of K^+ varied from 0.1 to 54mg/L. The potassium concentrations in water are generally low because of high degree of stability of potassium-bearing alumino-silicate minerals. Potassium ions assimilated by plants become available for resolution, when the plants mature and die or when leaves shed off. In the natural recycling that occurs in forests and grasslands this potassium is leached into the soil by rains during the dormant season or made available by the gradual decay of organic material. Some leakage of potassium to ground water and runoff during these processes would be expected. High concentration of potassium may also result from ashes of grass destroyed in fire. Areas with high proportion of potassium to sodium are uniformly low in dissolved solids as the rock formations do not contain trivially soluble minerals.

- ***Graphical representation of hydrochemical data***

The geochemical evolution of groundwater can be understood by plotting the concentrations of major cations and anions in the Piper (1944) tri-linear diagram. A.Qua software was used for plotting the Piper diagram (fig5.1). For the present study area, Piper plot shows ground water samples in the category of Ca-HCO_3 type followed by Mg-HCO_3 type, Na-CO_3 type, and Ca-Cl type. The Piper plot also shows that Alkaline Earth Metals (Ca + Mg) > Alkali Metals (Na + K) for the ground water samples. On the other hand, we have weak acids (HCO_3^-) more dominant than strong acids (Cl^- and SO_4^{2-}) in the samples. In the study area, the alkaline earths had a lower concentration than bicarbonate, which indicated exchange of Na+ ion from the alkaline earths and the water as base exchanged hardened water.

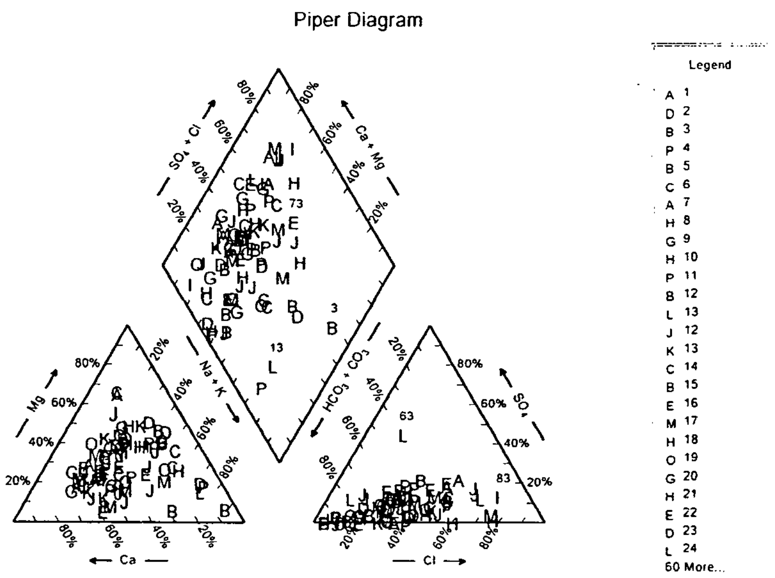
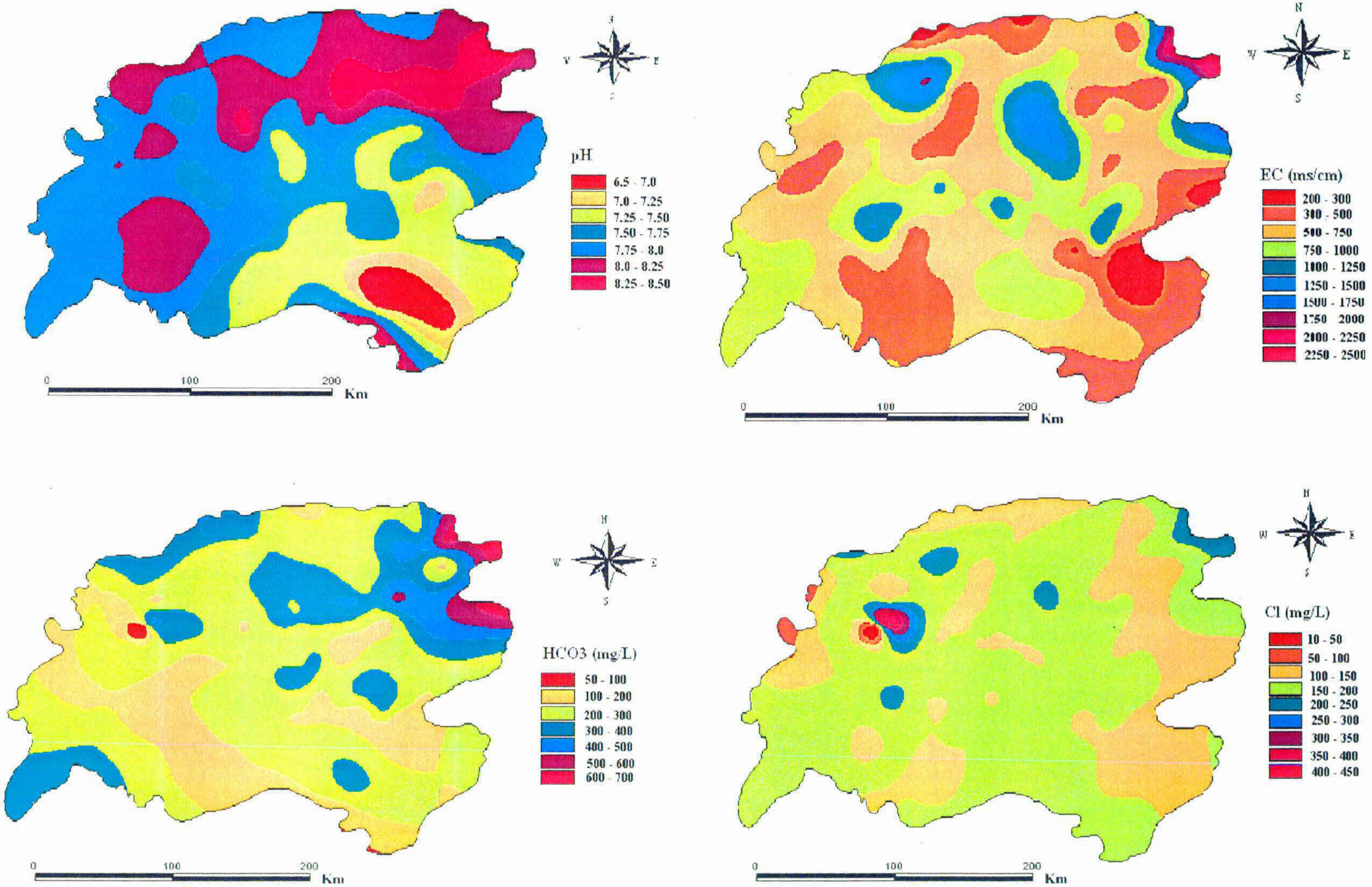
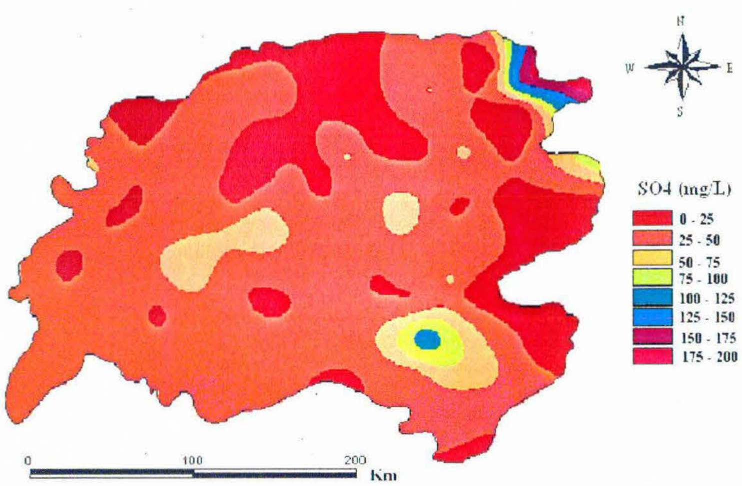
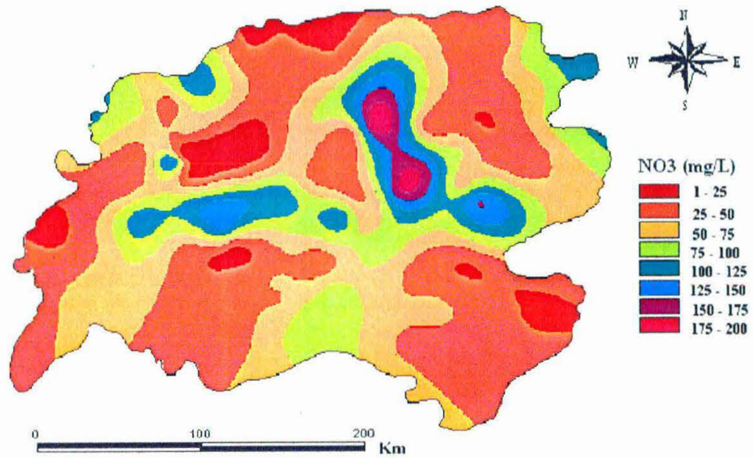


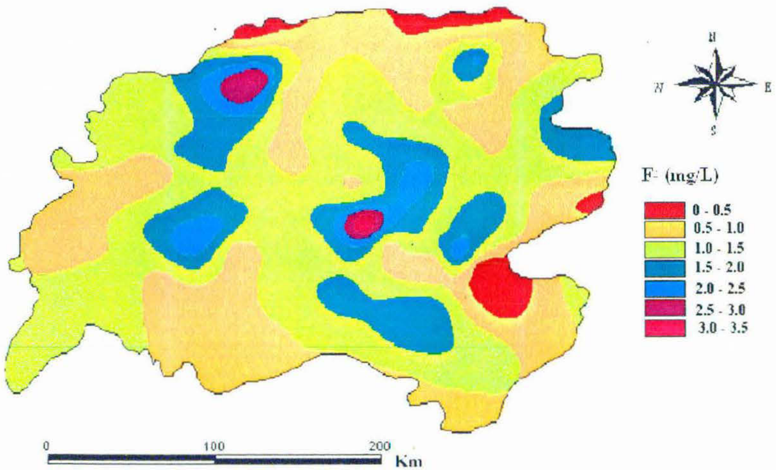
Fig. 5.1 Piper Diagram showing chemical characteristics of ground water

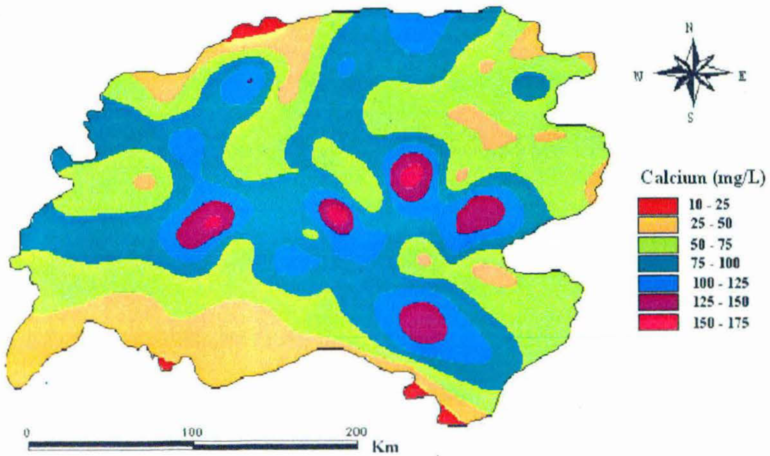
Fig. 5.2 Ground water quality maps of the study area (pH, EC, HCO_3, Cl, SO_4, NO_3, F^-, Ca, Mg, Na, and K)

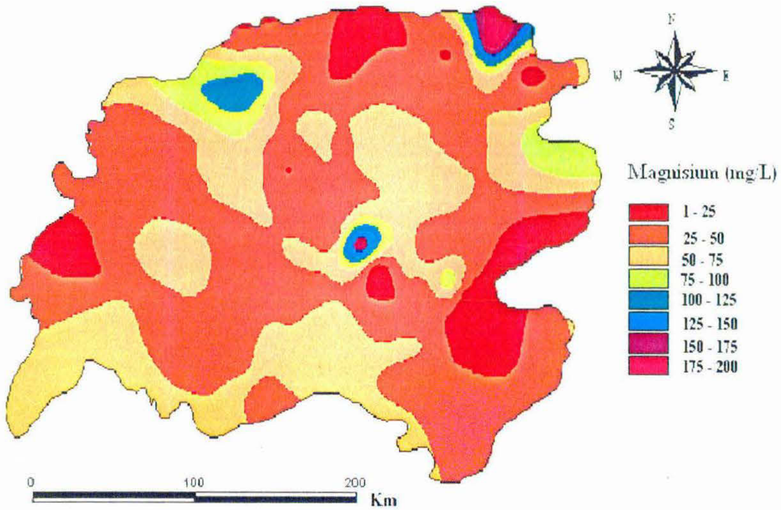


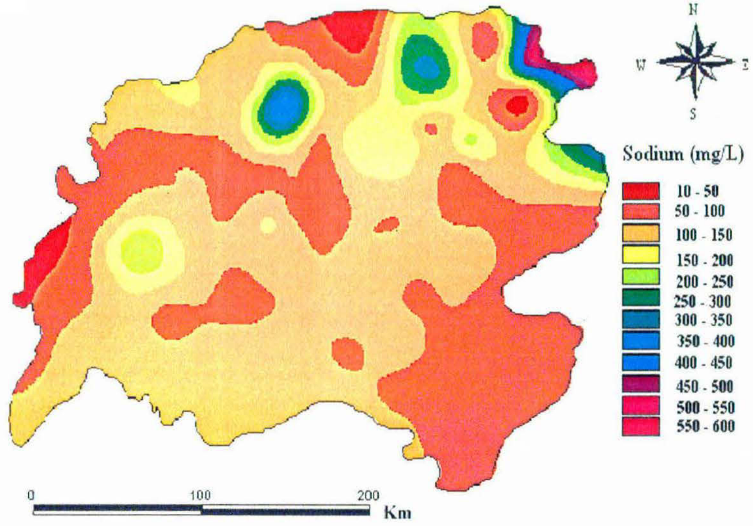

N
W
E
S
SO4 (mg/L)
0 - 25
25 - 50
50 - 75
75 - 100
100 - 125
125 - 150
150 - 175
175 - 200
0
100
200
Km

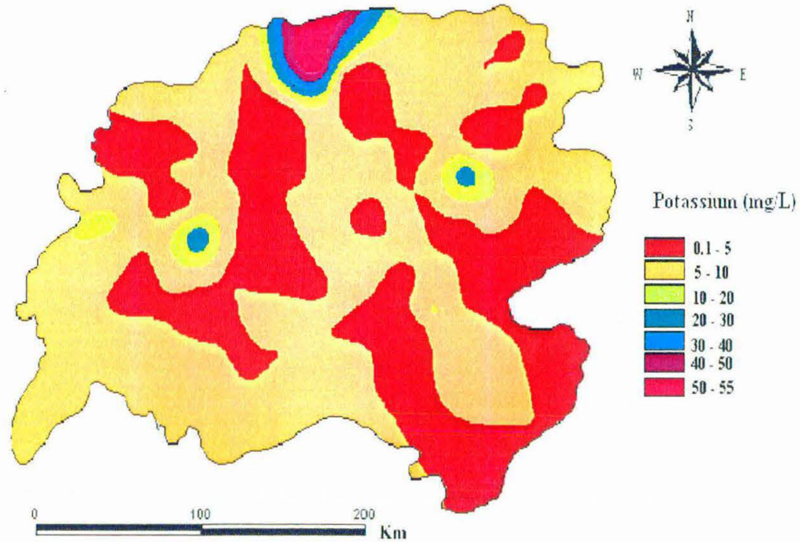

N
W
E
S
NO3 (mg/L)
1 - 25
25 - 50
50 - 75
75 - 100
100 - 125
125 - 150
150 - 175
175 - 200
0
100
200
Km


N
W
E
S
F- (mg/L)
0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
0
100
200
Km


N
W
E
S
Calcium (mg/L)
10 - 25
25 - 50
50 - 75
75 - 100
100 - 125
125 - 150
150 - 175
0
100
200
Km


N
W
E
S
Magnisium (mg/L)
1 - 25
25 - 50
50 - 75
75 - 100
100 - 125
125 - 150
150 - 175
175 - 200
0
100
200
Km


N
W
E
S
Sodium (mg/L)
10 - 50
50 - 100
100 - 150
150 - 200
200 - 250
250 - 300
300 - 350
350 - 400
400 - 450
450 - 500
500 - 550
550 - 600
0
100
200
Km


N
W
E
S
Potassium (mg/L)
0.1 - 5
5 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 55
0
100
200
Km

5.2 COMPARATIVE STUDY OF KEN AND BETWA RIVER WATER QUALITY

Streams and Rivers serve as integrators of terrestrial landscape characteristics and as recipients of pollutants from both the atmosphere and the landscape (Hunsaker & Levine, 1995). Everywhere in the world, the River is shown as a simple channel to remove the water excess in agricultural area, to receive effluents or to hydroelectricity generation. The chemical composition of Rivers varies greatly and is controlled by a series of factors such as climate, vegetation, topographic and geological characteristics of the catchment area. The comparative study of River basin, no doubt, is an important approach, which constitutes a powerful tool of assessment and understanding of the processes occurring in whole environments. One of the objectives of the present study was to carry out a comparative analysis of the hydrochemistry of two basins Ken and Betwa. These two river systems are under different human activities, geological substrate and soil type.

The seasonal rainfall variation, as well as, the nature of soil surface and the river basin geochemistry strongly influences the water chemistry of streams. The variability became key word in all efforts to characterize streams, and is influenced by edaphic factors, human activities and river-bed morphology. River water samples were collected from the different sites of Ken and Betwa River and were analyzed. Most of the samples were collected from near to lining canal (Fig. 5.3). Monitoring of surface waters is primarily done to detect the status and trends in water quality and to identify the pollution from anthropogenic or natural activities. Most important environmental problems in river water quality are eutrophication, acidification and emission dispersion where non point source pollution has become increasingly important within the last decades.

