Special Publication of the Palaeontological Society of India, No.2, 2005, pp. 245-260

SYNSEDIMENTARY TECTONICS IN THE WESTERN PART OF THE MARGINAL GANGETIC ALLUVIAL TERRAIN AND ITS IMPLICATION FOR AQUIFER DISPOSITION : CASE STUDY FROM DELHI-FARIDABAD-BULANDSHAHR REGION, INDIA

V.N. BAJPAI and K.N. KANDWAL
DEPARTMENT OF GEOLOGY, UNIVERSITY OF DELHI, DELHI-110007

ABSTRACT

Evidence of synsedimentary tectonics has been observed in the western part of the Marginal Gangetic Alluvial Terrain in terms of anomalous meanders of the Yamuna river in Delhi-Faridabad-Bulandshahr region. An alternate occurrence of the straight (sinuosity = 1.15), compressed (sinuosity = 3.1) and straight (sinuosity = 1.4) meanders reflect the response of uplift and subsidence successively. Further, the changes in nature of channels from straight to meandering and from meandering to straight in about last two hundred years indicate river metamorphosis, which may be due to human interference. However, such changes are observed beyond certain points, which happen to be the knick points on the longitudinal profile of the Yamuna river in the region. It is interesting to find on the subsurface hydrogeologic transects that the productive aquifers in thick sand bodies are associated with the zones below knick points, which possibly indicate the reactivation of step faults in the basement, controlled by NE-SW trending lineaments. Also, a general abundance of abandoned channels to the east of the Yamuna river and joining of the Hindan river from east indicate tilting of the terrain towards the Yamuna, which has given more accommodation space for deposition.

Key words: Synsedimentary Tectonics, Marginal Gangetic Alluvial Terrain, Aquifer.

INTRODUCTION

Marginal Gangetic Alluvial Terrain is known for being influenced by peninsular lineaments, which traverse in NE-SW, NW-SE and E-W directions. These lineaments, mostly deep seated faults, control the drainage and hence the depositional characteristics and aquifer disposition. Several such controls have been noticed in Mathura - Agra region (Bajpai, 1992) and in Banda-Allahabad-Mirzapur region (Bajpai, 1983, Bajpai and Gokhale, 1986, Tripathi *et al.*, 1989). Deep seated faults in northwestern part of the Ganga basin have been noticed in the regional gravity anomaly maps along the rivers Yamuna and Chambal (Sharma *et al.*, 1999). Bajpai (1983, 1992) observed the deep seated faulted grabens alternating with ridges in the subsurface controlling the aquifer disposition in NE-SW direction. The aquifers extend towards central Ganga alluvium following the same trend. Large uplift of the basement to the east of Delhi, which might be a part of Aravalli changing trend from NE-SW to E-W under Ganga basin, has been reflected in residual Bouguer gravity anomaly map (Mishra and Laxman, 1997). The uplift is the centre of several basement ridges from where they emanate as Delhi-Moradabad ridge, Delhi-Hardwar ridge and NW-SE ridge (Delhi-Lahore ridge). The present area of study on the residual Bouguer anomaly map (Mishra and Laxman, 1997) lies between Delhi-Moradabad region and Agra-Shahjahanpur basement ridge bordered by NE-SW trending Delhi ridges in the west. This has given rise to deposition in a large regional graben trending approximately NE-SW in the central Ganga basin. Rivers have hydrodynamically adjusted to neotectonic activity during deposition along these grabens associated with subsidence. Such hydrodynamic adjustments are reflected in meanders of the rivers of Ganga system (Bajpai, 1983; Bajpai, 1992; Singh, *et al.*, 1996), particularly in compressed meander loops of the Yamuna river in Delhi-Mathura-Agra region due to northeasterly extension of Great Boundary Fault (Bakliwal and Sharma, 1980; Ramasamy *et al.*, 1991). Compressed meanders along the Yamuna and Ganga rivers between the E-W trending Faridabad and Aligarh faults following the western continuation of the basement Moradabad high have also been noticed earlier (Prakash *et al.*, 2000). In the subsurface also all along the southern marginal alluvium in Uttar Pradesh anomalous sedimentary thickness has been documented following peninsular lineaments (Bajpai, 1983). Thick sand deposition in the subsurface along Ganga fault (Kumar, 1991) has also been documented in the western part of the upper Gangetic plain (Singh and Prakash, 1995). Synsedimentary tectonics has been reported in the marginal- central Gangetic alluvium (Singh and Bajpai, 1989) and along the western part of the Ganga basin giving rise to rapid subsidence during Late Pleistocene (Singh *et al.*, 2003). The deposition in the Gangetic basin, in general has taken place under the influence of active tectonics, particularly in the southern marginal Gangetic alluvial terrain where the peninsular and Himalayan lineaments have been active together. The basement may have been uneven due to dissection by active faults giving rise to grabens and subsurface ridges (Singh and Rastogi, 1973; Bajpai, 1989; Singh and Bajpai, 1989; Parkash *et al.,* 2000; Agarwal *et al.* 2002).

