Journal of Spatial Hydrology

Volume 2 | Number 2 Article 2

2002

AQUIFER GEOMETRY, BASEMENT-TOPOGRAPHY AND GROUND WATER QUALITY AROUND KEN GRABEN, INDIA

J. of Spatial Hydrology
Vol.2 No.2

AQUIFER GEOMETRY, BASEMENT- TOPOGRAPHY AND GROUND WATER QUALITY AROUND KEN GRABEN, INDIA

Ajay Srivastava
Assistant Professor
Department of Remote Sensing
Birla Institute of Technology
Ranchi, INDIA 835 215
Email: ajaybit@yahoo.com

ABSTRACT

In this study a systematic approach has been made for the analysis of Ken graben area by integrating the remote sensing data with the hydrologic data to study the subsurface geological and geomorphological details and to demonstrate the aquifer geometry, ground water quality in the region. The approach involves regional interpretation of geomorphological and structural features exposed at the surface and relating the same to the subsurface. The region has varying thickness of alluvium composed of alternating sand/kankar and clay strata deposited on an uneven basement. In the present study the geological, geomorphological and structural aspects of the terrain have been carried out using IRS LISS I/ II data. The subsurface features of importance in the ground water exploration such as buried channels have been identified. Efforts have been made to generate a digital elevation model of the subsurface topography with the help of depth to bedrock contours. This has facilitated identification of the areas with favourable aquifer disposition and subsurface geomorphic features that are potential sites for ground water development. Two different types of basement depressions are present in the study area, which affect aquifer geometry, ground water potential and quality. Digital elevation model (DEM) of the basement topography has been prepared by converting set of depth to bedrock contours to another set of contours. Variations in tone and texture associated with vegetation and geological features coupled with inferred ground water migration pattern in the study area have enabled the delineation of the brackish ground water pockets that are in close agreement with the field investigation. An overlay of the enhanced image on the digital terrain model of the basement has enabled an understanding of the exact subsurface geometry of the aquifers and their relationship to the surficial geomorphic features. Ground water hydrogeological status has been inferred from an integration of the information from structural, lithological and vegetational information, DEM along with available geologic, as well as topographic and hydrologic data.

Keywords: DEM, Basement topography, Remote Sensing, GIS, Aquifer geometry, Water quality, Fence diagram and cross-sections.

Introduction

The aim of the present work is to search the probable sites of buried and abandoned channels in the inter-drainage areas to provide a complete hydromorphic picture of the area. For a proper visualisation and study the influence of subsurface configuration and its effect on the geological and geohydrologic status of a region, a three dimensional picture is essential. This is usually achieved through the vertical sections or in the form of ribbon diagrams and fence diagrams. Three-dimensional means of visual display are especially useful in bringing out the relationship between basement topography, aquifer disposition and surface features. The use of spatial analysis, DEM for 3D visualization and terrain draping, thematic map overlays can be very helpful in the interpretation of remotely sensed data. Since, most of the geological features extend deep down into the Earth, as well as across it, the three dimensional spatial nature of geological features needs special attention. The subsurface morphology of the basin and the tectonics are the factors, which influenced the sedimentation pattern and guided the channels of Yamuna river system. The tributaries of Yamuna have incised meandering channels, with well-developed escarpments and terraces on both banks and narrow flood plains.

Geology and Subsurface Details

The study area (Figure 1) includes a part of the Marginal Gangetic Plain of Uttar Pradesh province. The climate of the area is dry. The area lies in the semi arid zone of Bundelkhand region. The annual rainfall is around 950 mm, with maximum precipitation (80%) received between July and September from the south-east monsoon. The terrain is flat with occasional hillocks at an average altitude of 117.5 m above mean sea level. River Yamuna and Ken are the main drainage. The hydraulic gradient of the ground water table in its vicinity is towards the river. The lateral extent of aquifers at various depths in the Gangetic alluvial terrain is controlled by the palaeochannel trends during Pleistocene-Holocene period. The aquifers, composed of sand-silt combinations, represent the channel deposits of the ever shifting drainage network with vast flood plains (Bajpai, 1986). This drainage pattern is closely related to the structural evolution of the area. The tributaries of these rivers have also played a significant role in the aquifer formation. Thus, the subsurface aquifer geometry in the region is an end product of various factors active during the Pleistocene and Recent periods. The aquifers show wide variations in their nature and geometry from place to place. The depth to bedrock, depth to granular zones and thickness of granular zone in individual bore holes of some of the locations are listed in Table 1.0. In the study area, a thick sand body occupies the central part of a graben (maximum depth 89 m and designated as 'Ken Graben' by Bajpai and Gokhale, 1991) and tapers in thickness both in the lateral as well as in the longitudinal directions. In the southern part, exposures of weathered granitic material are evidenced. Another depression (Baghelabari depression) lies between the inter river basin of Ken and Baghain rivers in this region. The depth varies between 20 m to 105 m in the region and it increases further south (Bhattacharya, 1984). According to Ahmad (1984), this inter river basin possibly was formed due to large scale structural dislocations perhaps in the post Vindhyan period resulting into 'mini graben'.

Basement DEM and Aquifer Geometry

The basic aim of the study is to correlate the surface geomorphological features from the images with sub-stratum information (well logs) to show spatial variations in aquifer geometry. Several image processing and GIS techniques such as false colour composites, contrast stretching, image smoothing, edge detection, band ratio, principal component analysis, image registration, digitization and interpolation have been adopted for extracting maximum hydrogeological information. The FCC (Figure 2) and enhanced images of the study area were interpreted visually and have been used to prepare the hydrogeomorphological map after limited field verification. The remote sensing keys used for aquifer detection using satellite images were local and regional relief setting, stream valleys, vegetation indices of moisture anomalies, alluvial plains, flood plains, alluvial fans, braided and meandering streams related to shallow ground water levels, braided and meandered plain, channel-fill, orientation of lineaments, fractures, geologic barriers like dykes, drainage network, weathered zones, orientation of ponds and lakes, land use and land cover have been identified.

For a complete understanding of subsurface structures and their geological evolution, it is usually necessary to produce maps, cross-sections and three-dimensional models of the subsurface. The availability of three-dimensional images and sections help better interpretations, even for inherently two-dimensional features. Contour maps of depth to bedrock were digitized which was later used to create an isopach and a digital elevation model (DEM) of the study area. The contour values of the isopach map (Figures 3) were structured differently to produce a DEM of the basement topography (Figures 4). Inputs for the GIS include the hydrogeomorphological map, DEM of the basement, soil isopach map and aquifer thickness data. Data from all these inputs were combined to reconstruct the aquifer geometry with basement elevation details. Most of the Digital Image Processing, GIS and hydrological analysis were carried out in ERDAS Imagine 8.5, ArcInfo 7.2.1 and Rockware software packages.