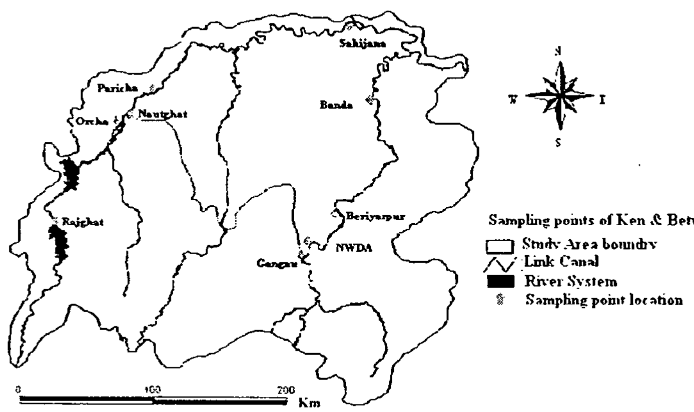


Fig. 5.3 Map showing location of sampling points of Ken-Betwa River linking area

A) pH

The pH of natural water is a useful index of the status of equilibrium reactions in which water participates, and shows whether it is acidic or alkaline. The water samples collected from the Ken River shows an increasing trend in downstream and same as in water samples of Betwa River with a gentle slope. This is may be of due addition of carbonate minerals and silicates except Rajghat in stretch of Betwa River. All the samples of both Rivers were alkaline because, having a pH value (> 7). The pH values have been found to show a positive correlation with TDS (Graph 5.1-5.2).

B) EC

The value of EC varied from 304 to 554 μS/cm. The EC value is found to be higher in Betwa River in comparison to Ken River. Sabater et al. (1990) reported that the lithology of the basin, the soil type and the various categories of land use, together with topographical characteristics. Seem to play a major role in the increase of salinity downstream. However, there is a tendency towards a stabilization of the chemical composition of the water from the source to the river mouth. This can be interpreted as an acquisition of chemical inertia by the water, which rises when the drained surface increases. That is, the water develops a growing resistance to experimenting sudden changes downstream (Graph 5.3-5.4).

C) Bicarbonate

Bicarbonate represents the major source of alkalinity. Bicarbonate concentration is pretty high is both of the river samples. It ranges from 123 mg/l to 243 mg/l. The concentration gradually increases in the downstream due to presence of carbonate rocks in the downstream (Graph 5.5-5.6).

D) Silicate

Silicate concentration in both rivers is showing an increasing trend in the downstream, ranging between 16.6 mg/L (Beriyarpur) to 18.4 mg/L (Gangau Weir) in Ken stretch and in Betwa stretch it is between 21.4 mg/L (Rajghat) and 24.4 mg/L (Sahijana) (Graph 5.7-5.8). The range of concentration of silica most commonly observes in natural water is from 1 to about 30 mg/L. Higher concentration of silica in surface water is related to silicate weathering.

E) Sodium, Potassium vs. Chloride Concentration

The water samples collected from Ken River shows that concentration of sodium increases downstream (ranging between 40 and 46 mg/L). In case of Betwa River sodium concentration was less in comparison to that of the Ken River, but at Sahijana it was high (43 mg/L). Potassium shows a lower concentration and erratic behavior in Betwa stretch may due to some local disturbance where as in Ken it is increasing with a gentle slope at the range of 3.5-4.2 mg/L. Chloride concentration was higher in Betwa River in comparison to that in ken River (Graph 5.9-5.13).

F) Fluoride

Fluoride concentration was high in all the samples but within permissible limit; this may be due to local lithogy of the area. Ranging between 0.34 mg/L (Gangau Weir) and 0.54 mg/L (Banda) in Ken River and in case of Betwa River its concentration ranges between 0.15 (Rajghat) and 0.36 mg/L (Paricha). Fluoride concentration has an increasing trend in the downstream in both the rivers (Graph 5.14- 5.15).

G) Sulphate

Sulphate concentration was moderately high in all samples collected from Ken River ranging between 20.3 mg/L (Gangau Weir) and 22.6 mg/L (Banda) and may be due to presence of pyrite. In case of Betwa River its concentration ranges between 9.1 mg/L (Rajghat) and 13.6 mg/L (Sahijana) (Graph 5.16-5.17).

H) Phosphate

Phosphorus occurs in natural waters and in wastewaters mostly as phosphates. The phosphate concentration is found lowest at Gangau Weir (0.11 mg/L) highest at Beriyarpur (0.17 mg/L). This is may be due localize addition of phosphate fertilizer, otherwise it is showing decreasing trend in Ken downstream. In case of Betwa River it is showing slightly increasing trend in downstream ranging between 0.12 mg/L (Sahijana) and 0.15 mg/L (Rajghat). Addition of agricultural run off in river water is probably the cause of this reverse trend in water samples (Graph 5.18-5.19).

I) Calcium-Magnessium

Both calcium and magnesium concentration showing a moderate increasing trend in downstream in both the rivers. Calcium concentration ranges between 17.65 mg/L (Gangau Weir) and 19.87 mg/L (Banda) in Ken stretch and in Betwa stretch its concentration ranges between 26.2 mg/L (Rajghat) and 29.3 mg/L (Sahijana). Magnesium concentration ranges between 11.56 mg/L (Gangau Weir) to 12.96 mg/L (Banda) in ken stretch, 11.4 mg/L (Rajghat) to 16.7 mg/L (Sahijana) in Betwa stretch. In all the water samples there is a positive correlation between calcium and magnesium concentration (Graph 5.20-5.23).

J) Iron

Iron concentration is moderate in all water samples collected from both Rivers. It shows a slightly decreasing trend in the downstream of Ken River, ranging between 0.784 mg/L (Beriyarpur) to 0.962 mg/L (Gangau Weir). Where as in Betwa River it shows a slightly incresing trend downstream except for one location with comparative lower iron concentration, ranging from 0.07 mg/L (Rajghat) to 0.12 mg/L (Paricha) (Graph 5.24-5.25).

K) Heavy Metals

Manganese concentration show increasing trend towards the downstream of Ken River, while it is decreasing in Betwa River. This is may be due to anthropogenic activities. In Ken stretch Manganese concentration ranges from 0.1005 mg/L (Gangau Weir) to 0.124 mg/L (Beriyarpur) where as in Betwa stretch concentration ranges between 0.132 mg/L (Sahijana) to 0.215 mg/L (Rajghat) (Graph 5.26-5.27).

Nickel concentration in Ken River shows a decreasing trend towards the downstream rangeing from 0.192 mg/L (NWDA GD site) to 0.2067 mg/L (Banda) and in Betwa it ranges between 0.169 mg/L (Paricha) to 0.241 mg/L (Rajghat) (Graph 5.28-5.29).

Cadmium concentration shows an increasing trend in downstream of Betwa River ranging from 0.0121 mg/L (Beriyarpur) to 0.0334 mg/L (Banda). In case of Ken River it has a decreasing trend that ranges between 0.039 mg/L (Sahijana) to 0.048 mg/L (Rajghat) (Graph 5.30-5.31).

Lead concentration in Ken River has an increasing trend downwards, ranging between 0.103 mg/L (Banda) to 0.5275 mg/L (Gangau Weir). In Betwa it is increasing downwards having a range between 0.103 mg/L (Sahijana) to 0.276 mg/L (Rajghat) (Graph 5.32-5.33).

L) Sampling location wise water type analysis:

(i)Water samples collected from Ken River:

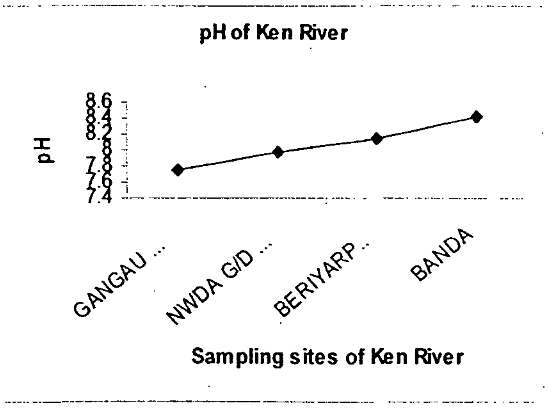
Sampling Location	Process Operating (Water Type)	Calculated TDS (mg/L)	Anion-Cation Balance (% difference)	Total hardness calculated (mg/L)
Gangau Weir	$Na\text{-}HCO_3$	303.070	0.314	91.676
NWDA G/D Site	$Na\text{-}HCO_3$	308.878	1.737	95.104
Beriyarpur Weir	$Na\text{-}HCO_3$	328.36	3.565	102.42
Banda	$Na\text{-}HCO_3$	339.54	0.874	102.98

All the samples collected from Ken River show $Na\text{-}HCO_3$ type water having a decreasing TDS towards the downstream. All the samples show a good Anion- Cation balance (within the range of 2%), except the water sample collected from Beriyarpur Weir.

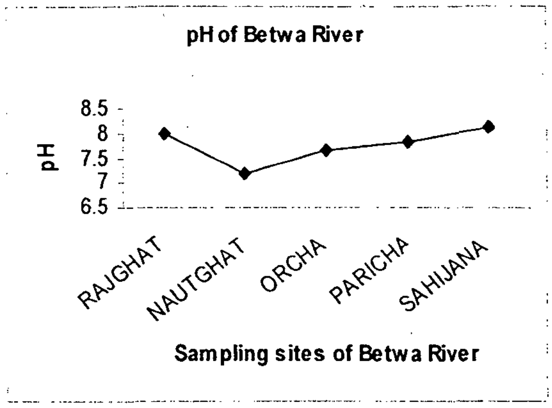
(ii)Water samples collected from Betwa River:

Sampling Location	Process Operating (Water Type)	Calculated TDS (mg/L)	Anion-Cation Balance (% difference)	Total hardness calculated (mg/L)
Rajghat	$Ca\text{-}HCO_3$	232.57	5.225	112.37
Nautghat	$Ca\text{-}HCO_3$	312.86	6.018	129.55
Orchha	$Na\text{-}HCO_3$	328.63	3.535	131.29
Paricha	$Na\text{-}HCO_3$	369.83	3.413	136.17
Sahijana	$Na\text{-}HCO_3$	410.03	3.979	142.18

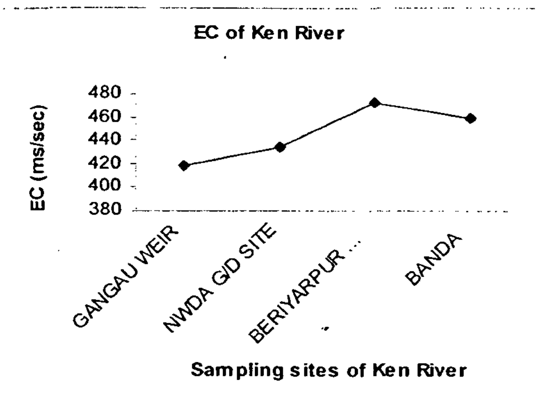
Water samples collected from Orchha, Paricha, Sahijana are of Na- HCO_3 type where as water samples from Rajghat and Nautghat are of Ca- HCO_3 type. All the water samples collected from Betwa River are nothing the 2% ion balance.