The present work examines the role of neotectonics in shaping the meander pattern of the Yamuna River in Delhi –Faridabad region of the western marginal Gangetic terrain together with subsurface distribution of aquifers in thick sand and gravel. Sinuosity measurements of the channels segments have been carried out based on 1: 50,000 Survey of India toposheets to search the areas of basement high and low. Longitudinal profiles along the Yamuna river have been prepared to understand the relation of subsidence with knick points. Further, hydrogeologic transects across and along the Yamuna river have been prepared based on tubewell lithologs of groundwater organizations to indicate the areas of thick sand bodies (aquifers) which may possibly be associated with rapid subsidence.

BOUGUER GRAVITY ANOMALY SECTION

Bouguer Gravity Anomaly Section along the river Yamuna on its western side from Delhi in the north to Hodel and its south has been plotted (fig.1). The original Bouguer gravity anomaly map of western part of the Ganga basin given by Mishra and Laxman (1997) with -5 mgal contour interval has been used in the present work. As evident from the section, the gravity values vary from –50 mgal towards Delhi to –65 mgal towards Hodel. To the south of Hodel, there is a sharp rise in gravity values towards Barsana - Vahaj region, where the quartzites of Delhi Supergroup are exposed. Thus, an overall gravity low lies between Delhi and Barsana with the deepest point at Hodel as indicated by the gravity value of –65 mgal. This gravity low can be attributed to the faults, one to the south of Delhi and the other to the north of Barsana.

SINUOSITY MEASUREMENTS

Sinuosity (ratio of channel length to direct length) measurements along the three segments of the river Yamuna (1, 2 and 3 inset of fig. 2) have been carried out using Survey of India toposheets nos. 53H/6, 53H/7, 53H/8, 53H/11 and 53H/12 (surveyed in 1971 and 1976). While the straight segments in Delhi- Tilpat and