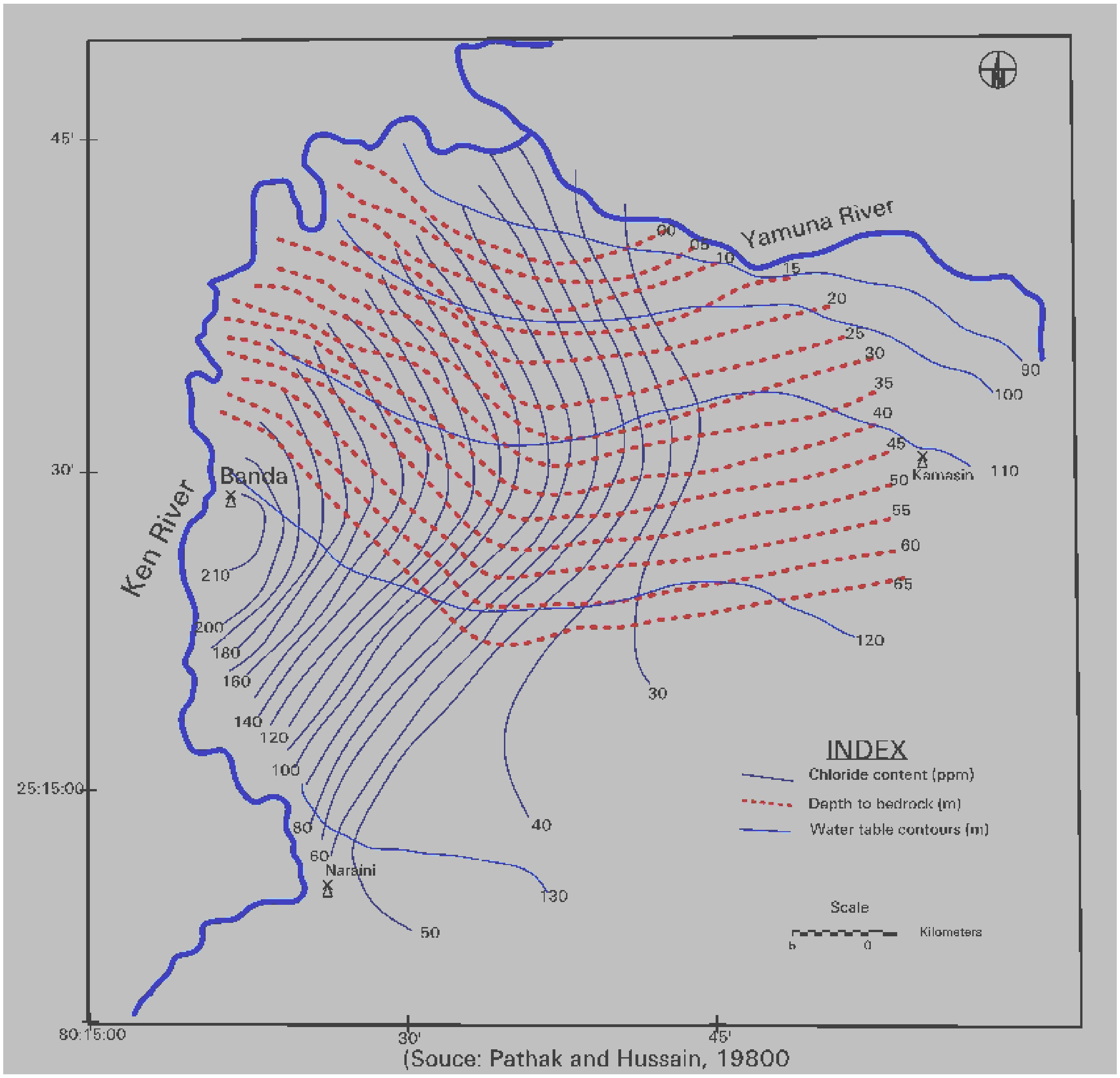


Figure 1. Study area-covering parts of Marginal Gangetic Plain, India

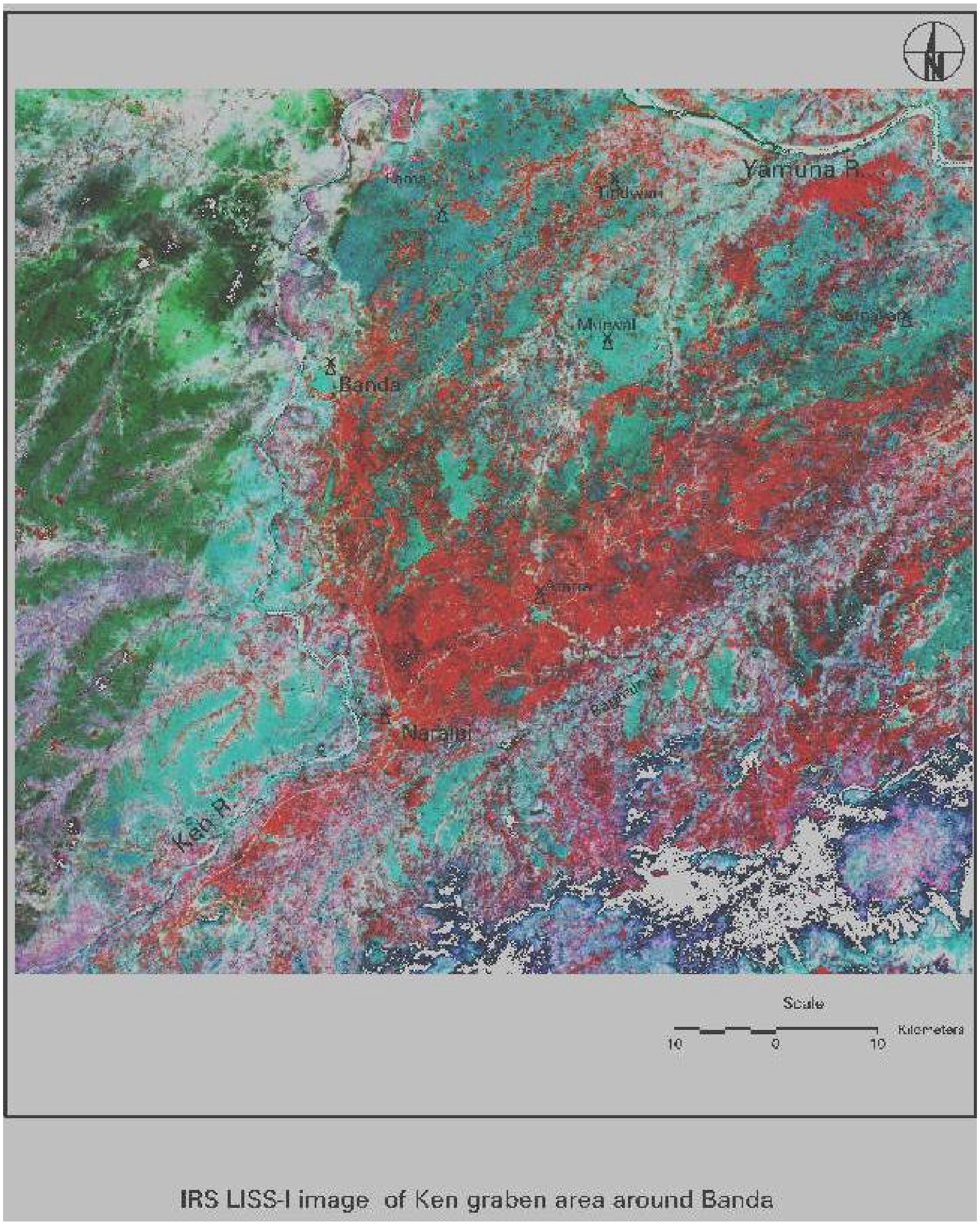
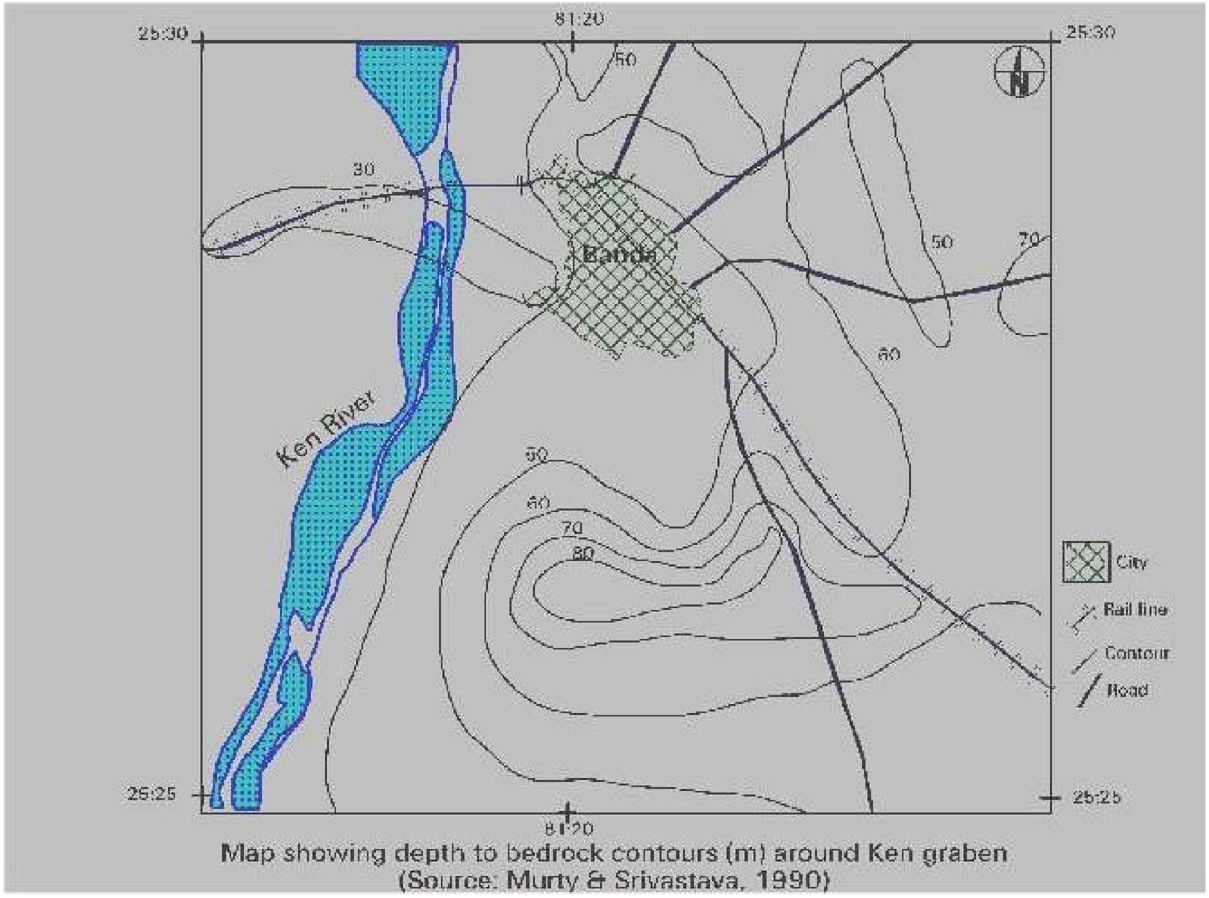