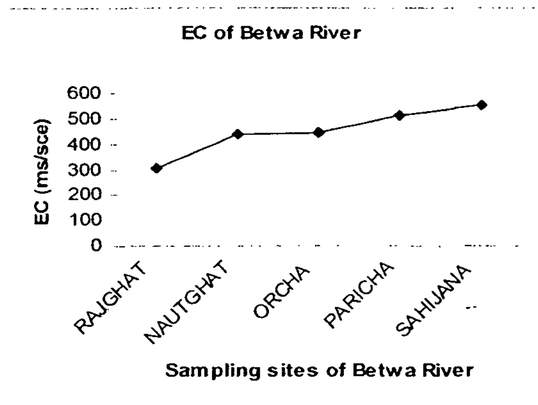
Graph5.1



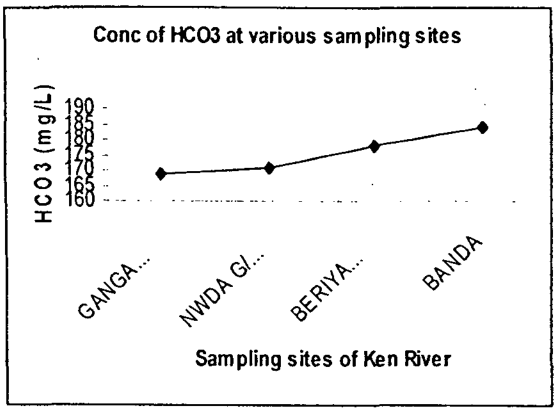
Graph 5.2



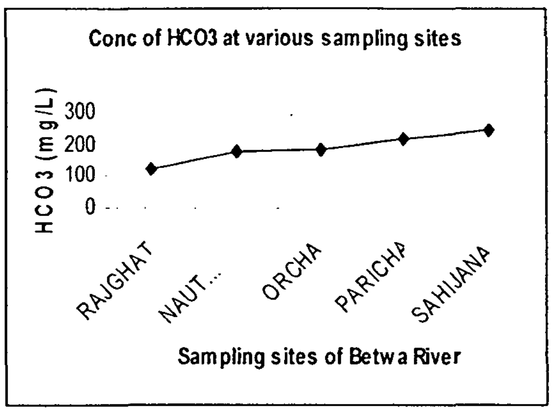
Graph 5.3



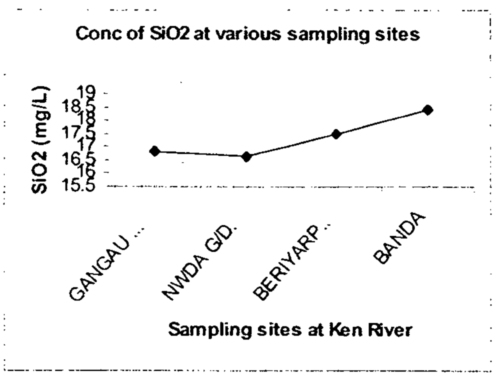
Graph 5.4



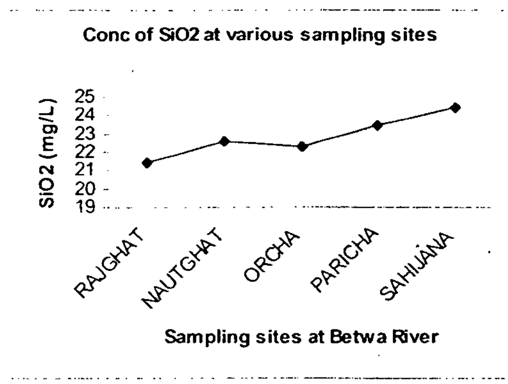
Graph 5.5



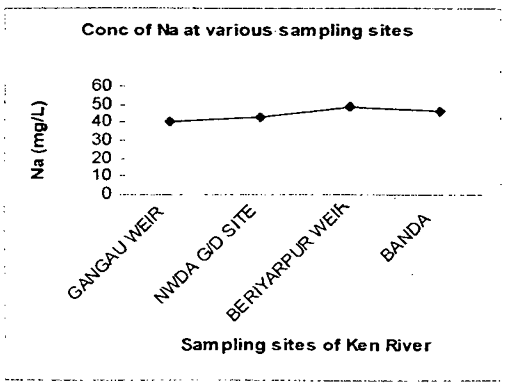
Graph 5.6



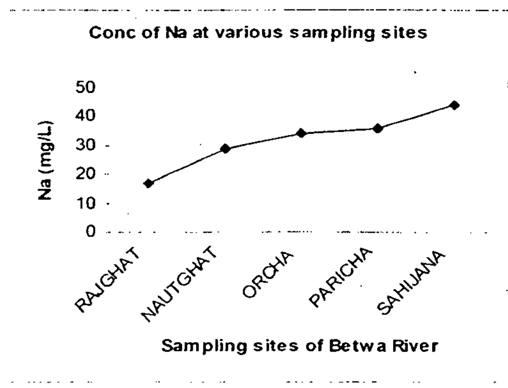
Graph 5.7



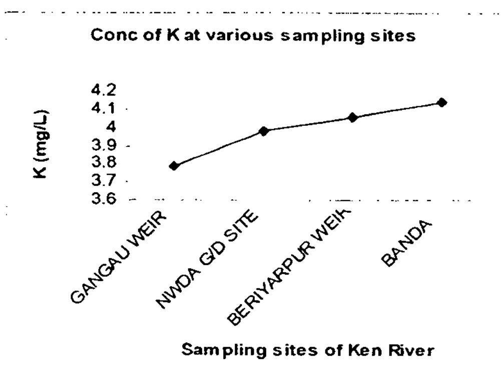
Graph 5.8



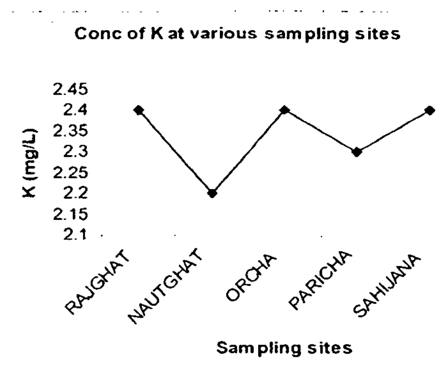
Graph 5.9



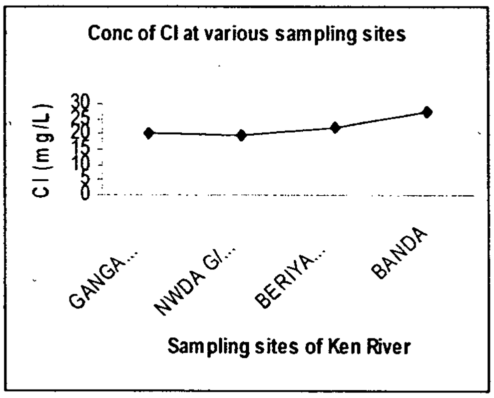
Graph 5.10



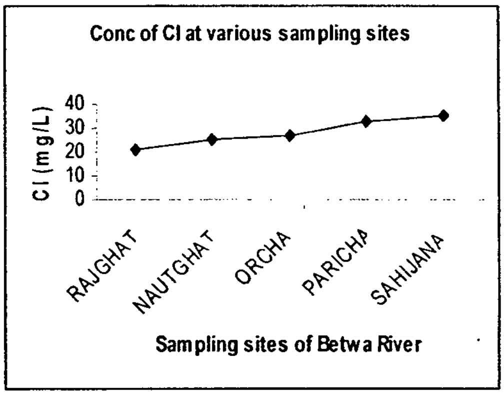
Graph 5.11



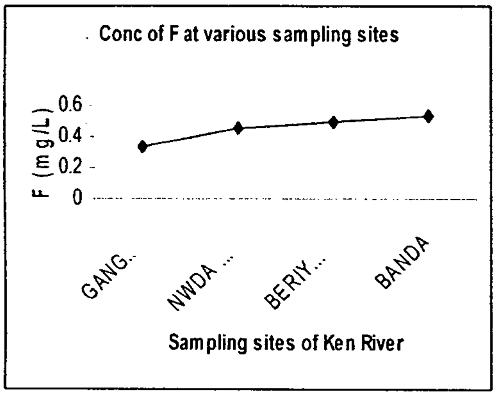
Graph 5.12



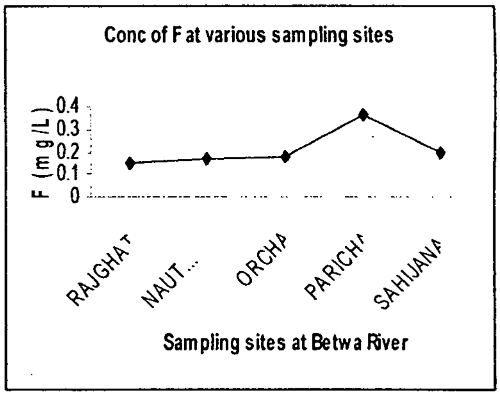
Graph 5.13



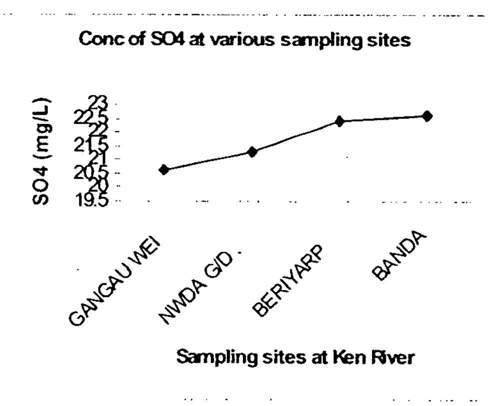
Graph 5.14



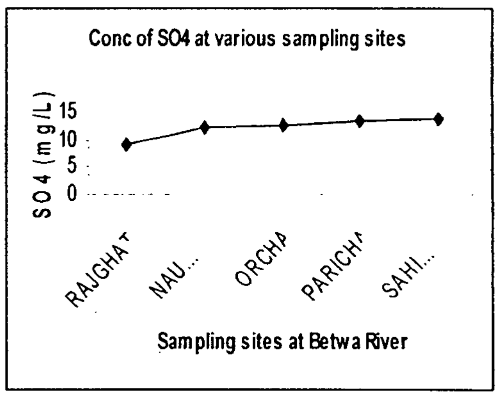
Graph 5.15



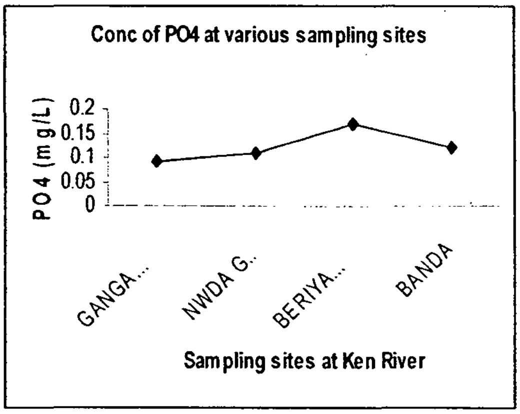
Graph 5.16



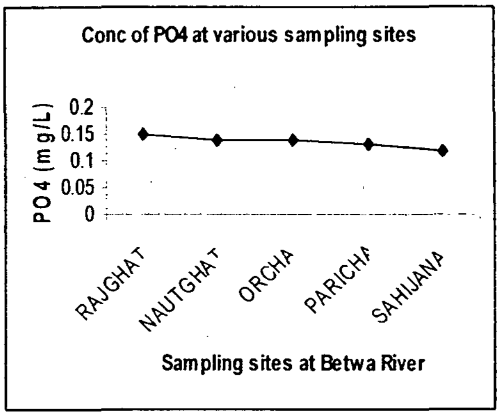
Graph 5.17



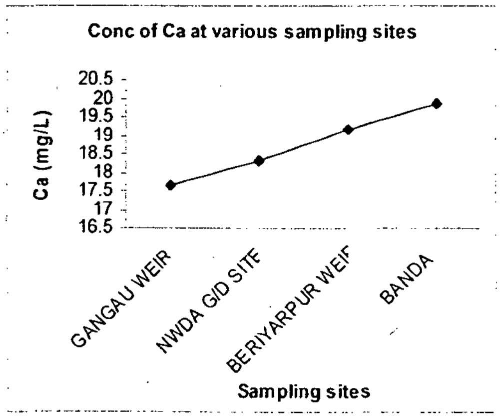
Graph 4.18



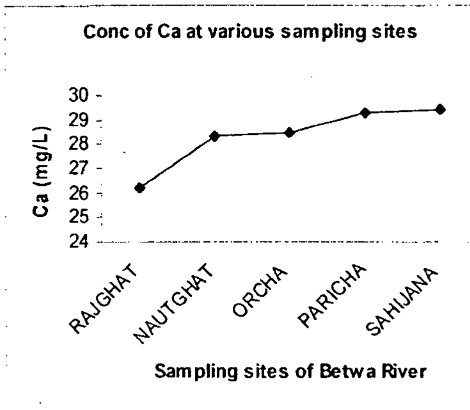
Graph 5.19



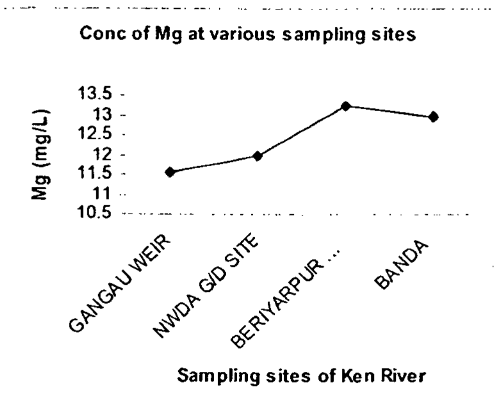
Graph 5.20



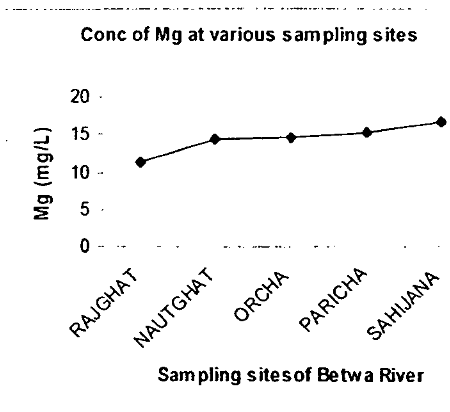
Graph 5.21



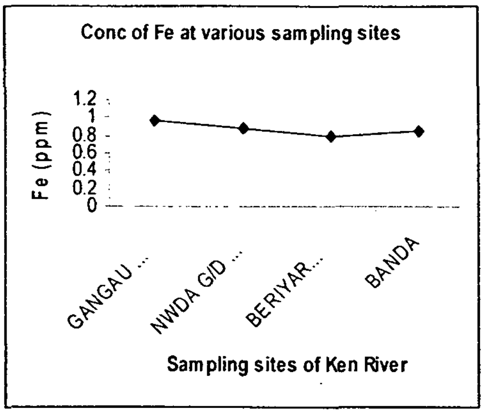
Graph 5.22



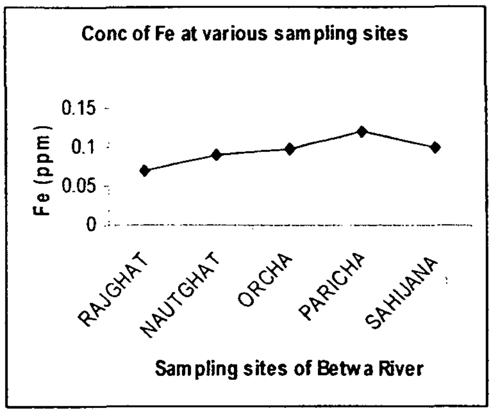
Graph 5.23



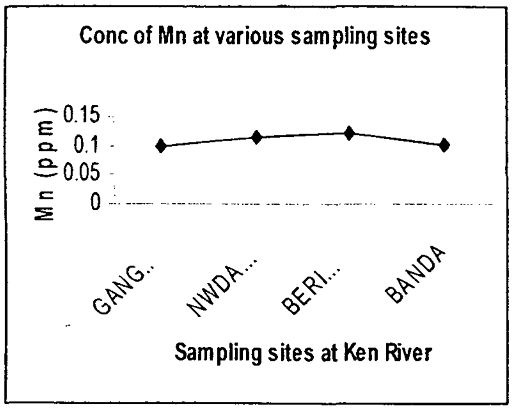
Graph 5.24



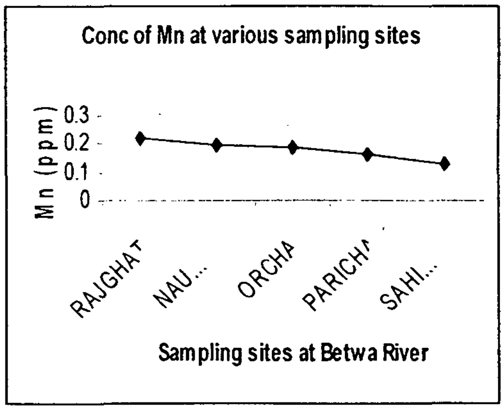
Graph 5.25



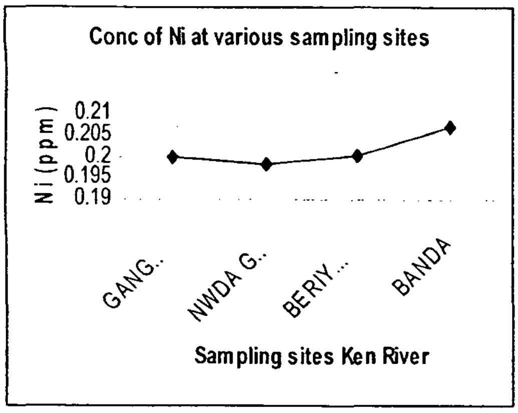
Graph 5.26



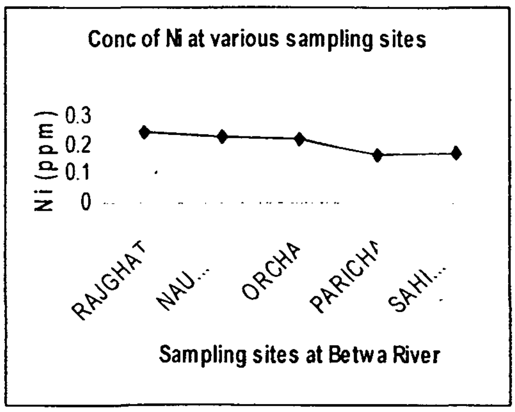
Graph 5.27



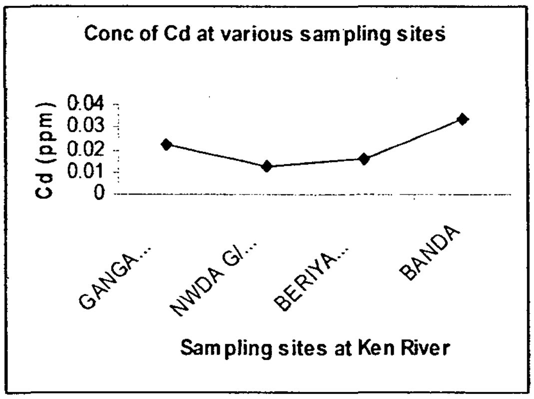
Graph 5.28



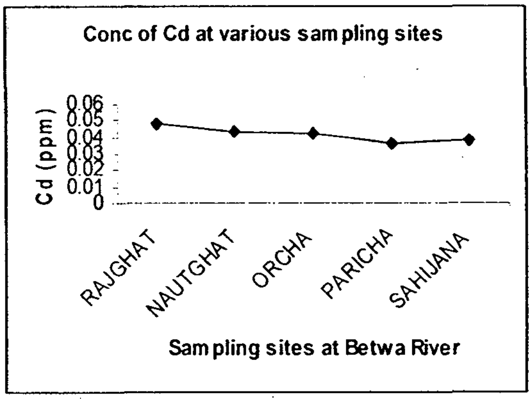
Graph 5.29



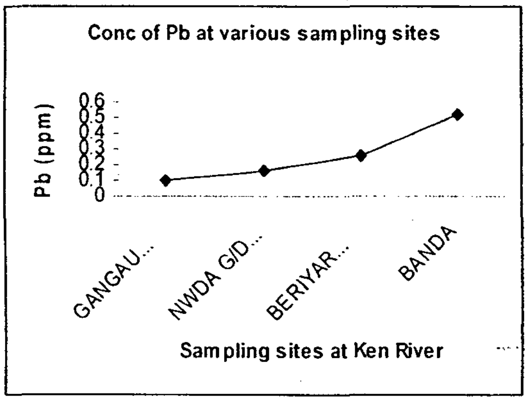
Graph 5.30



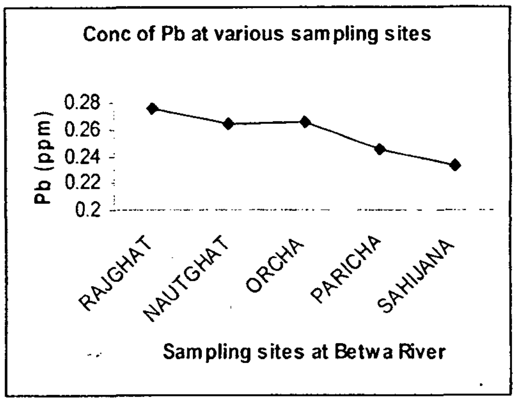
Graph 5.31



Graph 5.32



Graph 5.33



Graph 4.34

M) Graphical Representation of Hydrochemical Data

The geochemical evolution of river water can be understood by plotting the concentrations of major cations and anions in the Piper tri-linear diagram. A.Qua software was used for plotting the Piper diagram. For the present study area, Piper plot shows river water samples fall in the category of Na-HCO_3 type and Ca-HCO_3 type. The Piper plot also shows that Alkaline Earth Metals (Ca + Mg) are lower in concentration than the Alkali Metals (Na + K) in Ken River, while this relation is just opposite in Betwa River. On the other hand, we have weak acids (HCO_3^-) more dominant than strong acids (Cl^- and SO_4^{2-}) in these samples. In the study area, the alkaline earths had a lower concentration than bicarbonates, which indicated exchange of Na+ ion from the alkaline earths, and the water as base exchanged hardened water (fig.5.4 & 5.5). Therefore, this comparative study infers that the two river basins show differences in the water with regard to chemical composition. This separation was related to the differences in geological formation, soils type, land use and impacts of the existing in river basins.