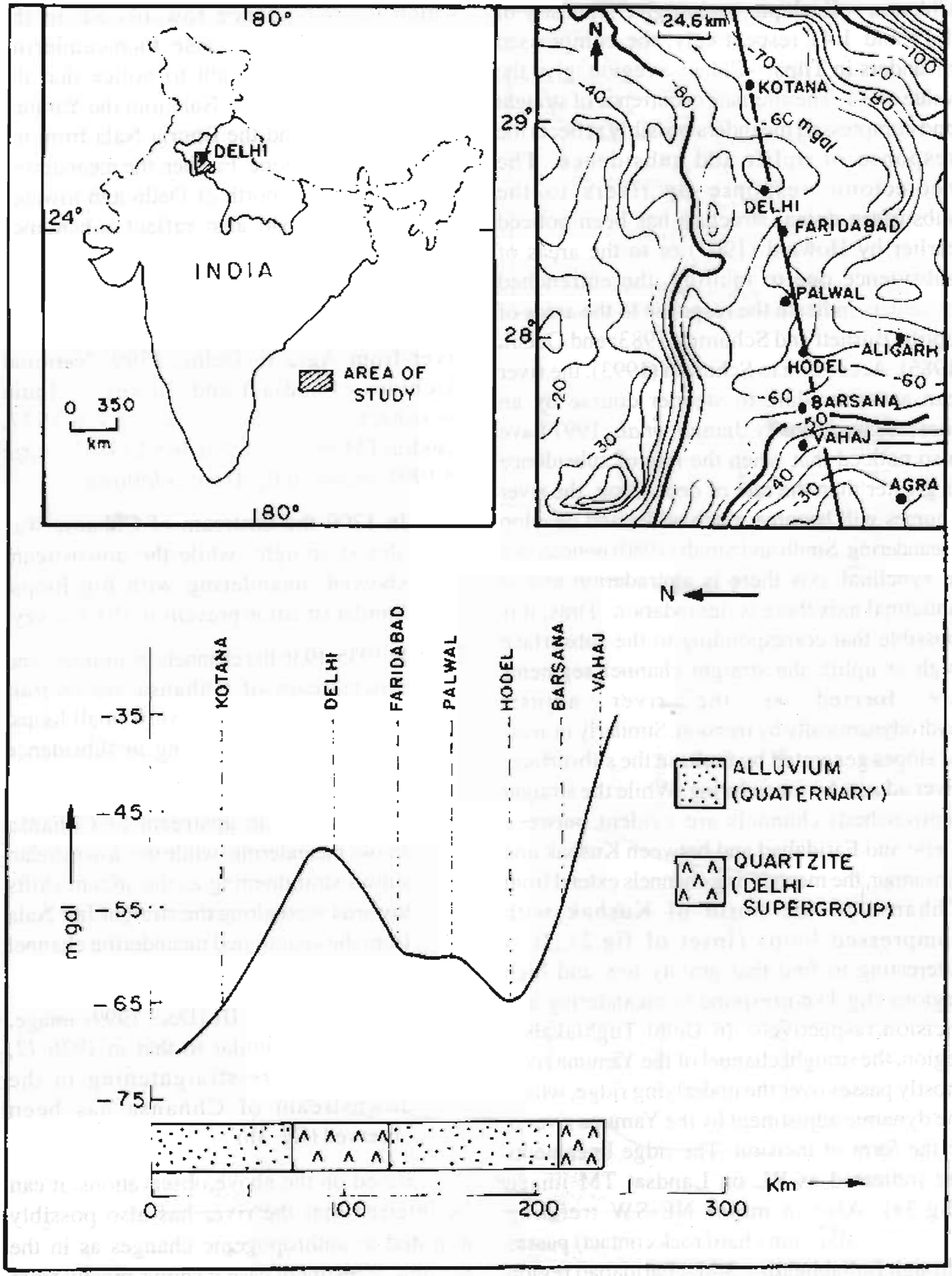

Fig.1. Bouguer anomaly section across Delhi - Hodel region (Section line in the inset on the Bouguer gravity anomaly map).

Chhansa – Kashipur region give sinuosity of 1.15 and 1.41 respectively, the compressed meanders in Tilpat –Chhansa region give the value of 3.1. The alternate occurrence of straight and compressed meanders possibly reflects the response of uplift and subsidence. The neotectonic response by rivers to the subsurface domal structure has been noticed earlier by Howard (1967) or to the areas of subsidence due to faulting, the entrenched meanders indicate the response to the areas of uplift (Burnett and Schumm, 1983; and Ouchi, 1985). According to Schumm (1993), the river can accommodate to steeper course by an increase in sinuosity. Jianjun *et al.*, 1997 have also noticed that when the rate of subsidence is greater than the rate of deposition, the river courses will become much wider and develop meandering. Smith and Smith (1980) noticed that at synclinal axis there is aggradation and at anticlinal axis there is degradation. Thus, it is possible that corresponding to the subsurface high or uplift, the straight channel segments are formed as the river adjusts hydrodynamically by incision. Similarly in areas of slopes generated by faults in the subsurface, river adjusts by meandering. While the straight (entrenched) channels are evident between Delhi and Faridabad and between Kushak and Hasanpur, the meandering channels extend from Chhansa to the north of Kushak with compressed loops (Inset of fig.2). It is interesting to find that gravity low and high regions (fig.1) correspond to meandering and incision respectively. In Delhi-Tughlakabad region, the straight channel of the Yamuna river mostly passes over the underlying ridge, where the dynamic adjustment by the Yamuna river is in the form of incision. The ridge lineaments are indicated as RL on Landsat TM image (fig.3a). Also, a major NE-SW trending lineament (alluvium - hard rock contact) passes through Ballabhgarh – Sihi – Faridabad region (fig.3a), which influences the Yamuna Channels. This lineament is basically a fault zone along which the subsidence towards SE in the subsurface has given rise to meandering channels. It is important to notice that the Hindan river and Lohia Nala join the Yamuna river from east and the Bhuria Nala from the west in this fault zone. Further, the meandering channels towards north of Delhi and towards south of Faridabad also reflect subsidence zones.