Figure 2. The FCC of the study area



Figures 3. The contour values of the isopach map

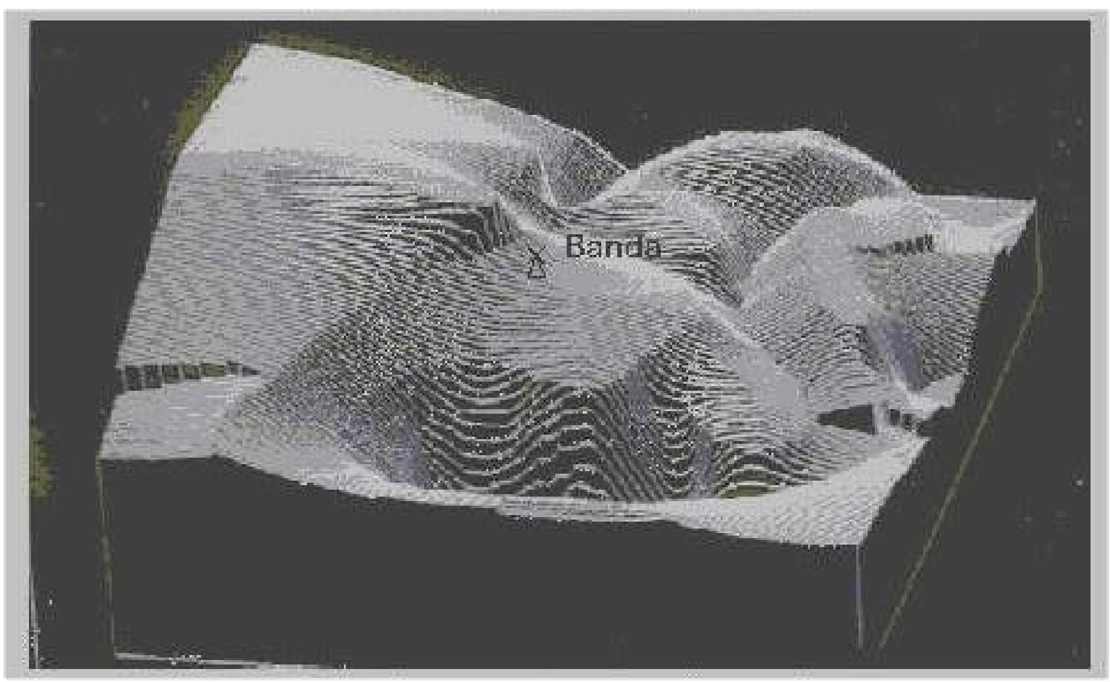


Figure 4. DEM of the basement topography

Table 1: Depth data of bedrock and granular zones in the area around Ken Graben (Source: Srivastava, 1974; Ahmad, 1984)

Locality	Depth to bedrock from the surface (in meters)	Depth to granular zones encountered (in meters)	Thickness of granular zones (in meters)
Kanwara-I (25^{0} 30' 40":80^{0} 19' 45")	50	14.72-25.72 39.72-49.72	21.00
Lama (25^{0} 34' 30":80^{0} 22' 30")	89	28.72-88.72	60.00
Maharajpur (25^{0} 43' 00":80^{0} 28'00")	131	70.32-105.20 126.72-130.72	39.40
Tindwari (25^{o} 36' 30":80^{o} 31'35")	104	53.72-88.72	35.00
Murwal (25^{0} 31' 10":80^{o} 28'50")	85	35.72-84.72	49.00
Satnayan (25^{0} 33' 00" :80^{0} 47' 30")	97	52.72-80.72	28.00
Kamasin (25^{0} 33' :80^{0} 55' 63")	59	51.72-58.72	7.00

Geomorphology of the Area

Regional and local geomorphology is well depicted in satellite images. False colour composites of the original bands and principal component images have been used for the interpretation of the geomorphic features. Geomorphic features and structural details from satellite images were interpreted for identifying ground water and facilitated the location of recharge zones and ground water conditions. Various geomorphic features have been identified in the image using remote sensing keys. The area has been divided into five major geomorphic units with their associated landforms (Srivastava et al., 1996).

- Recent flood plain of Ken and its tributaries containing point bars, channel bars and sand bars.
- Ken alluvial surface comprising of palaeochannels, meander cutoffs, meander scrolls.
- Stable alluvial remnants with dense vegetation.
- Ravinous tract along Ken and its tributaries.
- Low structural-cum-denudational hills.