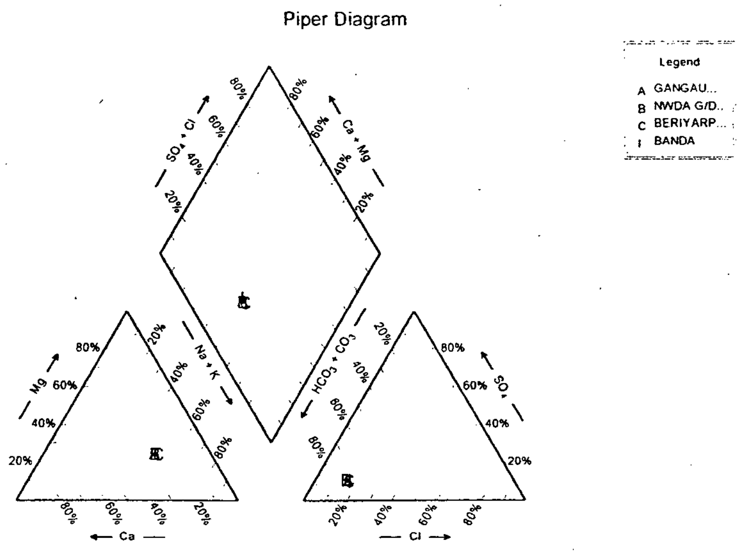


Fig. 5.4 Piper diagram showing chemical characterization of Ken River

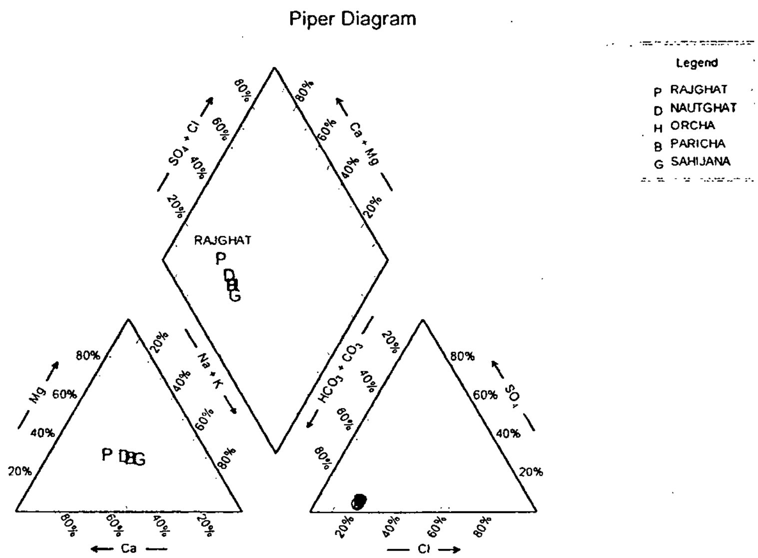
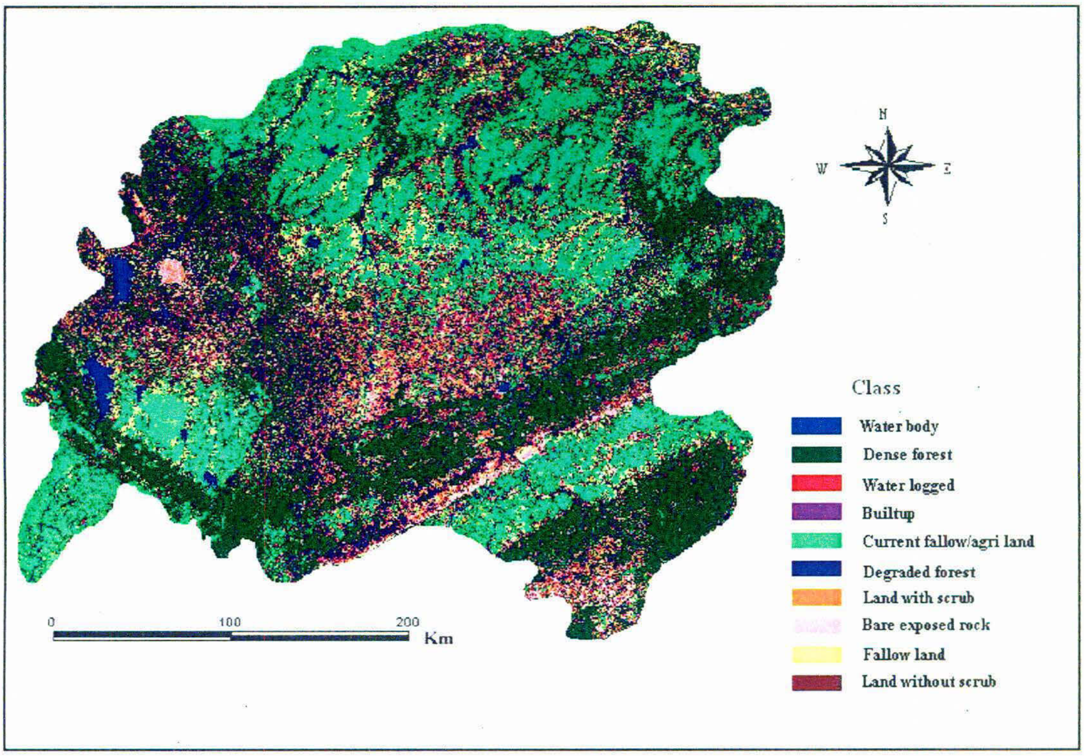


Fig. 5.5 Piper diagram showing chemical characterization of Betwa River

5.3 (I) LAND USE/LAND COVER

The characteristic of ground water is reflected on the soil and vegetation of the surface above it. Hence, the characteristics of the ground water at a particular area can be determined to a particular extent, by its surface manifestation in terms of the land use/ land cover pattern. This is the basis on which the classification of the image was performed by using unsupervised classification. In this particular type of classification spectral classes are grouped first, based solely on the numerical information in the satellite data, and are then matched by the analyst to information classes. Unsupervised classifiers do not utilize training sets as the basis for classification rather it involves algorithms called clustering algorithms, that examine the unknown pixels in an image and aggregate them into a number of classes based on the natural groupings or clusters present in the image values. The analyst specifies the desired number of classes. Thus unlike supervised classification, it does not start with a pre-determined set of classes, however it is neither done completely without human intervention. Land use/land cover study is useful in assessing impacts of river linking on land resources. Landsat satellite data and topographic maps were used to prepare the land use map of the study area based on standard land use/land cover map of NRSA through image classification procedure. This image classification process was carried out in Erdas Imagine 8.5 by using unsupervised classification. On this basis, the whole 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. Classified image was further exported into grid format in Arc view for overlay analysis (fig. 5.6). The water land cover class included rivers, lakes, and reservoirs. Due to seasonal variability in water quantity, some areas that were 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. Land cover units such as dense forest are very less prone to erosional process whereas other units such as barren lands have relatively high susceptibility to erosion.



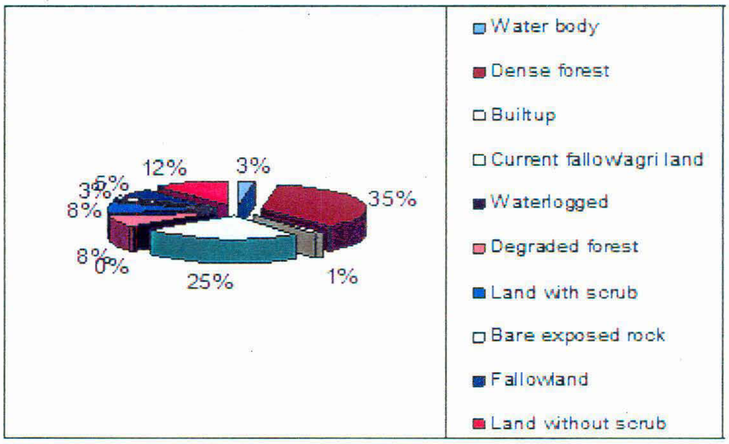


Fig. 5.6 Land Use/Land Cover Map of Study Area (based on unsupervised classification of Landsat Data 2000).

5.3 (II) LAND COVER CATEGORIES

a) Water: The delineation of water areas depends on the scale of data presentation and the scale and resolution characteristics of the remotely sensed data used for interpretation of land use and land cover. In the study area it covers around 2.58% of total area.

b) Agricultural land: Agricultural Land may be defined broadly as land used primarily for production of food and fiber. These are the lands primarily using for irrigation. In the FCC these are looking thick reddish to light reddish color. It covers around 24.53% of total area.

c) Dense forest: Forest Lands have a tree-crown aerial density (crown closure percentage) of 10 percent or more, are stocked with trees capable of producing timber or other wood products, and exert an influence on the climate or water regime. The forest area where the crown density is more than 40% of the canopy cover they appear in image as dark brown color. It covers around 36.11% of total study area.

d) Degraded forest: The forest area, where the crown density is less than 10% of the canopy cover, generally seen at the fringes of dense forest settlements. They appear in image as red to dark brown depending on the location and soil background. Most of these areas located on hills/mountains slopes within notified forest areas, at times closer to habitations. It covers around 7.82% of total study area.

e) Bare rocks: These are rock exposures of varying lithology, often barren and devoid of soil and vegetation cover. They are seen in greenish blue to yellow to brownish color depending on rock type. They are generally identified in steep isolated hillocks/hill slopes and eroded plains. It covers around 2.85% of total study area. River basin and intra-basin boundaries have bearing with the change in quality of the river in the linking river sectors (Mukherjee, S., 2003). Various litho units were analyzed under petrological microscope showing suitability of the location for inter linking of the rivers (fig. 5.4 plates).

f) Built-up area: Urban or built-up land is comprised of areas of intensive use with much of the land covered by structures, included in this category are cities, towns, villages, strip developments along highways, transportation, power, and communications facilities, and areas such as those occupied by mills, shopping centers, industrial and commercial complexes, and institutions that may, in some instances, be isolated from urban areas.

They appear in bluish green to bluish in the periphery of the study area. It covers around 1.18% of total area.

g) Land with or without scrub: This is land, which is generally prone to deterioration due to erosion and may or may not have scrub cover. Such land occupies relatively high topographic locations. Two sub classes were identified based on the vegetation present in such lands i.e. land with scrub and land without scrub. Land with scrub covers around 7.62% whereas land without scrub covers around 11.65% of total study area.

h) Waterlogged land: Waterlogged land is that land where the water is at/or near the surface and water stands for most of the year. It covers around 0.43% of total study area.

i) Fallow land: Cropland that is not seeded for a season; it may or may not be plowed. The land may be cultivated or chemically treated for control of weeds and other pests or may be left unaltered. It covers around 11.65% of total study area.

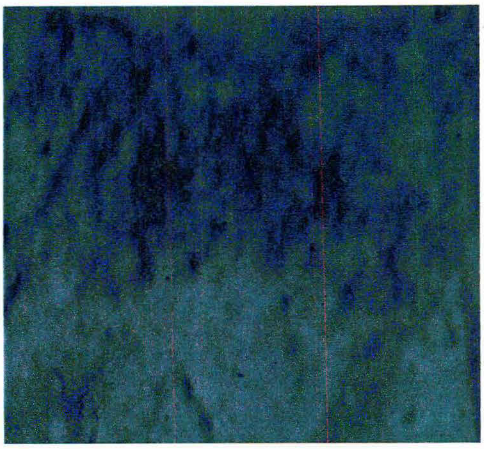
Class	Area in Km^2	% of different classes in study area Sq. Km.
Water body	1333.38	2.58
Dense forest	18634.05	36.11
Builtup	606.72	1.18
Current fallow/agri land	12657.22	24.53
Waterlogged	219.91	0.43
Degraded forest	4035.82	7.82
Land with scrub	3929.60	7.62
Bare exposed rock	1471.42	2.85
Fallow land	2704.16	5.24
Land without scrub	6011.10	11.65
Total study area	51603.39	100

Table.5.1 % of various classes in the study area as extracted from the Landsat data of year 1990.

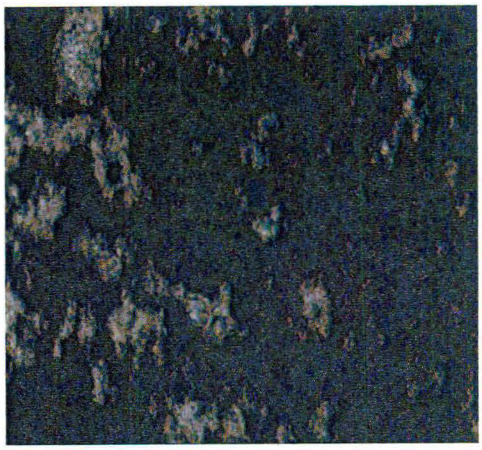
5.4 ROCK SAMPLES STUDY BY USING PETROLOGICAL MICROSCOPE

Following litho units were found in the inter-linking river basin sites.

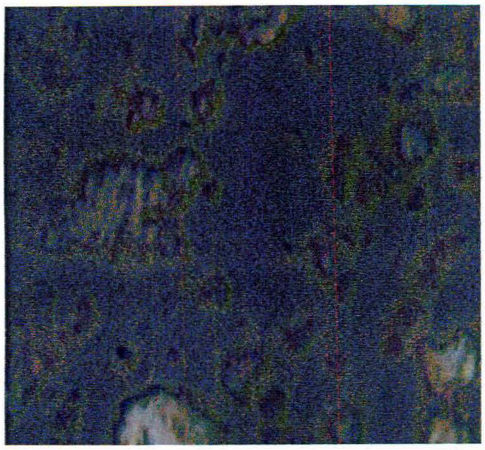
A. Quartzite: This thin section shows decussate structure in the quartzite. These are mainly present in Gangau weir site of Ken River. These structures develop when inequidimentional minerals usually mica and amphiboles are oriented in all directions and thus show a criss-cross arrangement in thin section. Quartzite is a tough and massive rock consisting almost wholly of quartz (fig.5.4A).



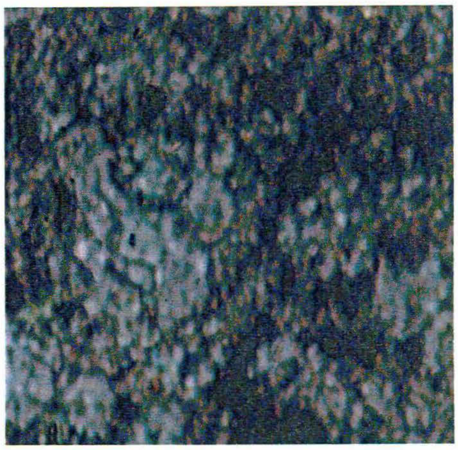
5.4 (A) Quartzite



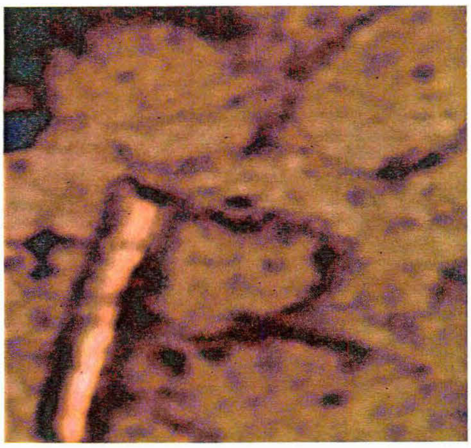
5.4 (B) Protoquartzite



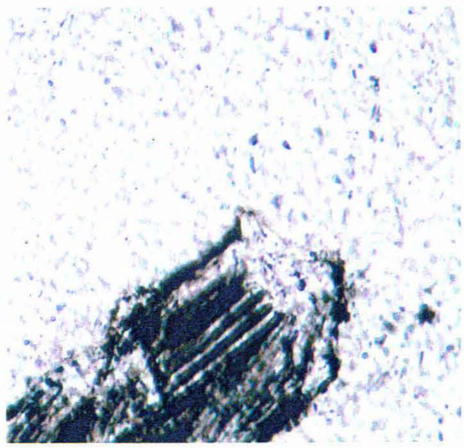
5.4 (C) Sandstone



5.4 (D) Fractured Quartzite



5.4 (E) Greywacke



5.4 (F) Orthoquartzite

B. Protoquartzite

This thin section shows presence of protoquartzite. Quartz grains are showing silica overgrowth with carbonate cement. Orthoquartzites grade into feldspathic sandstones, while with an increase in the content of rock fragments they grade into lithic sandstones, also known protoquartzites (fig. 5.4B). These rocks type are mainly present in Ken River near Banda District of Uttar Pradesh.

C. Sandstone

This slide shows the presence of sandstone, these are rounded to sub-rounded sandstone containing a carbonate and ferruginous cement and quartz. It is made of rounded grains, cemented together by a fine matrix of opaque minerals. Arkosic sandstones contain high abundances of Feldspar as well as Quartz. Because of this, they are believed to represent the weathered products of Granite (fig.5.4C). These rocks types are mainly present in Panna District of Madhya Pradesh.

E. Greywacke

This slide shows the presence of Greywacke (impure sandstone). These are commonly made of feldspar and plagioclase rock fragments with about 15% mud or silt, which acts as cementing material. This is a type of sandstone, which can be defined as predominantly siliceous sediments composed mainly of quartz with lithic fragments (fig.5.4E). These rocks types are mainly present in Lalitpur and Jhansi District of Uttar Pradesh.

F. Orthoquartzite

This slide shows the presence of orthoquartzite. In microscopic view it shows non-paleochroism, with low relief, low birefringence and lack of cleavage. Orthoquartzite are characterized by very hard quartz content and calcium carbonate and iron oxides were found as cementing material. Orthoquartzite are usually well sorted and grains are highly rounded, both features associated with considerable maturity (fig.5.4F). In this slide a lath shaped minerals grain embedded in quartz grains shows the presence of mica biotite. Biotite occurs in small amounts in many igneous rocks. It is black, shiny and often occurs in small hexagonal (6-sided) books. These rocks types are mainly present in Lalitpur and Jhansi District of Uttar Pradesh.

5.5. DIGITAL ELEVATION MODEL

The general topography of the catchments was studied through the digital elevation model generated from SRTM data. Digital elevation model generally refers to a regular array of elevations and is represented as a raster/grid map. Each cell in the grid has its own elevation value. Elevation in the Ken-Betwa basin was considered as one of the important variables for the assessing runoff. During monsoon season the area with high elevation having steep slope causes more discharge in lowland areas. The value of elevation obtained from the DEM varies from 72-648 m in the study area. This DEM data are classified by using Arc GIS 9.1 in seven classes. The elevation value of the study area where construction of Greater Gangau weir is going on is equal to 261m and where the link will finish, near to Barua Sagar, is equal to 218m. So this shows the alignment of link canal is good, that means it starts from the high elevation and ends with low elevation near Barua sagar (fig. 5.7). Low elevated areas in the basin are the places to be inundated first during flood. 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. The low elevated areas close to proposed dam is having high susceptibility to inundation.

5.6. SLOPE MAP

Slope is a measurement of how steep the ground surface is. The steeper the surface the greater is the slope. Slope is measured by calculating the tangent of the surface. The tangent is calculated by dividing the vertical change in elevation by the horizontal distance. Regional topography and slope data can provide important information on the nature of geologic and geodynamic processes operating on planets. The slope map was generated from the DEM using Arc GIS 9.1 spatial analysis tool. Degree of slope is a value between 0 and 90. The generated slope has classified into four categories. Most parts of the study area have slope within the range of 39 to 57 degree. Southern part of the area exhibits steeper slope, where as the northern parts are associated with lower slopes. Alluvial region lies in the northern part show lower slope while hilly region of southern part show steeper slopes (fig. 5.8). The intensity of erosion caused in the sloping areas, was higher than other processes due to small streams, gullies and denudational processes.