Besides tectonics, the observations on Survey of India Antique map (Plan of the Jumna river from Agra to Delhi, 1799, National Archives of India) and Survey of India toposheets of 1935-1936 and 1976-1977, Landsat TM image of 1990, IRS LISS III image of 1999 (shown in fig.4) are as follows:

1) In 1799 the upstream of Chhansa was almost straight, while the downstream showed meandering with big loops. Similar situation prevails in 1910 survey.
2) In 1935-1936 the channels in upstream and downstream of Chhansa are overall meandering with relatively small loops. This indicates the filling in subsidence zone.
3) In 1976-77 the upstream of Chhansa shows meandering, while the downstream shows straightening as the stream shifts towards west along the straight Jair Nala from the abandoned meandering channel in the east.
4) In IRS-1C LISS III (Dec. 1999) image, changes are similar to that in 1976-77, however more straightening in the downstream of Chhansa has been observed (fig. 3b).

Based on the above observations, it can be inferred that the river has also possibly adjusted to anthropogenic changes as in the tectonic adjustment case it shows mostly from straight to meandering and meandering to straight. However, in last 200 years (1799-1999),

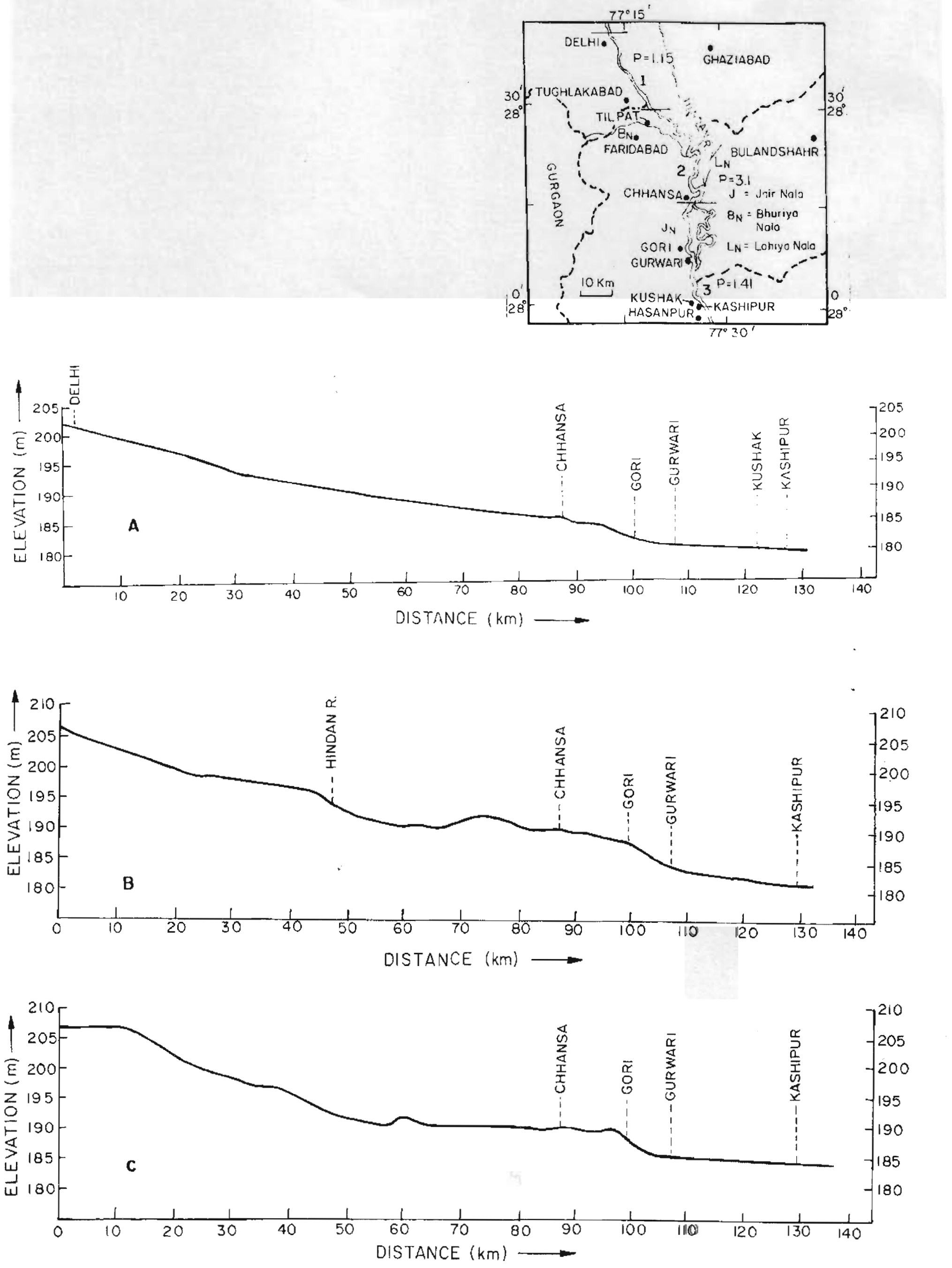

Fig. 2. Longitudinal Profiles Along The Yamuna River in Delhi-Faridabad-Bulandshahr region. (A) Channel Profile, (B) Left Bank Profile, (C) Right Bank Profile.