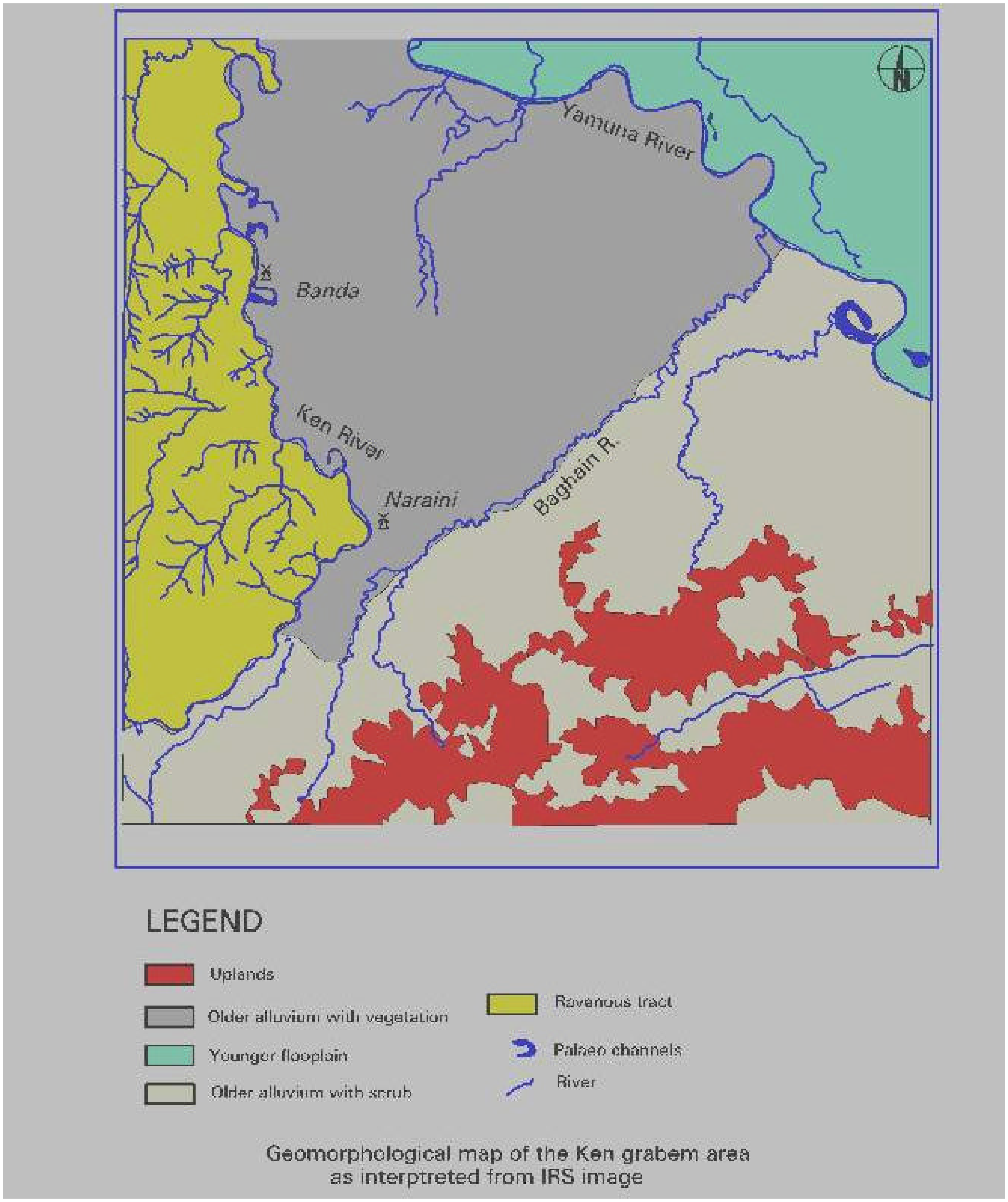


Figure 5. Geomorphological map of the study area

Basement Topography and Aquifer Distribution

The morphology of the area is largely determined by tectonic and fluvial processes that operated both during the Pleistocene period and recently. The meandering patterns of rivers and the location of abandoned channels associated with thick granular zones have been greatly influenced by the structure of the basement rocks and major tectonic trends. To understand the extent and geometry of the palaeochannel deposits of Ken river in this region, a fence diagram of transverse sections have been extended to the regions covering parts of

Yamuna flood plain in the north and eastern side of the terrain (Figure 6). A thick sand body with its trend parallel to the course of the river Ken has been reported earlier in the Banda district (Bajpai, 1983). The maximum thickness of the granular zone (60 m) in this graben is around Lama. The digital elevation model of the basement is very helpful in the correct visualization of the bedrock configuration and aquifer disposition. This sedimentary unit with a maximum thickness of more than 60 m is observed to be pinching in both the lateral and longitudinal directions. This depression corresponds to the 'Ken Graben' having elevated areas on either side with a mximum depth (131 m) around Maharajpur. It appears that the thickness of the granular zone in the Ken Graben area is controlled by the shape and depth of the depressions present in the bedrock. A distinct increase in the thickness of the granular zone with a general increase in the depth of bedrock has been evidenced within the Ken Graben region. This is indicative of the association between palaeochannel and Graben. The sand body appears to have its recharge from the elevated areas in the south with hydraulic continuity restored through intermittent sand lenses at various depths. Thus, sand body within the depression, confined between clay and hard rock contributes to the various artesian flowing wells in and around Banda town. It has been inferred that the Artesian conditions exist over a wide region within the eastern part of the Banda district where the thickness of overburden is less and this confined aquifer extends in the subsurface. The thickness of the alluvium overlying the granitic basement varies from place to place, indicative of uneven bedrock topography and possibilities of buried channels in the area. The aquifers show a wide variation in nature and geometry from place to place, which is the result of variations in basement topography and localized changes in their depth due to displacements along weak zones. The northward deepening of bedrock complex and subsequent increase in thickness of granular material suggest that the aquifer disposition is controlled by the geometry of the Ken Graben. This relationship can be understood by comparing the basement DEM (Figures 3 & 4), fence diagram (Figure 6) and the interpolated map showing variations in the thickness of the granular zone in the area (Figure 7). Most of the geomorphological features mapped on the satellite image are associated with a thick sand body beneath the surface overlying some conformable depressions in the basement complex. These bedrock depressions which are very common in this region, were once settling basins for the in flowing watercourses. Such buried channel deposits are the potential source of ground water. In addition to the fence diagram various section diagrams have been generated to understand the spatial variations in the aquifer geometry (Figure 8).

In the southern part, the weathered granitic material can be seen even on the top of the surface. It has been observed that the wells with basic rock encountered at the bottom yield less than that those located in the granites, because of the presence of possible fracturing in the form of joints in the granitic basement. These joints and fractures were once exposed before the formation of the alluvial cover. Even at present, the joints that are widely open at the surface have a tendency to close down with depth. The master joints are found to persist to a depth of 60 to 70 m, with a sufficient linear continuity (Ahmad, 1984). In the southern part, the depth to water level varies between 2.5 to 28.0 m below ground level. The water level is generally shallow towards the southern part of the Plain along the channel of Ken and deepens towards the course of Yamuna, the major stream of the region.

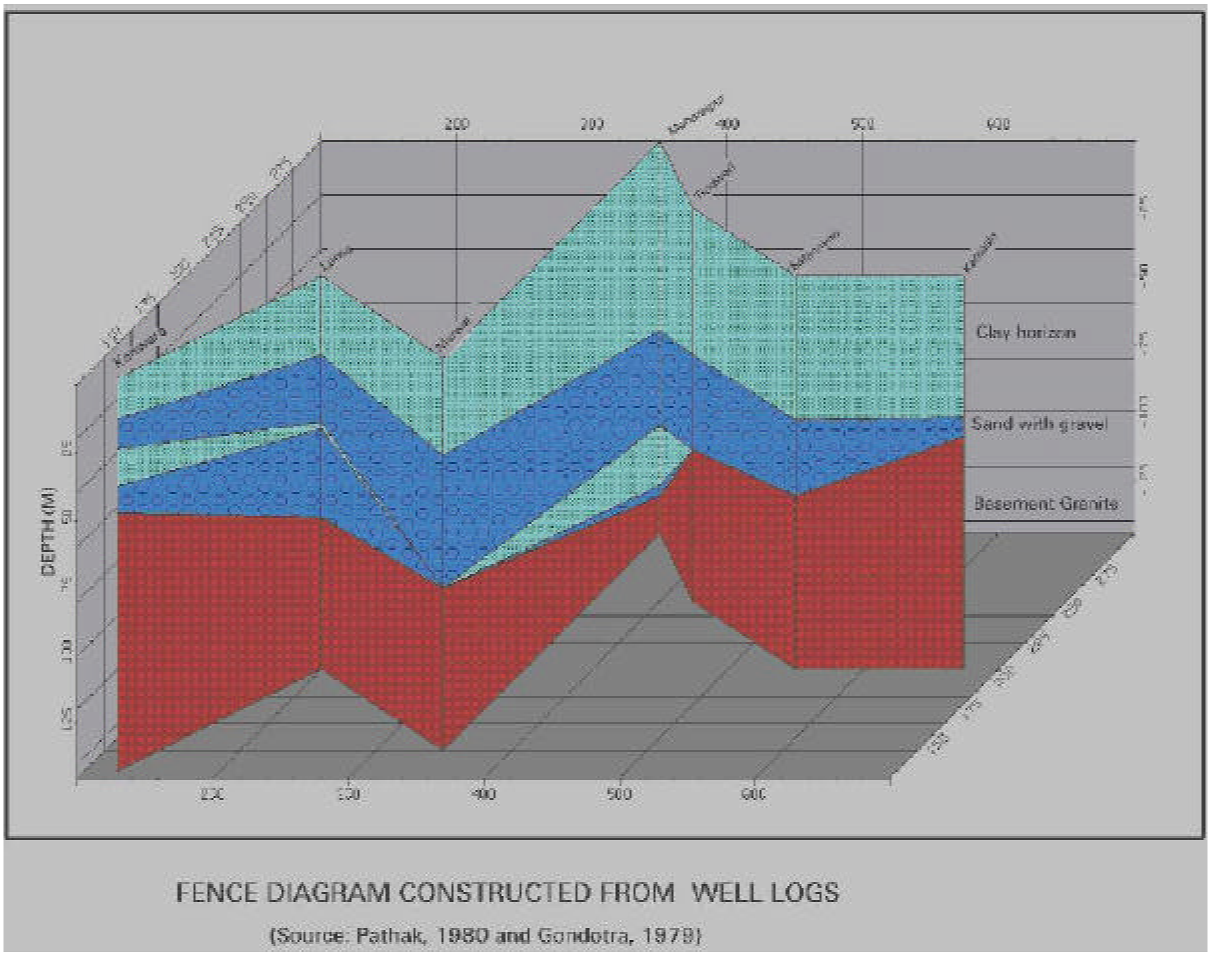


Figure 6. Fence diagram of transverse sections covering parts of Ken and Yamuna flood plain