5.7. ASPECT MAP

The aspect map was generated from DEM using Arc GIS 9.1 spatial analyst tool. Aspect identifies the steepest down slope direction from each cell to its neighbors. The value of each cell in an aspect dataset indicates the direction the cell's slope faces. Most of the area had aspect value of 112^0 to 157^0 showing southeastern slope. Aspect defines the direction of flow (fig. 5.9).

5.8. PLAN CURVATURE AND PROFILE CURVATURE MAP

The curvature of the cell is calculated on a cell-by-cell basis. The plan curvature and profile curvature can be calculated from DEM using Arc GIS 9.2 spatial analyst tool. The curvature tool can be used to describe the physical characteristics of a drainage basin. Curvature is useful in the study of erosion and runoff processes. The slope affects the overall rate of movement down slope. The profile curvature affects the acceleration and deceleration of flow and therefore, influences erosion and deposition.

Plan curvature was included as a contributing factor for inundation study. The higher the value of plan curvature indicates topographic convergence and therefore high vulnerability to inundation. In the fig. 5.10 most of the area had a value -0.082 to 0.082 (yellow) and -0.903 to -0.082 (red). So the area with a value -0.082 to 0.082 was more vulnerable to inundation than the area with a value -0.903 to -0.082.

Profile curvature was included as a contributing factor for erosion study. The lower the value of profile curvature indicates accelerated flow and therefore high vulnerability of erosion. In the fig. 5.11 most of the area had a value -0.049 to 0.92 (blue) and -1.02 to -0.049 (red). So the area with a value -1.01 to -0.049 was more vulnerable to erosion than the area with a value -0.049 to 0.92.

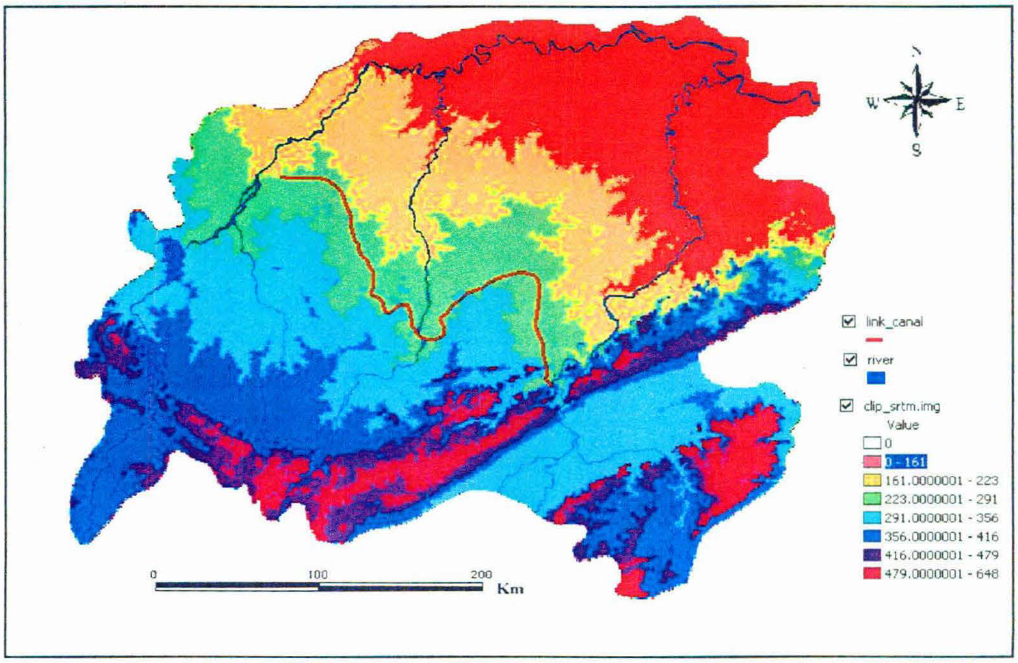


Fig. 5.7 Digital Elevation Model of the study area (SRTM classified)

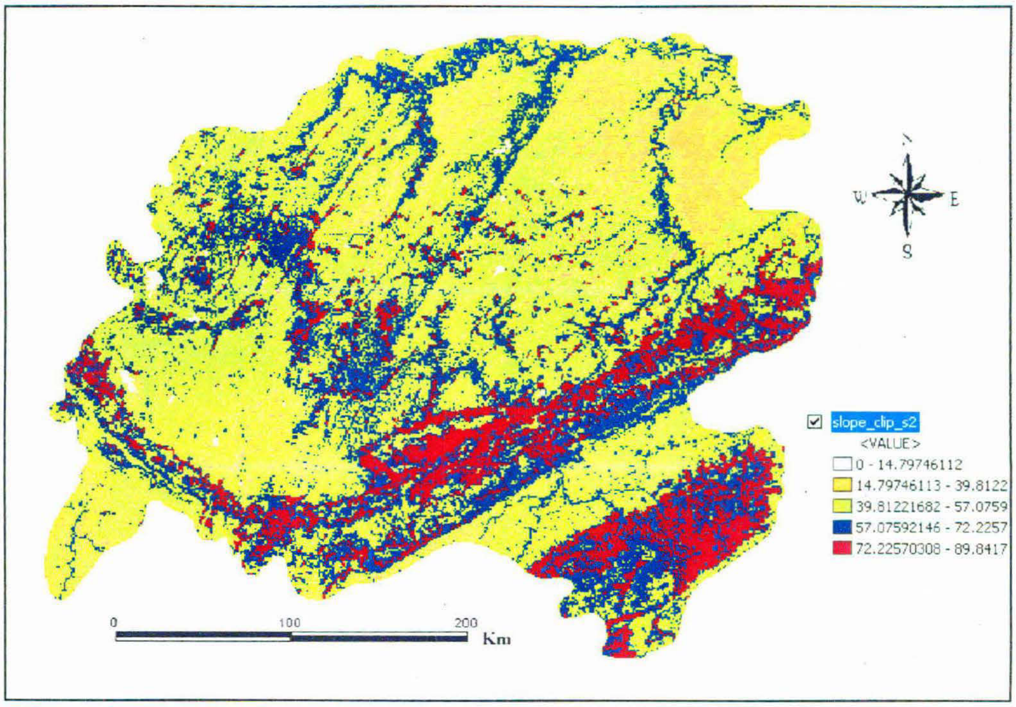


Fig. 5.8 Slope map of the study area

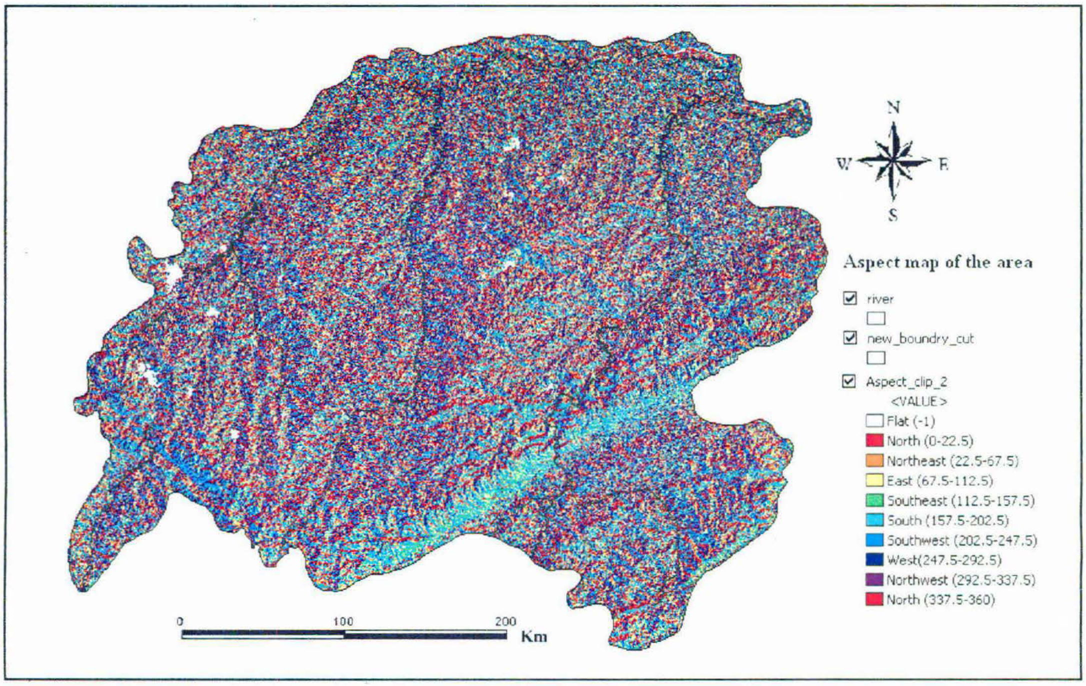


Fig. 5.9 Aspect map of the study area

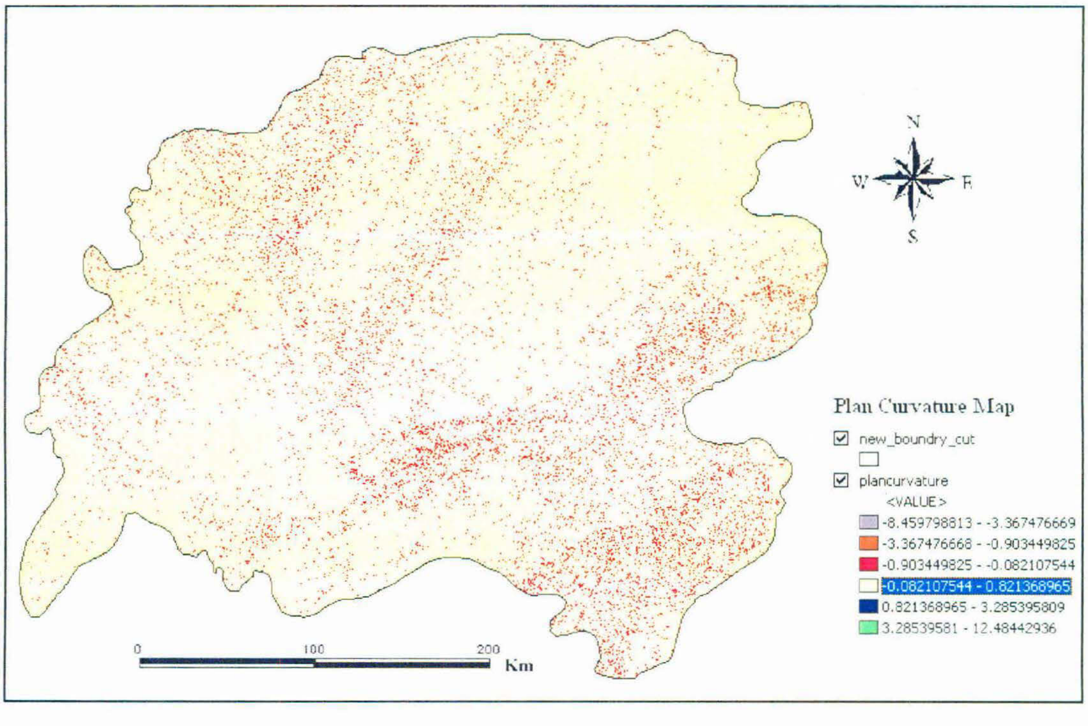


Fig. 5.10 Plan curvature map of the study area

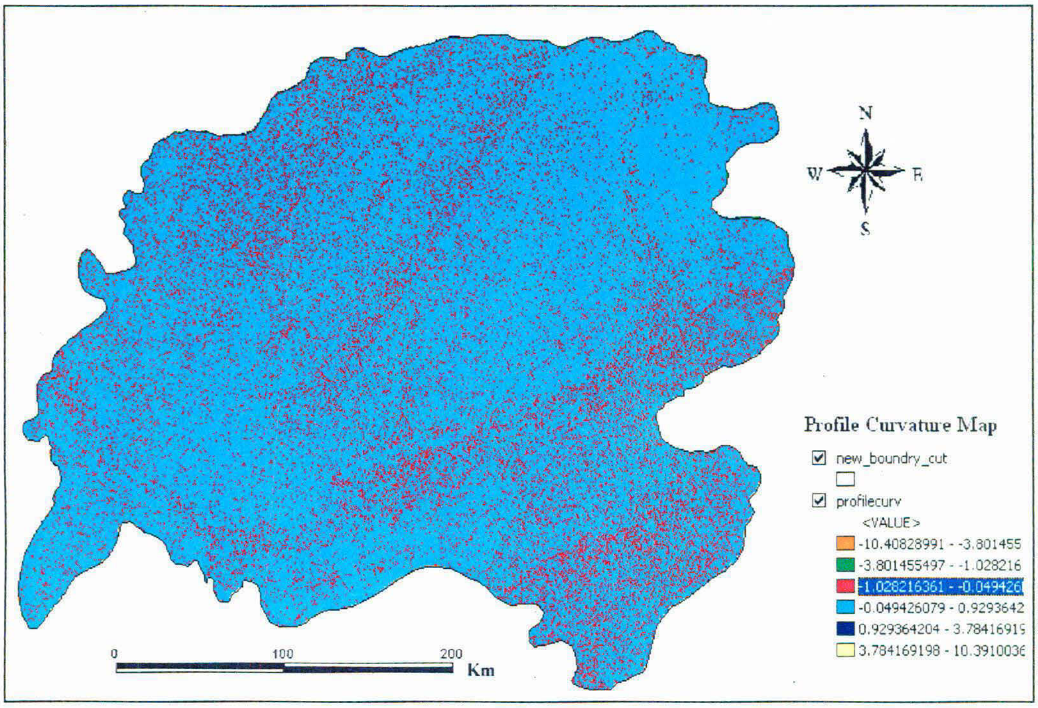


Fig. 5.11 Profile curvature map of the study area

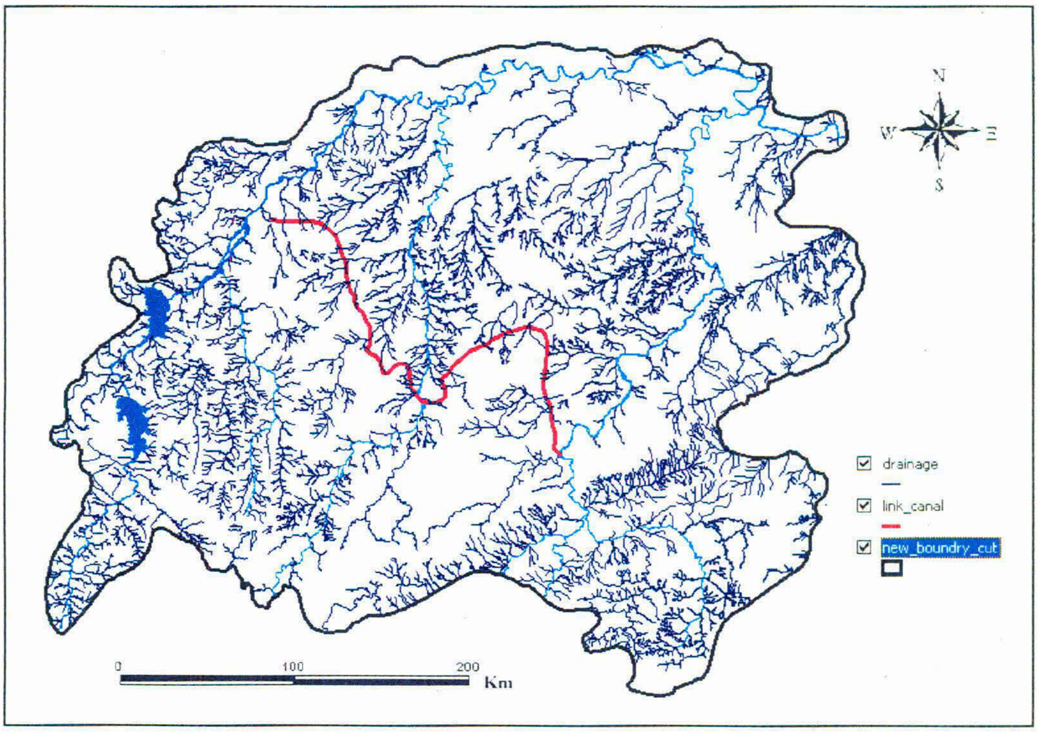


Fig. 5.12 Drainage network map of the study area

5.8. DRAINAGE NETWORKS

Evaluation of the characteristics of the drainage network of a basin using quantitative morphometric analysis can give information about the hydrological nature of the rocks exposed within the drainage basin. A drainage map of a basin provides a reliable index of the permeability of the rocks and also gives an indication of the yield of the basin (Wisler and Brater 1959). The yield of a basin is the flow per unit area and normally includes surface-water flows unless mentioned otherwise. Normally, such an analysis of drainage basins involves the evaluation of drainage parameters such as bifurcation ratio, length ratio, drainage density, constant of channel maintenance, length of overland flow and stream frequency. Hydrogeological observations, integrated with drainage analysis, provide useful clues regarding broad relationships among the geological framework of a watershed, surface flow and the recharge.

Stream flow is naturally composed of base flow and channel runoff. Anthropogenic withdrawals from the stream water hardly affect stream flow. The proportion of base flow to direct runoff, as well as the relation between rainfall and runoff, depends on the hydrogeological characteristics of the basin.

Drainage map of the study area was generated from the vectorization of topographic sheet as well as satellite imagery, representing the network of main streams in the catchments, followed by the tributaries upto the last order. The map of drainage network shows the major rivers Yamuna, Ken, Betwa, Dhasan, Jamni and a large number of other streams draining this region. The drainage pattern in the area was dendritic, pinnate type (fig. 5.12). The drainage density was generated from drainage map using line density tool of spatial analyst in Arc GIS 9.1. Southern part of the area exhibits greater drainage density, whereas the northern parts are associated with less drainage density (fig. 5.13). On the basis of drainage density the area was divided into excessively drained (red), well drained (blue) and moderately drained (green). Higher the drainage density lower is the infiltration and faster is the movement of the surface flow. High drainage density areas support high transportation ability; as a result these areas are getting inundated.