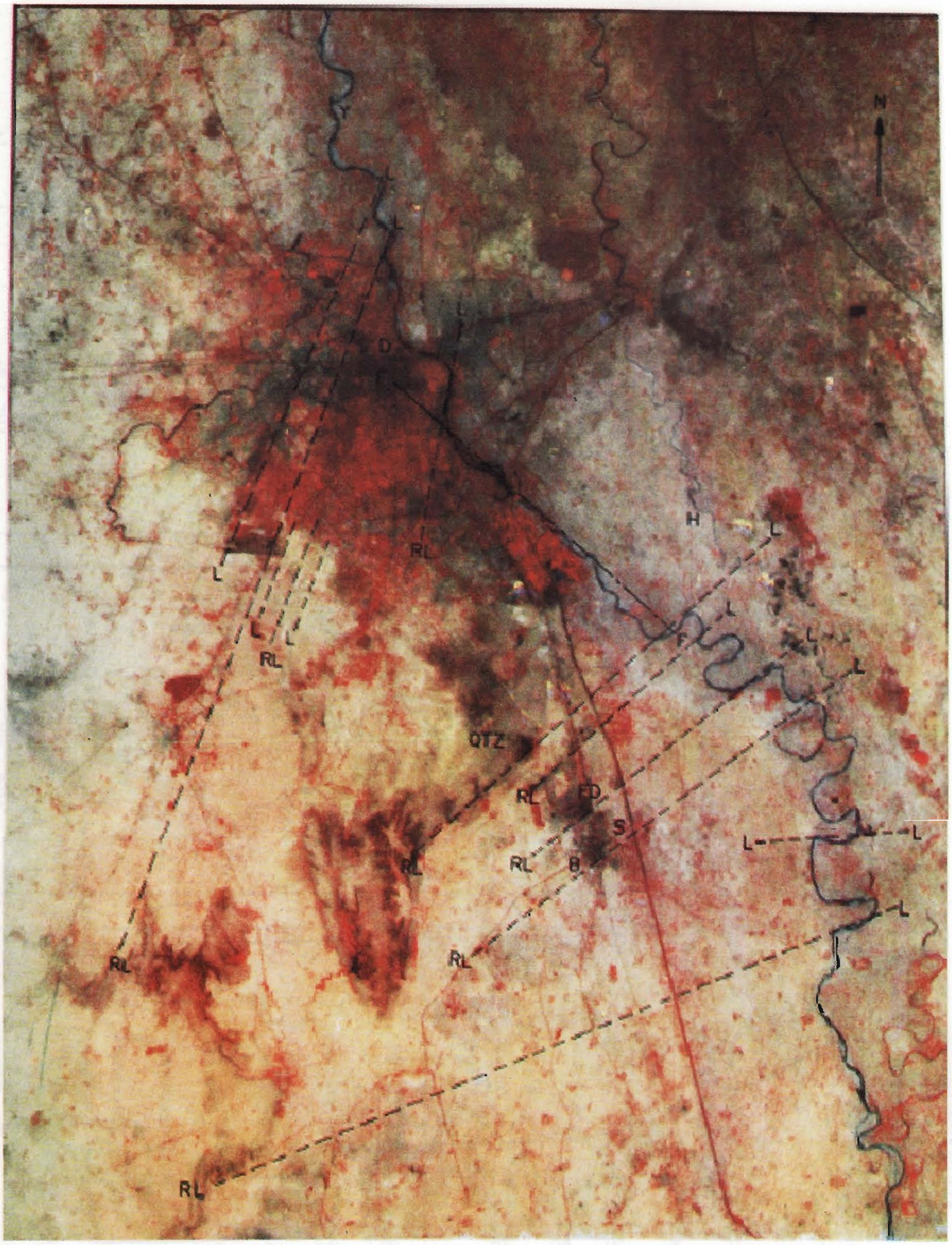

Fig. 3. (A) Lineaments and their relation with channel pattern of the Yamuna River (Y) in Delhi (D), Faridabad (Fd), Region. S- Sihi, B-Ballabhgarh, H-Hindan River, Rl-Ridge Lineament, Ff-fault, Qtz-quartzite.