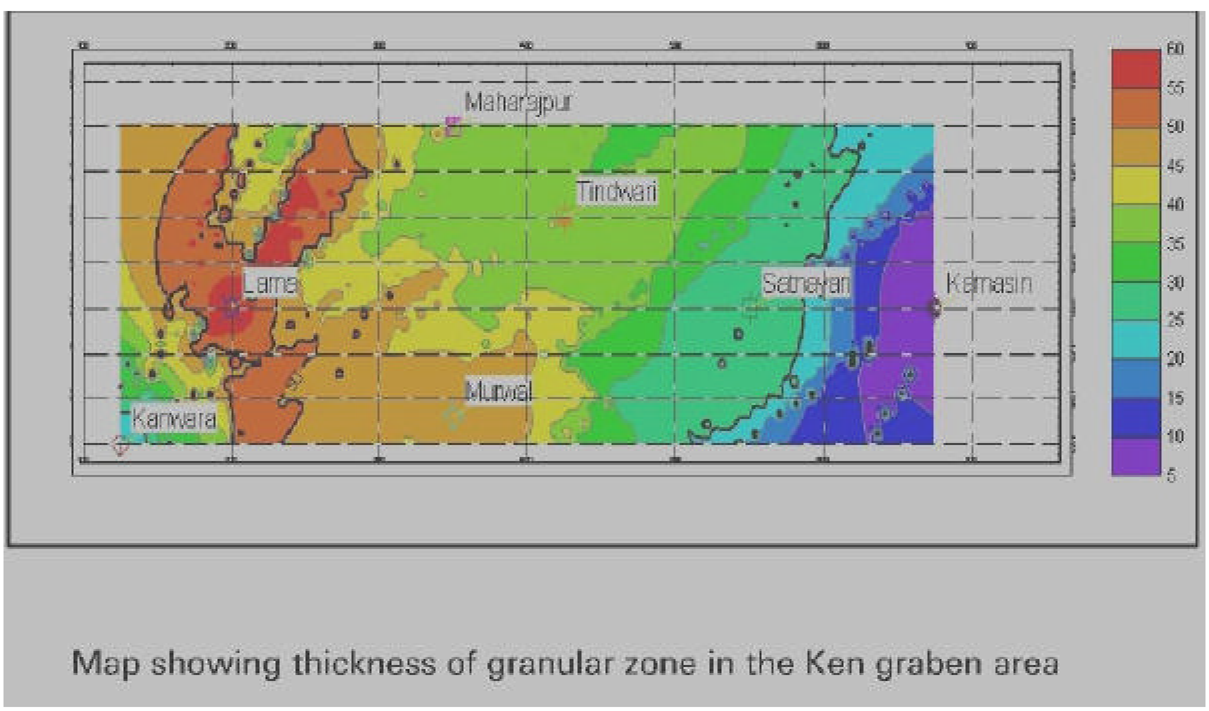


Figure 7. Interpolated map-showing variations in the thickness of the granular zone in the area.

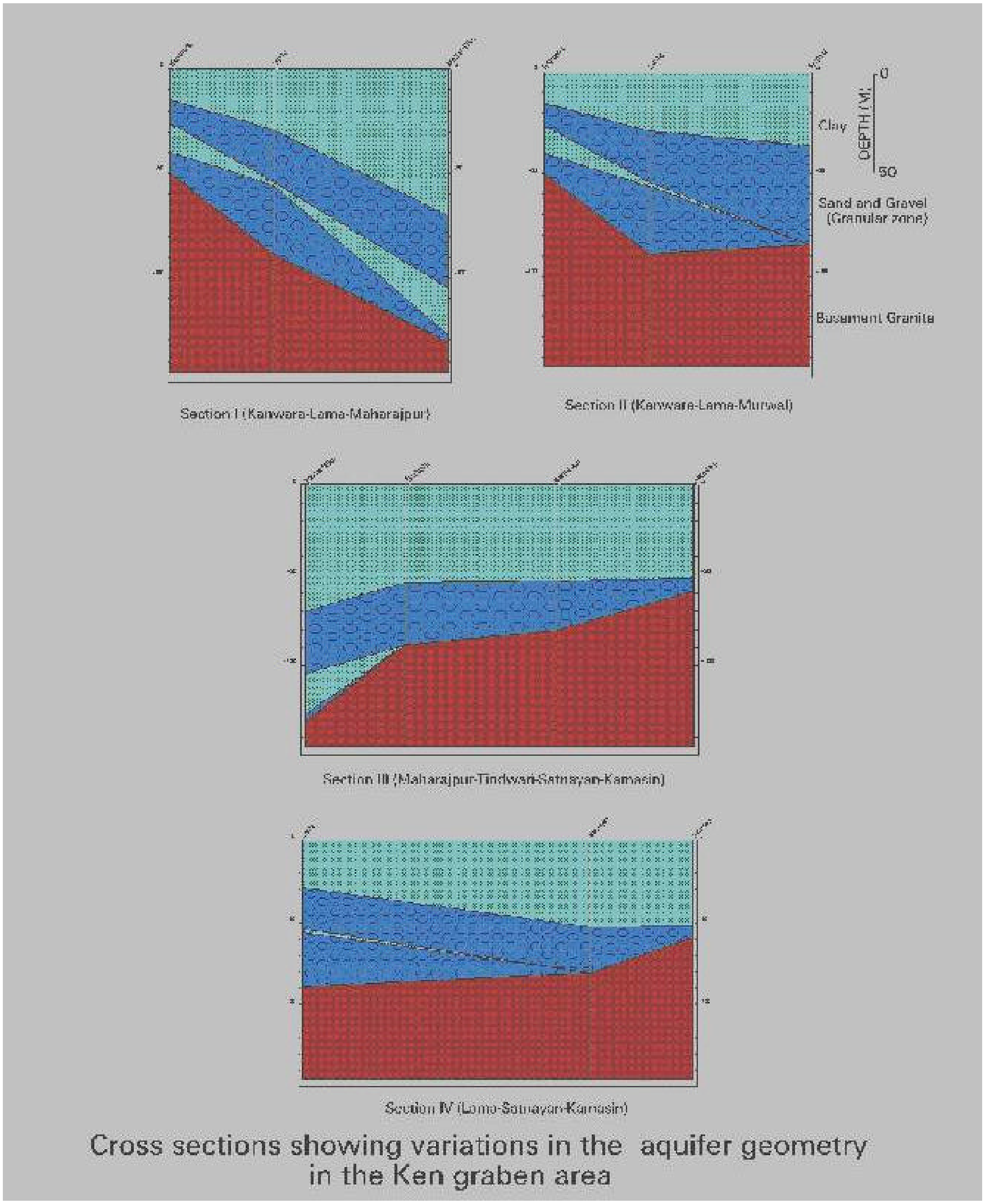


Figure 8. Spatial variations in the aquifer geometry.

SALINITY IN MARGINAL GANGETIC PLAIN

Despite the occurrence of ground water at shallow depths, supplied by confined aquifers with high piezometric head, the development of resources in this terrain is problematic due to the occurrence of high salinity. Electrical resistivity techniques have been used successfully for the delineation of salinity estimates of ground water on a local basis only. For regional, studies, these techniques are neither cost nor time-effective. Remote sensing techniques offer an excellent alternative. Soil and vegetation conditions, together with morphological characteristics, reflect the situation in a terrain, and they can be employed for the estimation of the depth and quality of near surface ground water. The integration of remotely sensed data and use of GIS can serve as a useful guide for the selection of training areas for classification, and to update a data base for the assessment of spatial and temporally dynamic phenomena (Walsh et al., 1990). Further, inferential methods using GIS for depth and quality estimates are required, in the case of ground water occurring at greater depths. A great deal of information relating to the extent and type of aquifer can be extracted from vegetation data, and this, along with geology, hydrology, and geochemical information, forms the basis of the present study. Vegetation plays an important role in such a terrain, since the vigor of its growth alone reflects the ground water quality and subsurface conditions. Soil condition is one of the most important parameters, as an overall reflection of the other hydrogeologically dependent landscape components (Polnov, 1952). The surface expression of the terrain, in terms of soil and vegetation, can be analysed distinctly on a satellite image. As the total vegetation cover in a given area is more reliable ground water indicator than the individual plants (Kruck, 1976), the general vigour of growth of plants, as represented on a satellite image, has been found more useful for the uniform and regional evaluation of ground water depth. A study on the basis of vegetation is valid since the scattered vegetation on the ground appears denser on satellite images, due to the smaller scale (Bajpai and Gokhle, 1991). Further, an assessment of water table depth would be ideal in a terrain of a similar morphology, and hence remote sensing techniques for the evaluation of ground water depths can be applied to an identical image, where the soil has sufficiently developed to support vegetation. A ‘similar tract’ approach forms the basis of hydrogeological extrapolation, where the hydrogeological data observed on a limited area is extended to obtain information for the entire area, in order to ascertain ground water conditions within the tract (Nefedov and Popova, 1969).