5.9. NDVI MAP

The surface moisture index relies on calculating the relationship between (Normalized Difference Vegetation Index) NDVI and Ts (transmissivity). Generally, for a given landscape, as NDVI increases, Ts will decrease. This is due to vegetation's ability to regulate Ts by partitioning absorbed radiation to latent heat flux (via evapo-transpiration) rather than sensible heat flux. Absorbed radiation and water availability are the two primary controls on Ts for a given surface. As water becomes limited at that surface, whether vegetated or not, the absorbed energy will be partitioned to sensible heat flux and the radiant temperature of that surface will increase. If a surface is wet, Ts will be low. However, as that surface dries, the Ts will increase accordingly. The relative increase in Ts is more significant in low NDVI areas, corresponding to bare soil or sparse vegetation. In high NDVI areas the relative change in Ts is not as noticeable due to the aforementioned ability of vegetation to regulate water relations. This is particularly true of forested areas that have access to sub-surface water. The result is a negative relationship between NDVI and Ts. As a given area dries, we would expect the relationship between NDVI and Ts, as measured by the slope of a line fit to the Ts/NDVI scatter plot, to become increasingly negative due to increased Ts for the low NDVI areas. It is this relationship that is the logical basis for the fire potential and drought indices. The nature and extent of vegetation has a strong control on runoff characteristics and sediment production/erosion potential of the catchments of the Ken and Betwa River. For this study vegetation map is generated by using ERDAS imagine 9.5, using NDVI (Normalized Difference Vegetation Index) function of image processing techniques. Higher value of NDVI shows dense vegetation so this area is less prone to inundation and erosion. The NDVI value of study area varies from -0.435 to 0.439. The NDVI map has classified into four classes by using Arc GIS 9.1. As land use/land cover map also shows that most of the area was covered by vegetation so the NDVI value in most of the part of study area was 0.038 to 0.12. In southern portion of the study area has Panna Tiger Reserve forest so it has dense vegetation so NDVI value was highest in southern portion of the study area. The higher value of NDVI in southern region shows dense forest of Panna tiger reserve (fig. 5.14).

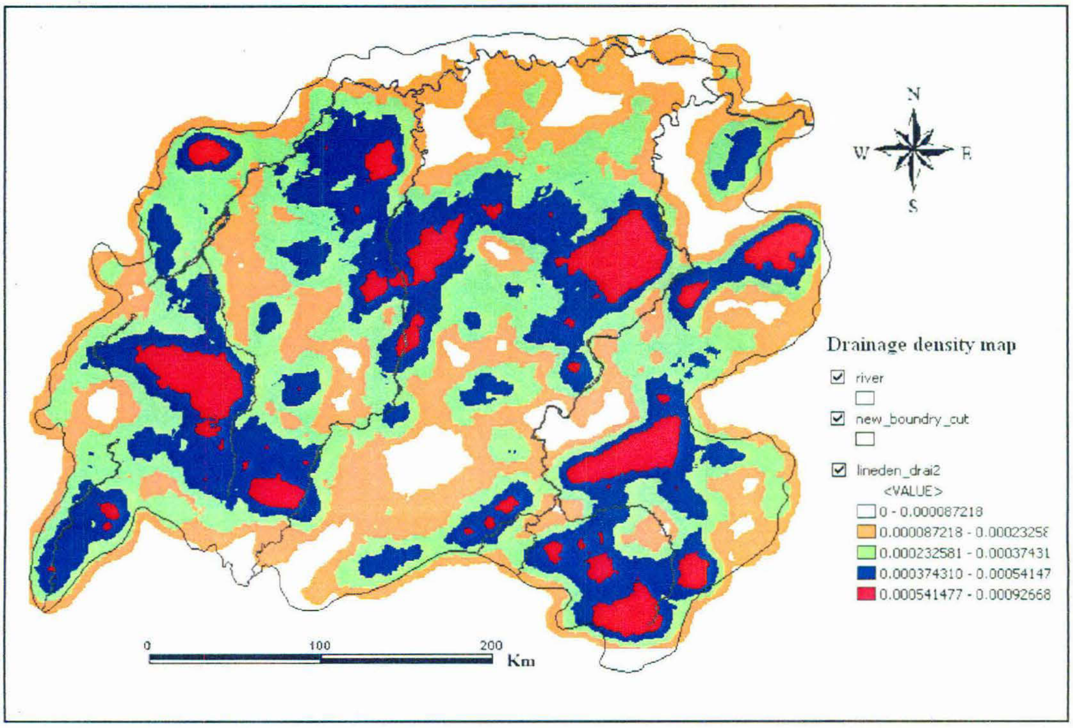


Fig. 5.13 Drainage density map of the study area

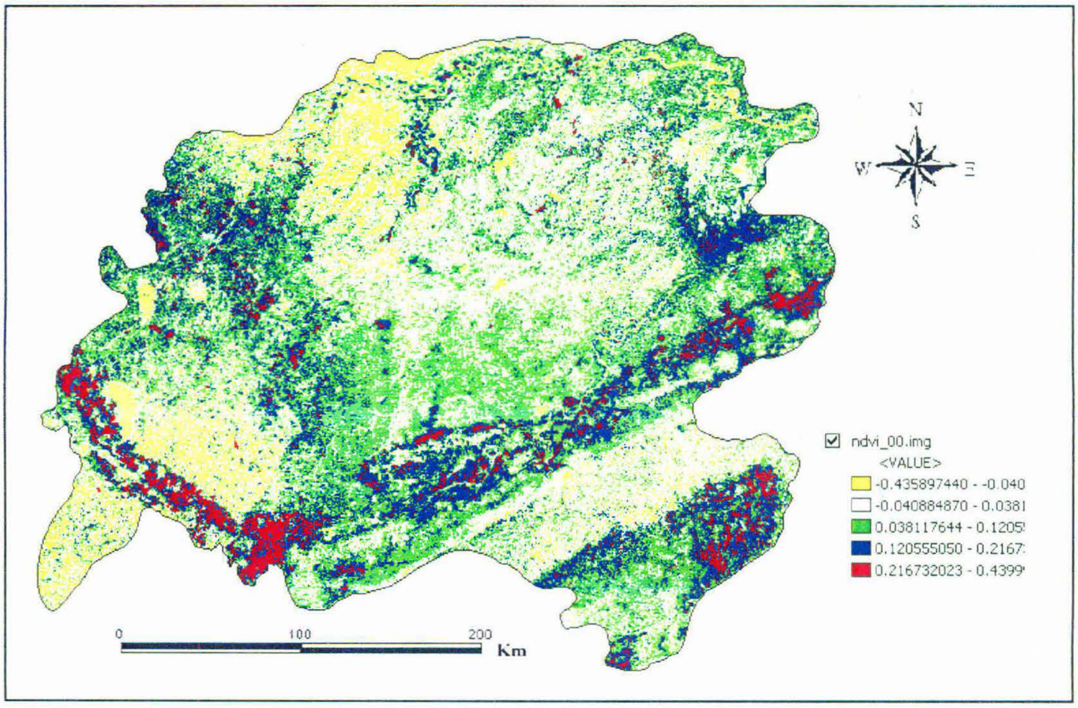


Fig. 5.14 NDVI map of the study area

5.10. RAINFALL MAPS

Annual rainfall maps were generated through interpolation in a GIS environment by using annual rainfall data of Indian Meteorology Department. The interpolated maps show that rainfall in this region varies both spatially and temporally. The annual rainfall in the year 1999 varied between 700 mm and 1850mm. But in the year 2004 annual rainfall of the study area was less (min 250mm and max 1375mm) in comparison to 1999 and 2003. A high intensity rainfall always intensifies the inundation as well as erosion.

In the year 1999 annual rainfall varied between 700 to 1850 mm, fig (5.15 A), shows that the eastern, southern and the central parts of the region received very high (>1200mm) rainfall, whereas annual rainfall was extremely low in the northern part. In the year 2000, which was a drought year, annual rainfall was lower and varied between 450-1000 mm. Figure (5.15 B) shows that the eastern part as usual received higher rainfall in comparison to rest of the region. In the year 2001, showed a large spatial variation in annual rainfall as the range was from 285 to 1400 mm (fig.5.15 C). The year 2002 was another drought year and annual rainfall was less in comparison to normal monsoon years. In 2002 annual rainfall varied between 500 and 1150 mm (fig. 5.15 D). In the very next year 2003, annual rainfall was reasonably high in most parts of the region, and was mostly above 1000 mm. Figure (5.15 E) shows that the region experienced large spatial variations in annual rainfall distribution many parts in the east north and south received extremely high rainfall, whereas some south-eastern, western and central parts received extremely low (<400 mm) rainfall. In the year 2004, the region received moderate amount of annual rainfall mostly about 800 mm. Figure (5.15 F) shows that eastern central and southern part of the region received comparatively higher (>800 mm) rainfall, whereas some pockets in the north and south east received very low (<400 mm) rainfall. From the above study the pattern of rainfall account in the major portion of the catchments increases from NE to SW 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 compare to the region where links end near Barua Sagar (Jhansi District).

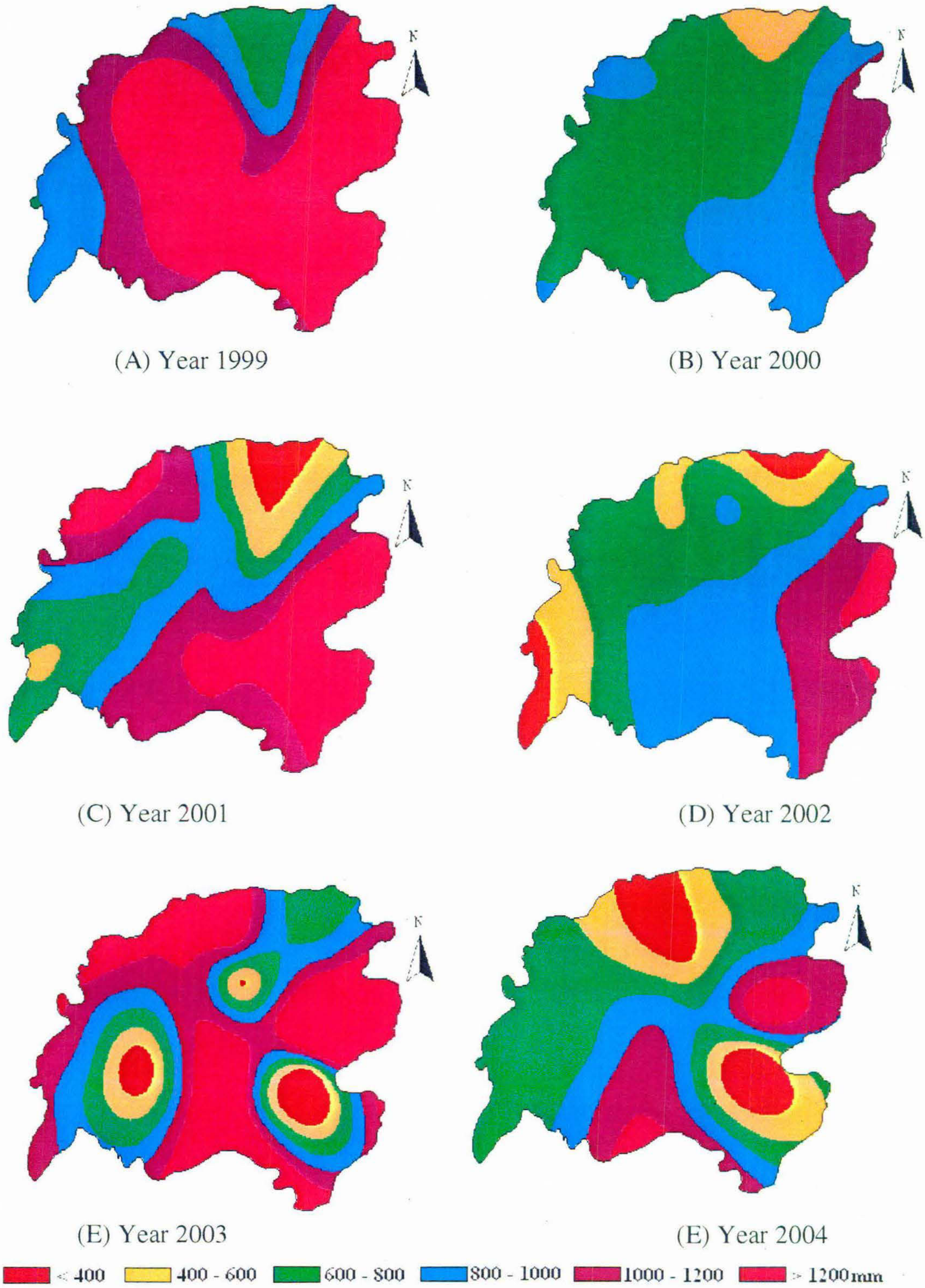


Fig. 5.15 Maps of annual rainfall (mm) on t temporal scale from 1999 to 2004.

5.11. DEPTH TO WATER LEVEL

Depth to water level data for 124 observation sites was obtained from Central Ground Water Board (CGWB) for the year 1999 to 2004. The ground water level data was converted into dbf format and imported into Arc View GIS and converted into shapefile. The observation points originally expressed as geographic coordinates were converted to UTM projection system for interpolation (fig. 5.16). Finally Interpolation of the ground water level was done by using Spline interpolator in Arc View 3.2.

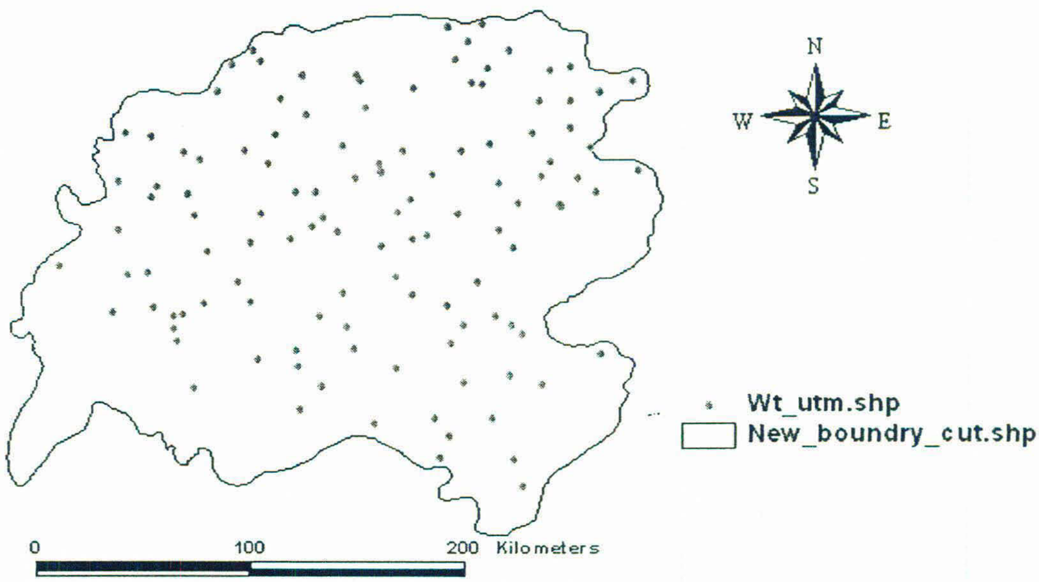


Fig. 5.16 Map showing location of monitoring wells

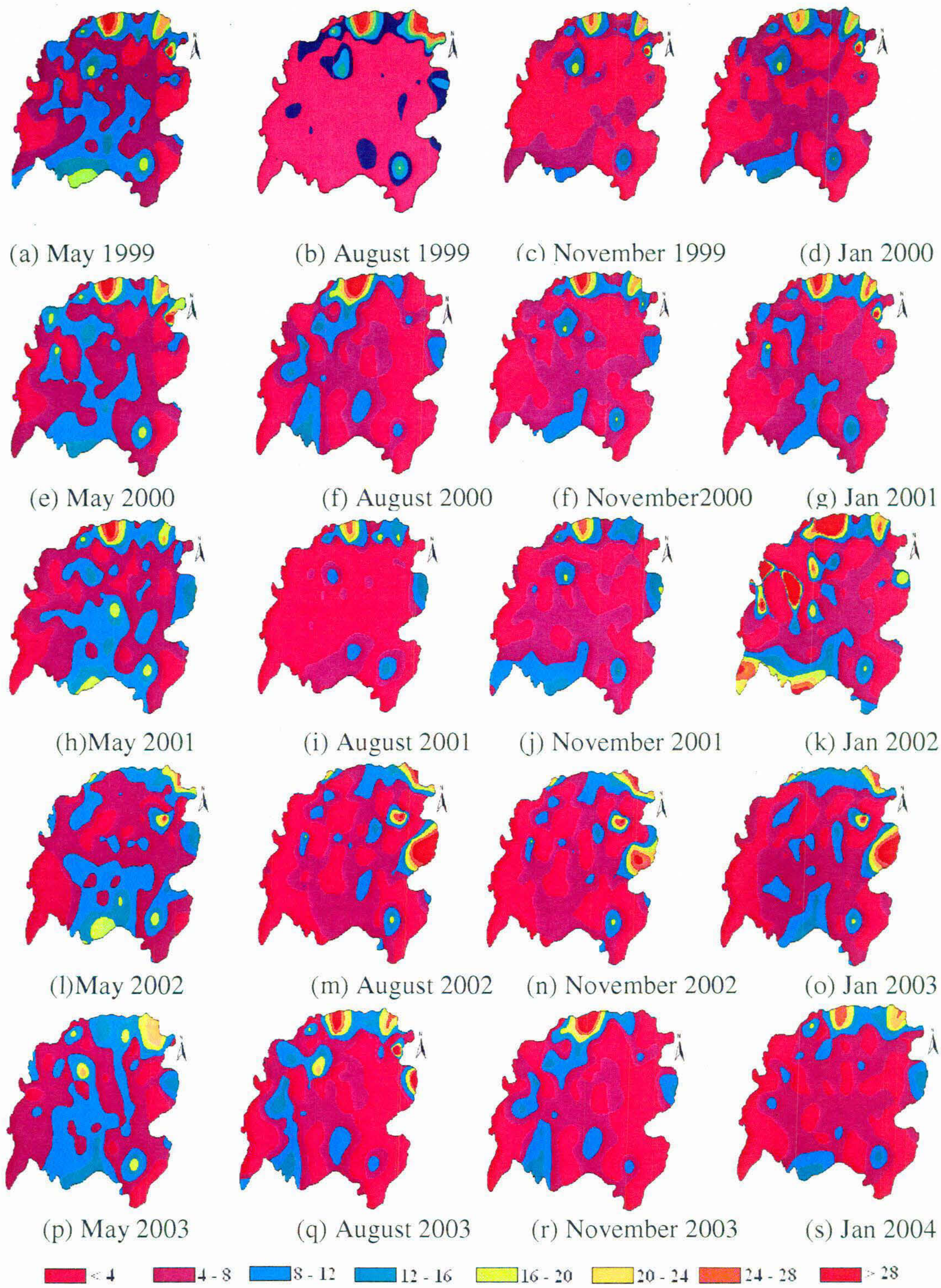
In the study area, as the precipitation is concentrated mainly in monsoon season, depth to ground water is generally reduced during monsoon and post-monsoon, whereas it gets deepened during pre-monsoon because discharge rates are greater than the recharge rates. Under natural conditions, depth to water-level is related to topography. Water levels are closest to land surface in valleys (discharge areas) and deepest in highland recharge areas. Maps of depth to ground water was generated for the year 1999-2000, 2000-2001, 2001-2002, 2002-2003, and 2003- 2004.The ground water depths are maximum in the northern portion of the study area, and minimum in the southern portion of the study area.