A procedure is presented for ground water exploration in terms of depth and quality in an alluvial terrain with shallow ground water occurrence. Variations in ground water quality have been mapped on the basis of field sampling and chemical analysis of ground water. A scheme of image processing and GIS techniques using false colour composites, vegetation indices, density slices, image registration, digitisation, overlaying, and supervised classification has been applied on IRS LISS-I (march-April’ 99) and LISS-II data of summer season. Various zones established within the terrain based on our research are in conformity with ground water salinity and depth contours. The problem of occurrence of extensive saline/alkaline soils in the Central and Marginal Indo-Gangetic Plain is explained on the basis of geological information obtained from the satellite image and available geophysical data.

Salinity Mapping

Reflectance variations of vegetation on the image are attributed to the different species of vegetation and their densities, which together provide evidence of shallow ground water conditions. Favourable growth conditions prevail in regions where the water table is situated below the are of influence of evapotranspiration, that is, within 10 m depth (Kruck, 1976). These regions appear predominantly darker in NIR band lighter in red band of IRS-1B image, indicating a dense coverage of vegetation with high chlorophyll content. Since the surface signatures investigated on the images are due to the net effect of ground water condition and vegetation, NIR band was found to be more useful than any other band. Areas having brackish water and saline soils associated with a high water table promote unfavourable growth conditions for green vegetation (Murthy and Srivastava, 1990). An indication of whether scanty vegetation in an area is due to the depth or salinity of ground water can be confirmed using FCC and NIR band, on which regions of high salinity appear lighter. The green vegetation index (GVI) is used in the present study which emphasize the vegetation vigour (Jensen, 1986), and can be expressed as:

$$GVI = [\{(NIR - R) / (NIR + R) * 127\} + 128]$$

The methodology adopted is illustrated in the flowchart (Figure 9). Reflectance zoning was obtained on a regional GVI map (Figure 8.5), which offers an effective enhancement of the different salinity zones for this type of interpretation. In the GVI map, the dense vegetation is in the eastern part, while there is much less vegetation in the northwestern part of the study area. In the first stage, the representative/training pixels were selected in each class of the ground cover. This selection was made on the basis of variance in grey level, and the pattern based on their tones and textures. These regions were correlated and identified on the GVI map. The reflectance response in the GVI image, with the vegetation characteristics and hydrogeological conditions (Srivastava, 1974 and Ahmad, 1984a) are illustrated in Table 2. In the present work, four zones were delineated corresponding to the decreasing order of the vegetation vigour in NIR band, as well as in the GVI map. These zones were marked on a density sliced image as areas of dense vegetation representing low salinity zones, medium to low salinity, high salinity zones, and ravenous/sandy zones. A gradual decrease of GVI value is shown with the increase of water table depth and chloride concentration (Figure 10). Further, a maximum likelihood classification (MLC) was performed to divide the whole area in the four zones, because it is more effective in discriminating vegetation vigour than enhancements such as band ratio and principal component. Generally, supervised classification yields unsatisfactory results in regions with vegetation of varying types and densities, due to overlapping reflectance by different species of vegetation and the bottom effects of ground. In the present study, a reflectance zonal map (Figure 11) of the area was prepared on the basis of the variance in reflectance of the various vegetated areas. The contour map of the chloride concentrations in ground water was digitized. This map was used to register the image. Geometric rectification using nearest neighbour resampling of the image was performed. The location of different levels of salinity was taken from the digitized map and their corresponding locations in the satellite image recorded. The location and their salinity values were used to train the classifier using the digitized map, and the reflectance zonal map of the area has been prepared. This map shows a close conformity with the actual ground water salinity results prepared by Central Ground Water Board (CGWB). For this work, field plots of the chloride content in ground water (Pathak and Hussain, 1980; Awasthi et al., 1980; Gondotra, 1979) have been utilized.

This map reveals that much of the area to the west of the Banda, along the river Ken, pertains to the high salinity and medium salinity zones. This tract also includes the ravines where the soil and vegetation are least developed, showing a clear contrast with the surrounding uplands on the images. The geochemical characteristics of the ground water in the area are reported by Srivastava (1974) and Ahmad (1984a and 1984b). In the eastern apart of the river Ken, the chloride concentration varies between 4 and 1150 ppm. The hardness, as $CaCO_3$, of ground water varies between 124 to 380 ppm. Bicarbonate ranges from 37 to 1201 ppm, but usually it is within 402 to 670 ppm (Srivastava, 1974). In the present study area, the chloride concentration varies between 170 to 210 ppm. In general, the wells located near the Banda town, where the alluvium is usually thin and yield brackish water. On the other hand, the wells on the northeastern side, with the thicker bed of coarse sand forming the aquifer, yield fresh water. Depth to water in the northern region varies from 2.50 to 7.22 m below ground level, whereas in the southern part it is from 9.40 to 18.90 m (Gondotra, 1979). Thus, the recharge zone is in the vicinity of Banda town and the hydraulic gradient is generally towards the major stream. The tube well water is better than the shallow ground water. Here the chloride percentage varies from 34 to 96 ppm and specific conductivity from 981 to 13.9 micromhos/cm at 25 ^{0}C (Srivastava, 1974). In fact, the marked difference in the chemical quality of the ground water throughout the study area is actually an index of channel and flood plain depositions in the area.

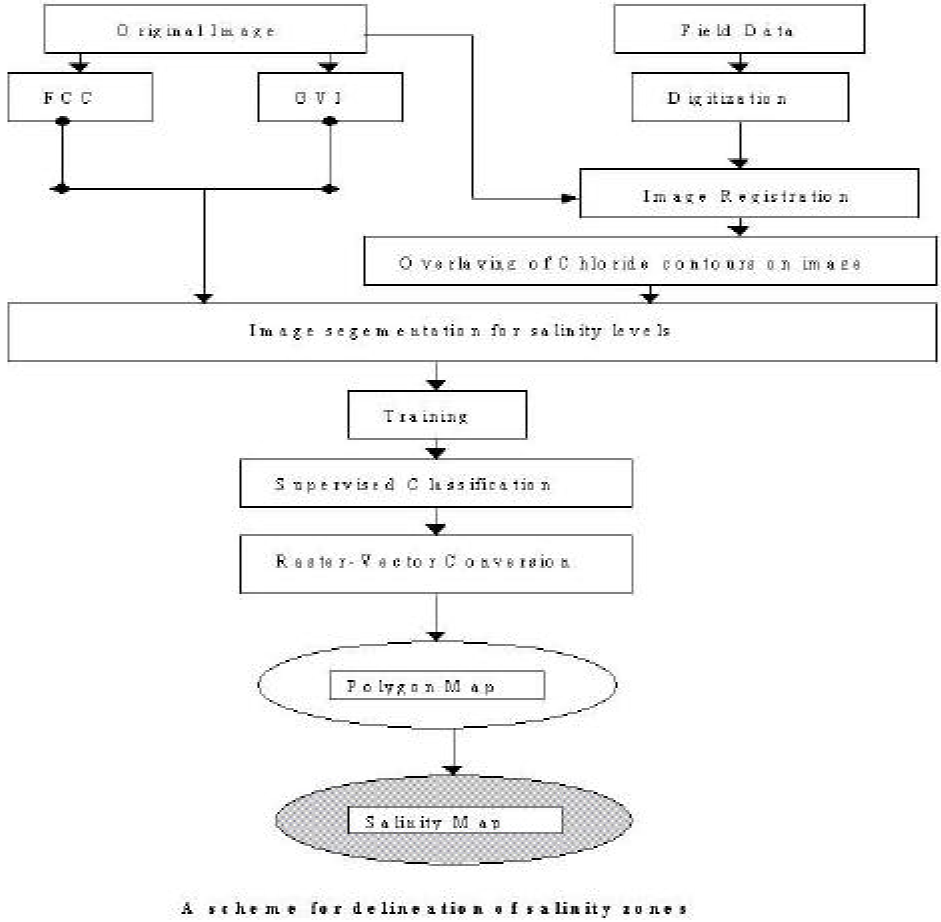


Figure 9. Flowchart showing methodology adopted is this study

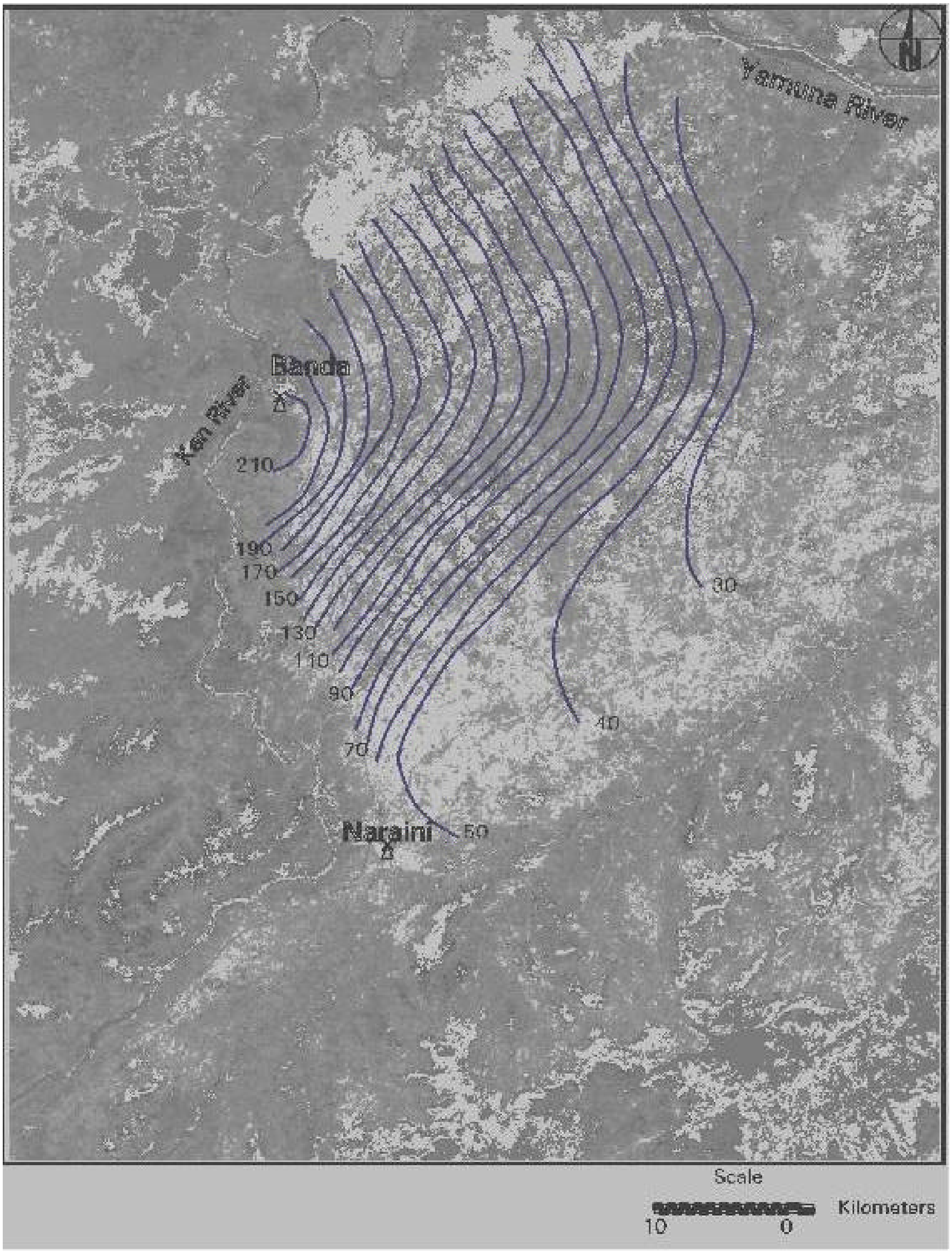


Fig. 10: GVI map overlaid with chloride contours.

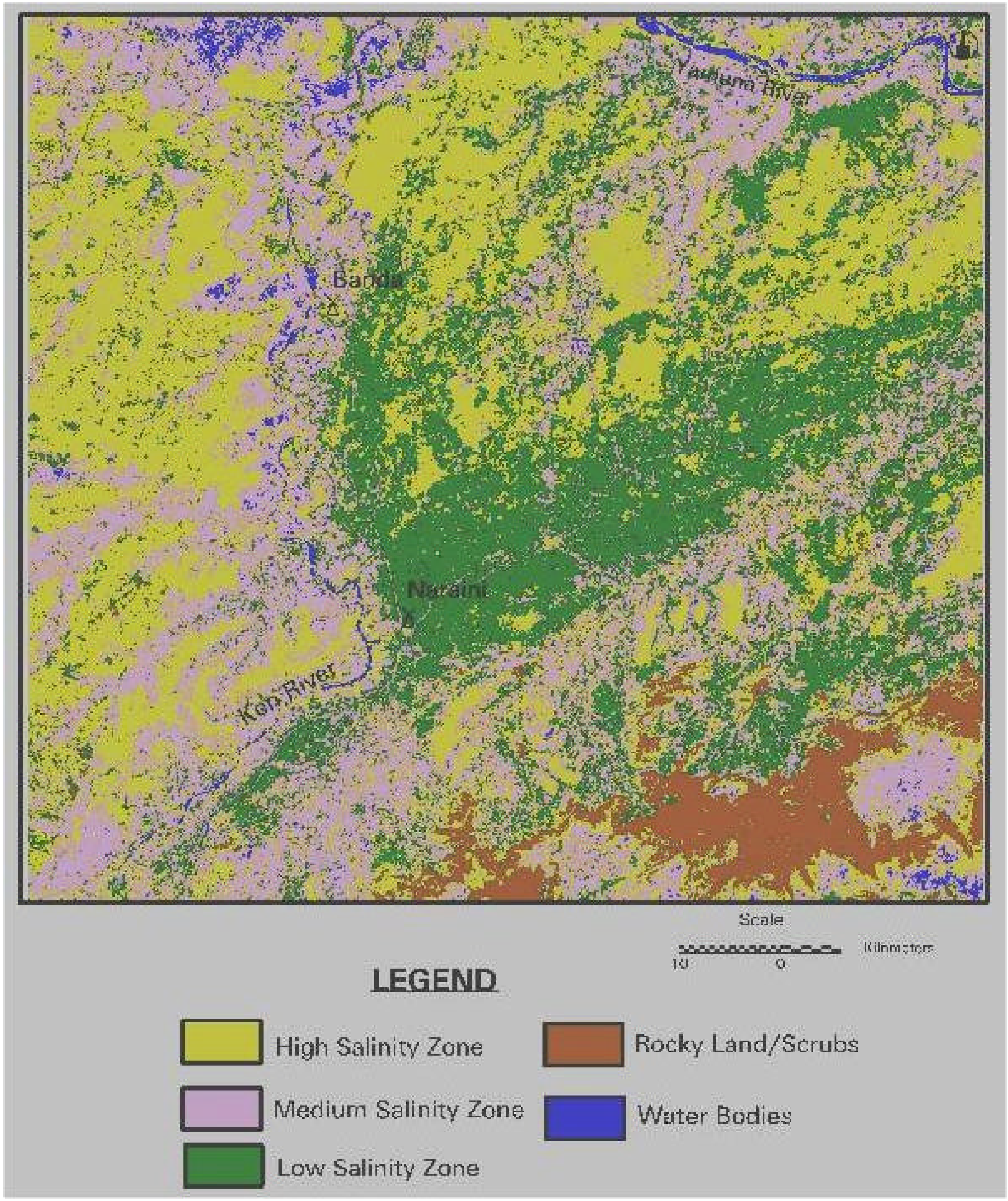


Fig. 11: Salinity map shows different ground water salinity zones.

Table 2. Reflectance response in GVI image with soil, vegetation characteristics and hydrogeologic conditions.

Zone	Reflectance zone	Image indication	Hydrogeological conditions
1	Low salinity zone	Large bright patches representing dense vegetation	Depth to ground water within 30 m. Normal salinity. Chloride content less than 180 ppm.
2	Medium to low salinity zone	Scattered small bright patches with sparse vegetation	Depth to ground water less than 20 m. Chloride content between 200-to180 ppm.
3	High salinity zone	Dark patches due to absence of dense vegetation	Depth to ground water between 1.5 to 7.22 m. Chloride content more than 210 ppm.
4	Ravenous/sandy zone	Dark patches along the surface streams	Depth to ground water very near to the surface.