The magnitude of seasonal fluctuation in water levels in response to monsoon recharge is related to aquifer porosity and storage. After recharge, the rise in water levels may be greater and sustained longer in aquifers with low permeability than in aquifers with high permeability. The range of seasonal fluctuation generally varied from region by region of the study area, reflecting the different hydrogeological conditions and possible spatial variation in recharge rates or storage characteristics of the aquifer.

Figure (5.17 a) shows that pre monsoon ground water level during May 99 varied mostly from 4 to 12 meter below the surface. The impacts of rainfall-recharge is evident as ground water level during August 99 was very shallow (<4m Below Ground Level (bgl)) in the entire region (fig 5.17 b). Ground water level in the immediate post monsoon period slightly decline; however it was still very shallow ($\leq$ 4 m) in most parts of the region (fig5.17 c). In most parts of the region the water table slightly decline during the winter of 2000 (fig 5.17 d).

During the pre monsoon of the year 2003 ground water level was greater than 8 m in many parts of the region (fig 5.17 p). However during the monsoon due to the effect of rainfall-recharge, water table attained shallower depth ($\leq$5m) in most parts of the region (fig. 5.17 q). Ground water level during the post monsoon of 2003 varied in between 2 to 8 meter bgl (fig. 5.17 r). Even during the winter of 2004 water level did not decline, and mostly lied within 4 to 8 meter bgl in most part of the regions (fig. 5.17 s).

Fig. 5.17 Interpolation maps of water level from May 1999 to January 2004



The impacts of Ken-Betwa River linking can identify on the basis of the following impact factors i. e. water quality, quantity, inundation, and erosion. In the study area have different types of soil classes. So permeability of soil is also a factor for erosion. If the soil has low permeability therefore a higher runoff rate and increased the vulnerability of the area to erosion and surface water quality degradation. The soil with high permeability value like sandy soil has higher infiltration of surface water to ground water, which can be positive for increasing the ground water table and storage of water in the ground for future use. Vulnerability to inundation was a combination of factors like elevation, slope, drainage density, plan curvature. Vulnerability to erosion was a combination of the factors like slope, profile curvature, drainage density, NDVI. Water quality degradation was a combination of the factors like anthropogenic activity, erosion, soil type, rock type, and drainage pattern. The areas close to dam fall in high inundation zone resulting from impoundment of water. Medium hazard areas arte identified both in upstream and downstream areas. Low hazards areas were observer in the Betwa basin where the effect of water transfer was very less. Submergence will be measured depending on how close is the location with respect to dam. As the elevation of the dam other parameters are constants, so the location closed to the proposed dam will be more susceptible to inundation. The south-western part of the study area and along the bank of Ken River at upstream of dam fall in high vulnerable areas. Soil erosion results into siltation in the reservoir and reduction of the storage capacity.

CHAPTER VI

CONCLUSION

Although water is essential for sustaining life on the Earth and all kinds of socio-economic developmental activities, the growing global scarcity of water is fast becoming a major social and economic crisis. Rapidly developing countries like India, already suffering from the increasing population and shortage of all kind of natural resources including the water, need a mammoth project such as the Ken-Betwa Link Project (KBLP) to combat the water scarcity. The KBLP involves connecting the Ken and Betwa rivers through the creation of a dam, reservoir, and canal to provide storage for excess rainfall during the monsoon season in the upper Ken basin and deliver this water for consumption and irrigation purposes to the upper Betwa basin.

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. The reservoir (Greater Gangau Weir) would affect the land around the reservoir rim. The introduction of a huge reservoir would be disturbing the delicate balance between soil, water, and plants through rise in ground water table (water logging), and further agitating the natural salt distribution in the soil. The agricultural fields around the reservoir rim would be rendered unfit for cultivation. Construction of the dam and transferring the water through the catchments has been propagating the changes on the land system. So it will cause change in cropping pattern of Bundelkhand region.

Normally, the steep inclined surfaces and high altitudes areas are free from inundation as the water flows out rapidly towards the lowland flat areas. The down land flat areas can be therefore submerged after a heavy downpour if there is poor water percolation through the soil. Geomorphological maps of the study area show that upstream side of the reservoir has denudational hills. NDVI maps also show good vegetation cover in the upstream side of the reservoir. As the downstream side of the dam has less vegetation (low NDVI). So it is more prone to erosion and will have less water retention capacity. So 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 comes under medium intensity of impacts but the Panna and Panna-Ajaigarh region comes under highest impact areas, which incorporate the Panna reserve forest, but less in Betwa basin.

As for as ground water quality concerns most of the study area have good water quality, but in some areas the quality has degraded like in the areas of Ramnagar of Banda District, Gursarai of Jhansi District, Charkhari of Mahoba District which shows problem of salinity. Ramnagar of Banda District, Charkhari of Mahoba District, Gursarai of Jhansi District, Panna District, Orchha and Prithvipur of Tikamgarh District have high chloride concentration. Ramnagar, Bisanda of Banda District, Charkhari and Pahari of Mahoba Disrtict, Chorgaon of Jhansi District, Bara of Lalitpur District, Chatarpur and Mankari of Chatarpur District, Ajaigarh of Panna District, Jatara, Palera, Daigura, Baragaon and Majna of Tikamgarh District have nitrate pollution. The higher concentration of fluoride was observed in Ramnagar of Banda District, Kabrai, Belatal, Terha and Kapsa of Hamirpur District, Charkhari of Mahoba District, Jakhaura of Lalitpur District, Laundi and Kukrel of Chatarpur District, Beriyarpur of Panna District.

As far as surface water quality of Ken and Betwa River both have good water quality very less pollution within the limit of WHO (1984) standard.

Ultimate goal of the project is, water resource management and sustainable use of water. This can only be done by creating new sources of water, but also through conservation policies and practices that maximize the utilization of existing water resources. The site-specific conditions of the project area should be considered when developing a water management plan. Additionally, alternative dam designs, water harvesting techniques, and conjunctive-use could be ways to develop a more appropriate plan for the Ken-Betwa region.

Proper balance of distribution of water in space and time will generate more food for the deprived people, more irrigation potential especially for marginalized subsistence farmers and a huge employment opportunity.

The research work in this dissertation can be improved by assessing more data like

- Gauge, Discharge, Sediment yield data of both rivers from Central Water Commission. The chances of getting these data are very less because both the rivers are in classified system. I had tried for these data for whole year but finally I didn't get it.
- Use of high resolution, multi-date satellite data, and high resolution DEM data can improve the quality of research.
- Detailed investigation of lithounits in the river sites of interlinking area.

REFERENCES

Ahmad, S. M. (1984), "Hydrogeological Investigations for Augmenting Water Supply in Drought Affected Areas of Banda District, Uttar Pradesh", Central Ground Water Board Report No. 1932: Lucknow.

Alagh, Y. K. Pangare, G. and Gujja, B. (2006), "Interlinking Rivers in India: Overview and Ken-Betwa Link", Delhi Academic Foundation: Delhi.

Amarasinghe, U. A. *et al.* (2005), "Spatial Variation in Water Supply and Demand across River Basins in India", Research report 83, International Water Management Institute: Colombo.

Auden, J. B. (1933), "Vindhayans of Son valley", *Memoir Geological Survey of India*, Vol. XII, Part II.

Batellan, O. Zhong-Min and Smedt, DE F. (1996), "An adaptive toolbox for hydrological modeling", IAHS, publication no. 235.

Berner-Kay, K. and Berner, R. A. (1987), *The Global Water Cycle, geochemistry and environment,* Prentice-Hall: Englewood Cliffs.

Bhattacharya, D. C. (1983), "A report on Ground water targeting in the vicinity of village Kharela district Hamirpur", RSAC, 83: 001.

Bhattacharya, D. S. and Bhattacharyya, T. K. (1976), "Geological and geophysical investigations of a basaltic layer in Archaean terrain of eastern India", *Bull. Geol. Soc. Am.* Vol. 81, pp. 3073–78.

Biswas, A. K. and Tortajada, C. (eds.) (2005), *Appraising Sustainable Development: Water Management and Environmental Challenges,* Oxford University Press: New Delhi.

Biswas, M. R. (1978), "North America Water Transfer: An Overview" Interegional Water Transfer: Problem and Prospects Vol. 6 (Oxford Pergamon Press).

Biswas, M. R. (1979), "Agriculture and Environment Technical Memoir", International commission on Irrigation and Drainage: New Delhi, No. 3, pp. 225-55.

Biyani, A. K. and Gupta, S. K. (2004), 'River linking', *Current Science,* Vol. 87, pp. 277–8.

Burrough, P. A. (1986), *Principles of Geographic Information System for Land Resources Development*, Oxford University Press: New York.

Cevik and Topal, (2003), "GIS-based landslide susceptibility mapping for a problematic segment of the natural pipeline, Hendek (Turkey)", *Environmental geology,* Vol 44, No.8, pp. 949-62.

Chakrabarti, R. and Basu, A. R. (2006), "Trace element and isotopic evidence for Archean basement in the Lonar crater impact breccia, Deccan Volcanic Province", *Earth Planet. Sci. Lett.* Vol. 247, pp. 197–211.

Charon, J. E. (1974), Hydrogeological applications of ERTS satellite imagery. In: Proc UN/FAO Regional seminar on remote sensing of earth resources and environment, Cairo, *Commonwealth Science Council,* pp 439–456.

Cooke, V. and Doornkamp, J. C. (1984), *Geomorphology in environmental management,* Clarendon Press: Oxford.

Cox, K. G. et al., (1974), *An introduction to the practical study of crystal, minerals, and rocks,* Mc Graw Hill Publication: London.

Daene, C. (2002), "Linking GIS and water resources management models: an object-oriented method", *Environmental Modelling & Software,* Vol. 17, pp. 413–25.

Dasgupta, S. and Mohan, R. (2004), "The 21st Century: Asia Becomes Urban", *Economic and Political Weekly*, Vol. 40, No. 3, pp. 213-223

Dijck, S. G. E. V. (2001), "Geomorphological impacts and feasibility of lying-out ski-trails in a glacial cirque in the Vosges (France) using GIS and multi-criteria analysis", *Geomorphology and Environmental Impact Assessment*, pp. 177-89.

Edet, A. E. (1993), "Hydrogeology of parts of Cross River State, Nigeria: evidence from aerogeological and surface resistivity studies", PhD Dissertation, University of Calabar: Calabar, Nigeria.

Evans, R. O. *et al.* (1992), "Water Table Management on a Watershed Scale." *Journal of Soil and Water Conservation*, Vol. 47, No.1, pp. 58-64.

Flügel, W. A. (1996), Hydrological Response Units (HRU's) as modeling entities for hydrological river basin simulation and their methodological potential for modelling complex environmental process systems. - Results from the Sieg catchment, *Die Erde*, Vol. 127, pp. 43-62.

Food and Agricultural organization of the United Nations (2005), "FAO statistical databases". Retrieved at: <www.faostat.fao.org>

Food and Agriculture Organization of the United Nations (2007), "Land and Water Integration and River Basin Management". Retrieved at: <http://www.fao.org/docrep/V5400E/v5400e00.HTM>

Goel, D. (2005), "A political-economical analysis of India's river interlinking project", PhD thesis, Florida State University (Social Sciences-International Affairs).

Golubev, G. and Vasiliev O. (1978), "Inter-regional water transfers as an Interdisciplinary Problem in Long-Distance Water Transfer- A Chineese Case Study and International Experiences", UNU: Tycooly.

Gourdji, S. et al., (2005), Indian Inter-linking of Rivers: a preliminary evaluation, M. S. thesis, University of Michigan.

Government of India (1999), "Report of the national commission for integrated water resources development plan", Ministry of Water Resources: New Delhi.

Government of India (2003), Ministry of Rural Development, Annual Report 2002 – 2003, New Delhi.

Government of India (2003), Ministry of Water Resources, Annual Report 2002 – 2003, New Delhi.

Government of India (2004) "Agriculture Statistics at a glance", Ministry of agriculture: New Delhi. Retrieved at: <http://www.agricoop.nic.in/statatglance2004/atglance.pdf>

Government of India (2004), Central Ground Water Board, Annual Report 2003– 2004, New Delhi.

Government of India (2004), Ministry of Agriculture and Cooperation, Annual Report 2003– 2004, New Delhi.

Government of India (2004), Ministry of Environment and Forests, Annual Report 2003 –2004, New Delhi.

Greenbau, D. (1985), "Review of remote sensing applications to groundwater exploration in basement and regolith", British Geological Survey Report OD 85/8, pp. 36-46.

Gurjar, B. R. (2003), "Interlinking of rivers: A climatic viewpoint", *Current Science*, Vol. 84, No. 11, 10 pp. 1380-81.Hermann, R. (1981), "Environmental implications of water transfer- A Chinese case study and international experiences", United Nation University.

Horton, R. E. (1945), "Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology", *Geological Society of America Bulletin*, Vol. 56, pp. 275–370.

Howard, B. C. (2003), "The World's Crisis, *The Environmental Magazine.*

Huh, Y. *et al.* (1998), "The fluvial geochemistry of the river of Eastern Siberia. Tributaries of Lena River draining the sedimentation platform of the Siberia Craton", *Geochim Cosmochim Acta*, Vol. 62, pp.1657-76.

Hunsaker, C. T. and Levine, D. A. (1995), "Hierarchical approaches to the study of water quality in rivers", *BioScience*, Vol. 45(3), pp. 193-203.

Islam, N. (2006), "The Commercial Approach vs. the Ecological Approach to rivers: An essay in response to the Indian River Linking Project (IRLP)", *Futures,* Vol.38, pp. 586–605.

James, A. J. (2003), "Institutional Challenges for Water Resource management: India and South Africa", *Water, Households and Rural Livelihoods.*

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

Korse, K. H. (2004), "River linking project: case-specific approach is needed", *Current Science,* Vol. 87, No.12, p. 1643.

Krueger K. *et al.* (2007), "Assessment of the India river linking plan: a closer look at the Ken-Betwa pilot link", M. Sc. Dissertation, University of Michigan.

Kumar, A. and Srinivasa, R. (2004), "Interlinking of rivers: a boon or bane", *Environ People*, Vol. 11(1), pp. 25–29.

Mallet, F. R. (1869), "Vindhayans of central provinces", Memoir Geological Survey of India, Vol. II, Part. I.

Mather, P. (1999), "Land cover classification", Advances in Remote sensing and GIS analysis, Wiley & Son: Chichester.

Medlicott, H. B. (1860), "Vindhayan rocks of Bundelkhand", Memoir Geological Survey of India, Vol. II, Part. I.

Meijerink, A. M. J. *et al.*, (1994), "Introduction to the use of Geographic Information Systems for practical hydrology", ITC–UNESCO, No. 23.

Micklin, P. P. (1977), "NAWAPA and Two Siberian Water-Diversion Proposals: A Geographical comparison and appraisal", *Soviet Geography*, Vol. 18, No. 2, pp. 81-99.

Mirza, M. M. Q. (ed.) (2004), *The Ganges Water Diversion: Environmental Effects and Implications*, Kluwer Academic Press: The Netherlands.

Mishra, A. K. *et al.*, (2007), "Proposed river-linking project of India: a boon or bane to nature", *Environmental Geology*, Vol. 51, pp. 1361–76.

Mishra, R. C. and Saxena, M. N. (1956), "Xenolithic and other older rocks of Bundelkhand granite, type area Bundelkhand", Proc. 23rd Indian science congress, 157.

Mukherjee, S. (1989), "Geology and geochemistry of Pegmatites and associated rocks of Jorasewar and Sapahitola, Hazaribagh district, Bihar, with special reference to application of Remote Sensing techniques in exploration of natural resources", PhD Thesis, BHU: Varanasi.

Mukherjee, S. (1990), "Targeting potential groundwater sites in parts of Jhansi district, Uttar Pradesh by using satellite remote sensing techniques", All India seminar on groundwater investigation, management and geophysical techniques, Vol. 1.