In the standard NIR FCC and classified map ravenous areas with low vegetation appear similar to the high salinity zones. The difference between these two classes is clear in the FCC PC (RGB: 1 3 2). A regular variation is established between the GVI on one hand, and the water table depth and chloride concentration on the other. The areas of medium salinity may develop higher salinity over time, as the inflow of ground water continues.

Conclusions

In the present work, the analysis of surface geology, subsurface details from hydrological, geophysical data and GIS have helped to select prospective areas for ground water exploration. It has been shown that the most remarkable areas of ground water availability correspond to the commonly occurring depressions in the bedrock. These depressions formed the site of intensive deposition of coarse gravel and coarse sand due to rapid erosion of the material from adjacent regions and subsequent transportation to the favourable sites. The nature of ground water storage in the crystalline rocks is very complex and possibilities of extracting ground water vary considerably not only among different rocks but in the same rock at different places. Earlier, the exploitation of the ground water was on the basis of immediate individual needs, ignoring completely the hydrogeology and the resources of the place. However, an efficient tapping of ground water in the area is to be on the basis of a comprehensive hydrogeological picture with complete knowledge of the nature and capability of aquifer, source and exact extent of its recharge. The geomorphology of the area is in congruence with the geometry of the basement complex with granular zones indicating the presence of buried channels. Visual interpretation of IRS images have shown that most of the geomorphic features coincide with the known successful tube well sites as reported earlier (Murty and Srivastava, 1990). The palaeochannels, meander cutoffs and meander scars constitute prominent aquifers with excellent yields. The aquifers in the region have a direct hydraulic continuity with the river Ken through the overlying silty clay and thus have good potential for ground water development. The areas falling outside the bedrock depressions are not suitable for large-scale ground water development since the formations are predominantly silty and clayey in nature. The presence of topographic depressions in the basement and their lateral extent should be established and it should be judiciously correlated with the geometry of buried channels because it can be very helpful in understanding aquifer geometry and ground water recharge zones.

The subsurface morphology of the basin and the tectonics are the factors that have influenced the sedimentation pattern and guided the channels of Ken river and its tributaries. The bedrock depressions formed the site of intensive deposition of coarse gravel and sand due to rapid erosion of the material from adjacent regions and subsequent transportation to the favourable sites. It has been observed that small scale local subsidence are commonly present inside the lowlands also, as neotectonic processes changed the drainage and consequently formed the abandoned channels, which may be inside these depressions and now acting as the recharge areas of the flow regions. This study indicates that the most remarkable areas of high salinity correspond to commonly occurring depressions in the bedrock. This is because of the low gradient of water table in the region, and the related discharge from the neighbouring areas, resulting in an increase in the dissolved solids with the migration of ground water towards the Ken graben region. The salinity zones thus delineated are in close agreement with the earlier reported chemical analysis of ground water (Gondotra, 1979; Awasthi et al., 1980 and Hussain, 1980).

The evolution of the saline/alkaline soils present in the southern part of the Indo-Gangetic basin can be related to the geological evolution of the area. The spatial position of the salt affected regions coincide with a major subsurface tectonic element known as Faizabad Ridge. Vast stretches of critically salt affected regions of western Uttar Pradesh have been found to form a crescent shaped pattern conformable to the position and shape of the northern margin of the Faizabad ridge. Presence of saline soils and brackish ground water in the marginal parts of Gangetic basin has been attributed to the low gradient of a shallow ground water table with hydraulic gradient towards the major streams and basement depressions as salts accumulate in these depressions due to the inflow of ground water (Srivastava et al., 1997). Kumar et al. (1996) have carried out chemical analysis of reh which shows higher concentration of Na and K (7.5 - 16.20 %) and at least 4-5 levels of kankar horizons encountered at many places in the western part of the U. P. Plains. The presence of these kankar horizons represents various stages of upliftment and subsequent erosion. Khan et al. (1995) have found that the area to the west of the ridge uplifted in step like manner along different cross-faults, while in east it shows horst and graben type of structures. The sudden increase in the basement depth in the peripheral regions of Faizabad ridge and presence of some major streams (such as Ganga, Yamuna, Ken, Betwa and Chambal rivers) are plausible for favourable conditions for the salt accumulation in this belt. Soil salinity/alkalinity problem is not very severe in the areas lying in the southern peninsular region due to shallow basement. Older alluvial plain is more affected by the problem of salt efflorescence. GIS and Remote Sensing should be also used for the simulation models of salt movements in the subsurface with hydrologic regime of the region. There is a need to study the effect of land use changes on soil quality, ground water quality, availability, consumption trend over a period of time and ways to optimise the use by integrating the spatial and non-spatial data.

REFERENCES

AHMAD, S. M. (1984a). Hydrogeological investigations for augmenting water supply in drought affected areas of Banda district, U.P., India. Report of the Central Ground Water Board, India.

AHMAD, S. M. (1984b). Ground water exploration in Bundelkhand granite in southern Banda district, U.P., India. Report of the Central Ground Water Board, India.

AWASTHI, J. N., GUPTA, A., and KHARE, A. K., (1980). Quality of ground water in Banda district, U.P., India. Report of the Central Ground Water Board, India.

BAJAPAI, V.N., and GOKHALE, K.V.G.K. (1986). Hydrogeological characteristics of marginal Gangetic alluvial terrain in Uttar Pradesh. Journal of Geological Society of India, 28, 9-20.

BAJAPAI, V.N., and GOKHALE, K.V.G.K. (1991).Application of Landsat-based reflectance zoning in estimating ground water depth salinity: a case study from the Gangetic alluvial terrain in Uttar Pradesh. Proceedings of the 12th Asian Conference on Remote Sensing, Singapore, 30 October-5 November (Singapore: National University of Singapore), B-4-1-B-4-6.

BHATTACHARYA, S. C. (1984). Report on systematic hydrogeological surveys in parts of Hamirpur, Banda, and Fatehpur districts, U.P., India. Report of the Central Ground Water Board, India.

JENSEN, J. R. (1986). Introductory Digital Image Processing. London: Prentice and Hall.
KRUCK, W. (1976). Hydrogeological investigations in the Argentine Pampa using satellite imageries. Natural Resource and Development, vol. 13, pp. 33-46.

MURTY, C. D. and SRIVASTAVA, J. B. (1990). Feasibility report for drilling of tubewells for augmentation of water supply to Banda city, U.P., India. Report of the Central Ground Water Board, India.

NEFEDOV, N. E. and POPOVA, P.A. (1969). Deciphering Ground water from Aerial Photographs, English translation from Russian (New York: Amerind).

PATHAK, B. D. and HUSSAIN, A. (1980). Ground water assessment of Ken canal command area, Banda district, U.P., India. Report of the Central Ground Water Board, India.

POLNOV, B. B. (1952). Geograficheskie Raboty [Geographical Essays]. (Moscow: Izd. Anssr).

SAXENA, V. N., AGARWAL, K., and ARORA, D. K. (1982). Ground water availability in blocks of Banda district, U.P., India. Report of the Central Ground Water Board, India.
SRIVASTAVA, A., TRIPATHI, N.K. and GOKHALE, K.V.G.K. (1999). Basement Topography and Aquifer Geometry around Ken Graben, U.P., India, International Journal of Remote Sensing, vol. 20, no. 11, pp. 2295-2305.

SRIVASTAVA, A. and SINGH, R.P. (1998). Subsurface control on Salt-affected Regions of Indo-Gangetic Basin, Journal of Geological Society of India, vol. 50, Oct., pp. 473-476.

SRIVASTAVA, A., TRIPATHI, N.K and GOKHALE, K.V.G.K. (1997). Mapping Ground water Salinity using IRS-1B LISS II data, International Journal of Remote Sensing, vol. 18, no. 13, pp. 2953-2862.

SRIVASTAVA, A., TRIPATHI, N.K. and GOKHALE, K.V.G.K. (1996). Hydrogeological Investigations in Gangetic Basin Using Remote Sensing and Basement DEM- A Case Study. Proceedings of 17th Asian Conference on Remote Sensing, Colombo, Nov. 4-6, 1996, pp. J1-J6.

SRIVASTAVA, M. L. (1974). Hydrogeological condition in Banda district, U.P., India. Report of the Central Ground Water Board, India.