Mukherjee, S. (1991), "Ground water appraisal report Hamirpur district Uttar Pradesh", Remote sensing applications centre Uttar Pradesh: Lucknow.

Mukherjee, S. (1996), "Targeting saline aquifer by remote sensing and geophysical methods in a part of Hamirpur-Kanpur, India", *Hydrology Journal*, Vol. 19, pp. 53–64.

Mukherjee, S. (1998), "Eco-Conservation of a part of J.N.U. campus, by GIS analysis", Proceedings: National Seminar on artificial recharge of groundwater organized by CGWB, 15-16 Dec.: New Delhi.

Mukherjee, S. (1999), "Remote sensing Applications in Applied Geosciences", Manak Publications: New Delhi, ISBN 81-86562-69-9.

Mukherjee, S. (2001), "Quantitative and qualitative improvement in groundwater by artificial recharge, a case study in Jawaharlal Nehru University, India", FACT and IRCSA, Vienna Margraf Verlag, Germany.

Mukherjee, S. (2003), "Systems approach to National River Linking Project", *Geography and You*, Vol.3, No. 3-4, pp. 42-43.

Mukherjee, S. (2004), *Text book of Environmental Remote Sensing*, Macmillan India Ltd: New Delhi, ISBN: 1403922357.

Mukherjee, S. (2007), *New Trends in Groundwater Research*, Cooperjal Publications: London, ISBN: 1-90608303-7.

Mukherjee, S. and Das A. K. (2005), "Drainage morphometry using satellite data and GIS in Raigad district, Maharashtra", *Journal of Geological Society of India*, Vol. 65, pp. 577-86.

Mukherjee, S., Jaiswal, R. K. and Krishnamurthy, J. (2003), "Role of Remote sensing and GIS techniques for generation of groundwater prospect zones towards rural development- an approach", *International Journal of Remote Sensing*, Vol.24, No.5, pp. 993-1008.

Mukherjee, S., Kumar B. A., and Kortvellessey, L. (2005), "Assessment of groundwater Quality South 24 Parganas, West Bengal, Coast", *India Journal of Environmental Hydrology (USA)*, Vol. 13, pp. 1-8.

Mukherjee, S., Veer, V., Tyagi, S. K and Sharma, V., (2007), "Sedimentation study of Hirakund Reservoir through remote sensing techniques", *Journal of Spatial Hydrology*. Vol.7 (1), pp 122-130.

National Research Council Committee on USGS Water Resources Research (2000), *Investigating Groundwater Systems on Regional and National Scales*, National Academy Press: Washington D.C.

National Water Development Agency (2007), "Ken-Betwa Link Project Feasibility Report", Retrieved at: <http://nwda.gov.in/index3.asp?sublink2id=23?>

National Water Development Agency (NWDA) (2002), Terms of Reference for Preparation of the Detailed Project Report: Interlinking of Rivers. Retrieved at: <http://nwda.gov.in/writereaddata/linkimages/9.pdf>

National Water Development Agency (NWDA) (2005), Environmental effects on linking of Rivers, Retrieved at: <http://pib.nic.in/archieve/lreleng/lyr2003/rfeb2003/24022003/r2402200320.html>

National Water Development Agency (NWDA) (2005), Retrieved at: <http://nwda.gov.in/indexab.asp?langid=1>

National Water Development Agency (NWDA) (2006), Benefits of National Perspective Plan. Retrieved at: <http://nwda.gov.in/index2.asp?sublinkid=49&langid=1>

Navdanya (2007), River Interlinking Plan. Retrieved at: http://www.navdanya.org/earthdcracy/water/riverlinking-intro.htm.

Okomoto (1983), "Japanese water transfer: a review, Long-Distance Water Transfer- A Chinese case study and international experiences water resources series", Vol. 3, United Nations University.

Pachauri, A K, Gupta, P V, and Chander, R. (1998), "Landslide zoning in a part of the Garwal Himalayas", *Environmental Geology*, Vol. 36, No. (3-4), pp. 325-34.

Pati, J. K. (2007), "Geology and geochemistry of giant quartz veins from the Bundelkhand Craton, central India and their implications" *J. Earth System Science,* Vol. 116, No. 6, pp. 497–510.

Patron, A., et al., (2001), "GIS applications for Environmental Impact Assessment: An analysis of the effects of motor way project in an alpine valley", *In geomorphology and Environmental Impact Assessment.*

Phadke, R. (2002), "Assessing Water Scarcity and Watershed Development in Maharashta, India: A Case Study of the Baliraja Memorial Dam." *Science, Technology and Human Values*, Vol 27, No 2.

Prakash, Bharatendu *et al.*, (1998), "Problems and Potentials of Bundelkhand with Special Reference to Water Resource Base", Center for Rural Development and Technology: New Delhi.

President Abdul Kalam's Independence Address (2005), Speech posted on The Hindu, online edition of India's National Newspaper, August. Retrieved at: <http://www.hinduonnet.com/thehindu/nic/presidentiday.htm>

Prime Minister Mr. Atal Bihari Vajpayee (2003), Speech at the 'Freshwater Year-2003' at Vighyan Bhawan posted on the Sustainable Development, February.

Radhakrishna, B. P. (2003), "Linking of major rivers of India—Bane or boon?", *Current Science*, Vol. 84, No. 10-11, pp. 1390-94.

Rajamani, V. *et al.*, (2006), "Linking Indian rivers versus Bay of Bengal monsoon activity", *Current Science*, Vol. 90 No.1, pp. 12–13.

Ram, B. (2005), "Presentation on Ken Betwa Link Project", University of Michigan. Ann Arbor, MI. October 25.

Rangachari, R. *et al.*, (2000), "Case Study: Dams in India", Report to the World Commission on Dams, November.

Reddy, S. (2007), "Hydro-Geomorphic impact assessment of Ken-Betwa interlinking project", M Tech Dissertation, IIT Kanpur.

Rivers for Life, Interlinking of India's Rivers: The Story So Far, Retrieved at: http://studentorgs.utexas.edu/aidaustin/water/interlinking-rivers.pdf.

Saraf, A. K. et al., (1999), "Landuse modelling in Geographic Information System for Dwarkeshwar watershed, Bankura District", *Proceedings of the National Symposium on Remote Sensing Applications for Natural Resources: Retrospective and Perspective,* Indian Space Research Organisation, Bangalore, pp. 99–100.

Saraf, A.K. and Chaudhary, P. R. (1998), "Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharges sites", *International Journal of Remote Sensing*, Vol. 19, No. 10, pp. 1825-41.

Sharma, B. R. and McCornick, P. G. (2006), India: country case study on domestic policy frameworks for adaptation in the watersector. In: 'Working together to responds to climate'' Expert group seminar in conjunction with the OECDGlobal Forum on Sustainable Development (http://www.oecd.org)

Sharma, R. P. (1982), "Lithostratigraphy, structure and petrology of the Bundelkhand Group" in K. S. Valdiya, S. B. Bhatia and V. K. Gaur (eds), *Geology of Vindhyachal*, Hindustan Publishing Corporation: New Delhi, pp. 30–46.

Shiva, V. and Jalees, K. (2003), "Living waters, the impact of the river linking project", Sujalam. Pub. Navdanya: New Delhi.

Shukla, A.C. and Asthana, V. (2005), "Anatomy of Interlinking Rivers in India: A Decision in Doubt". Retrieved at: <http://www.ideals.uiuc.edu/bitstream/2142/42/1/Shukla-AsthanaOP.pdf>

Singh, Arun Kumar, (2003), "Inter-linking of Rivers in India: A Preliminary Assessment", New Delhi, India.

Singh, R. and 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,* VOL. 90, NO. 10, pp. 1431-35.

Singh, Satyajit (1997), *Taming the Waters: The Political Economy of Large Dams in India*, Oxford University Press: New Delhi.

Srivastava, A. (2007), "Aquifer Geometry, Basement-Topography and Ground Water Quality Around Ken Graben, India", *Journal of Spatial Hydrology,* Vol. 2 No. 2, pp. 1-18.

Strahler, A. N. (1952), "Dynamic basis geomorphology", *Geological Society of America Bulletin*, Vol. 63, pp. 923–938.

Tarboton, D. G., Bras, R. L. and Rodriguez-Iturbe, I. (1991), "On the extraction of channel networks from digital elevation data", *Hydrological Processes*, Vol. 5, pp. 81–100.

Task Force on Interlinking of Rivers (TFILR) (2004), Retrieved at: <http://www.riverlinks.nic.in>

Thakkar, H. (2005), Ken Betwa Link: Why it won't click. New Delhi, India. Retrieved at: <http://www.sandrp.in/riverlinking/knbtwalink.pdf>

The South Asian (2005), Retrieved at: <http://www.thesouthasian.org/archives/2005/interlinking_of_river_in_indi.html>

Thomas, M. (1966), "Some geomorphological implications of deep weathering patterns in crystalline rocks in Nigeria", *Trans Inst Br Geog*, Vol. 40, pp. 173–93.

Thornbury, W. D. (1985), *Principles of Geomorphology,* Wiley Eastern Ltd.: New Delhi.

Vaidhyanathan, N. S., Sharma, G. and Sinha, R. (2002), "Mapping of erosion potential in garwal Himalaya", *International Journal of Remote Sensing*, Vol. 23, (20), 4125-59.

Van Dijk, A. (2001), GIS and Remote Sensing techniques in Land and water management: Kluwer Academic publishers, ISBN:079236788X.

Wadia, D.N. (1981), *Geology of India,* Tata McGraw-Hill: New Delhi.

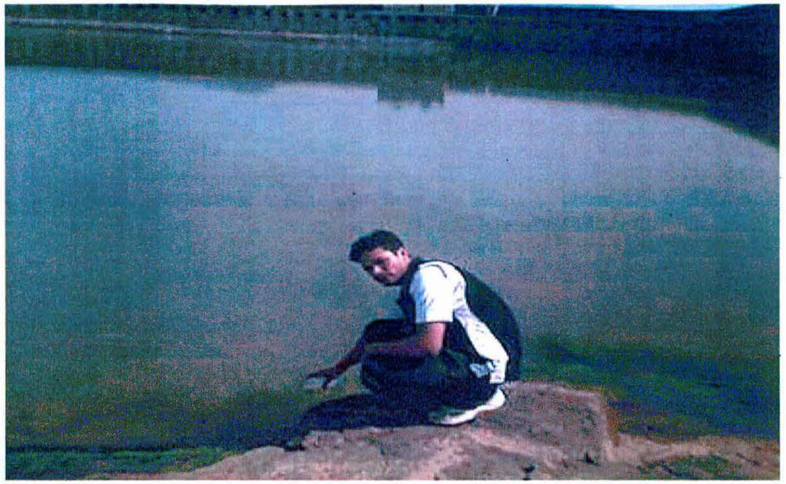
WHO (1984), Guidelines for drinking water quality-II pp. 333, Geneva, Environmental Health Criteria, 5.

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

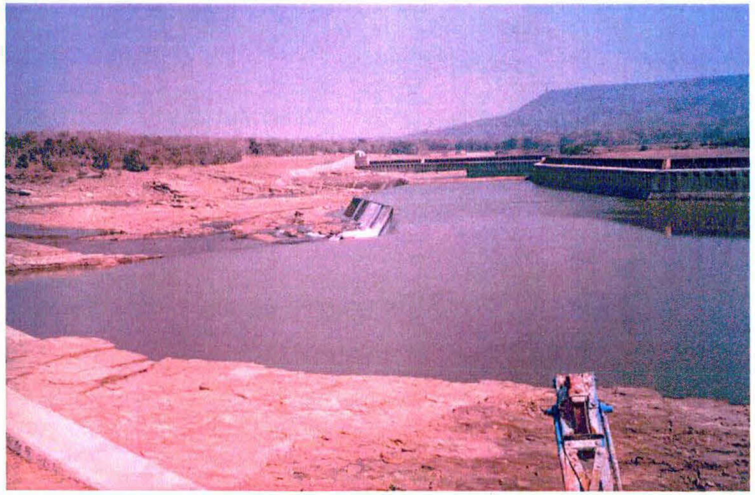
World Water Council (2000), "A water secure world; vision for water, life, and the environment", Marseille: World Water Council. Retrieved at: <www.worldwatercouncil.org/vision/documents/commissionReport.pdf>

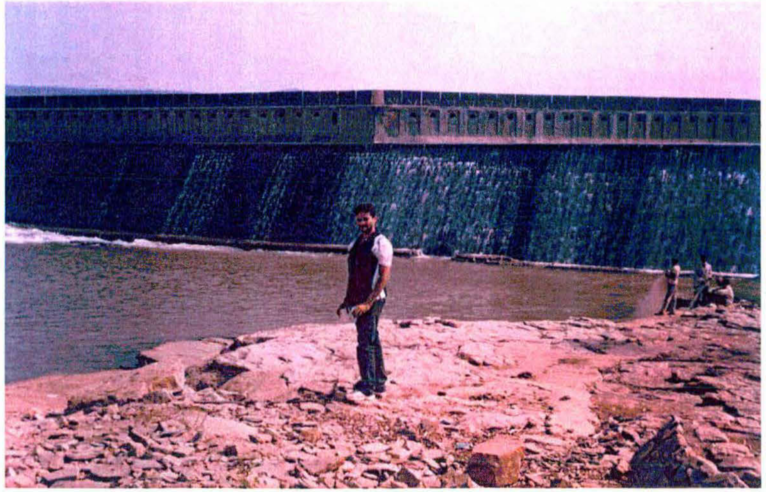
FIELD PHOTOGRAPHS

(i) Gangau Weir Command Area (November, 2007)

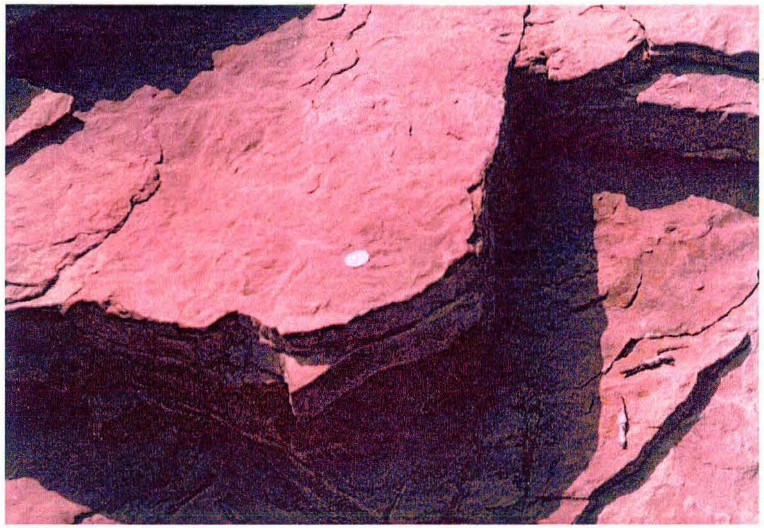


(ii) Water Sample Collection from Gangau Weir Site

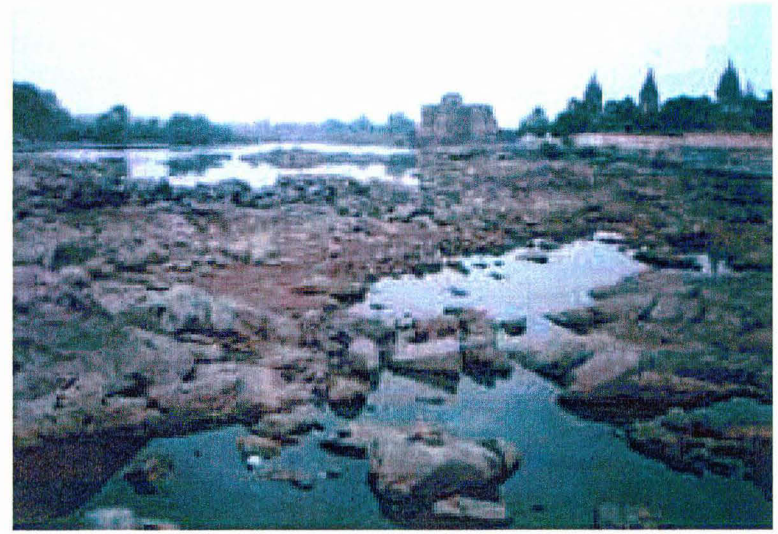




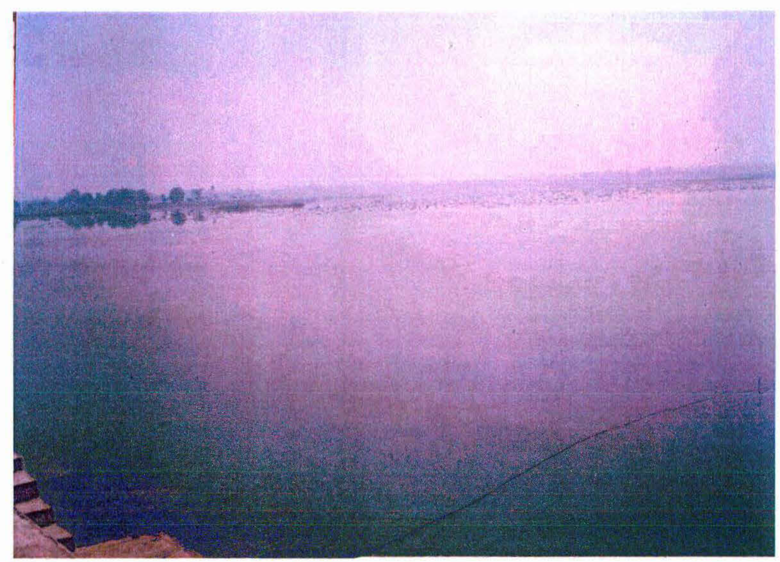
(iii) Ken River Flowing Near Gangau Weir



(iv) The Site of Rock Samples Collected (Panna Tiger Reserve)



(v) Betwa River Near Orchha, Tikamgarh



(vi) Barwa Sagar Reservior Where Linking Canal Ends