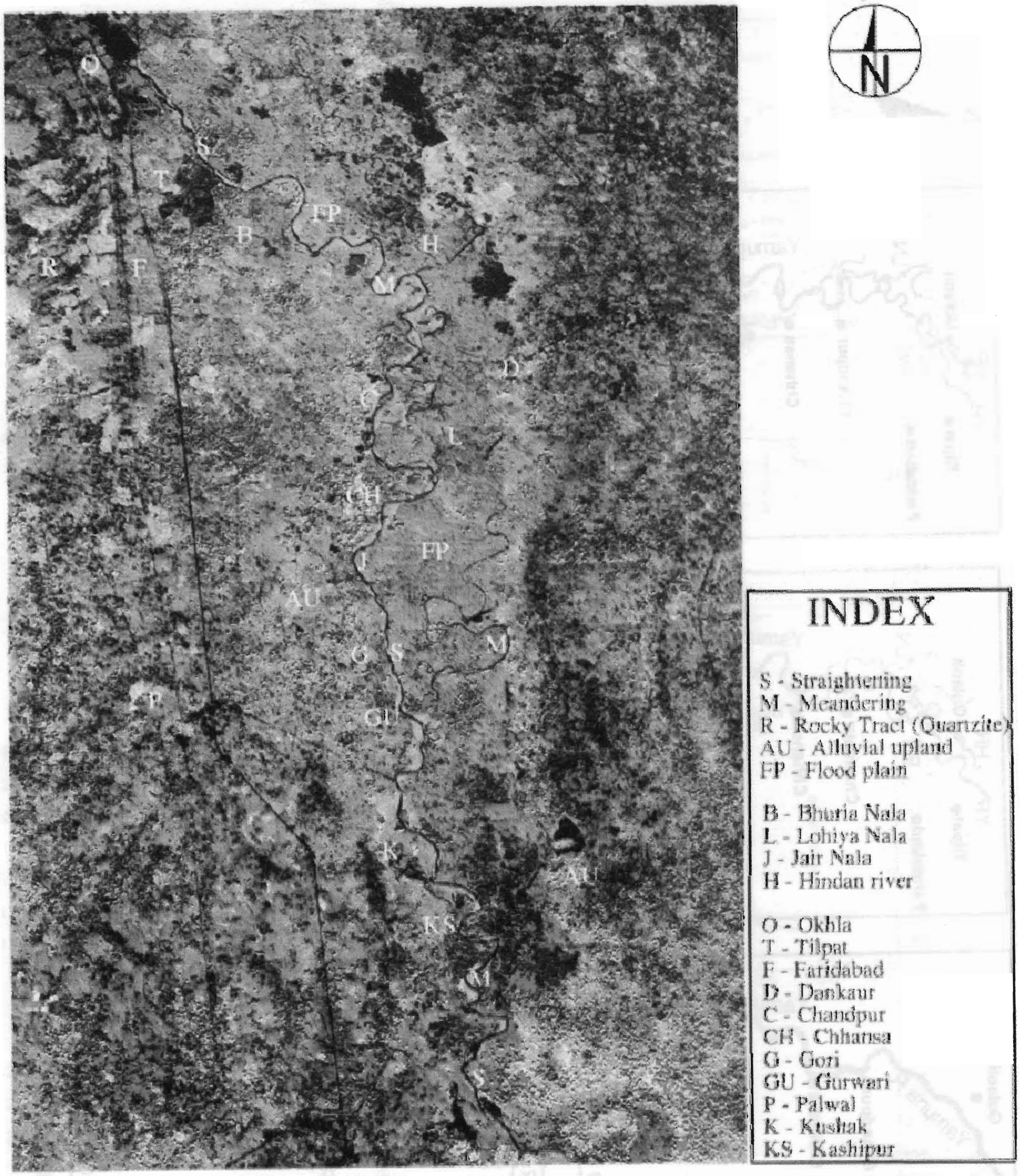

Fig. 3. (B). IRS-1C Liss –III image of Delhi-Faridabad-Bulandshahr region showing alternating meandering (M) and straightening (S) channel pattern of the Yamuna River.

the changes corresponding to deforestation in the upstream area have taken place, which has resulted into incision in the downstream of Chhansa following Jair Nala (inset fig. 2A). However, in 1999 the downstream of Chhansa shows entrenched channel, which may be the result as in adjustment of deforestation in further upstream together with more rainfall. The heavy pumping from tubewells installed in the aquifers situated on the right bank of the

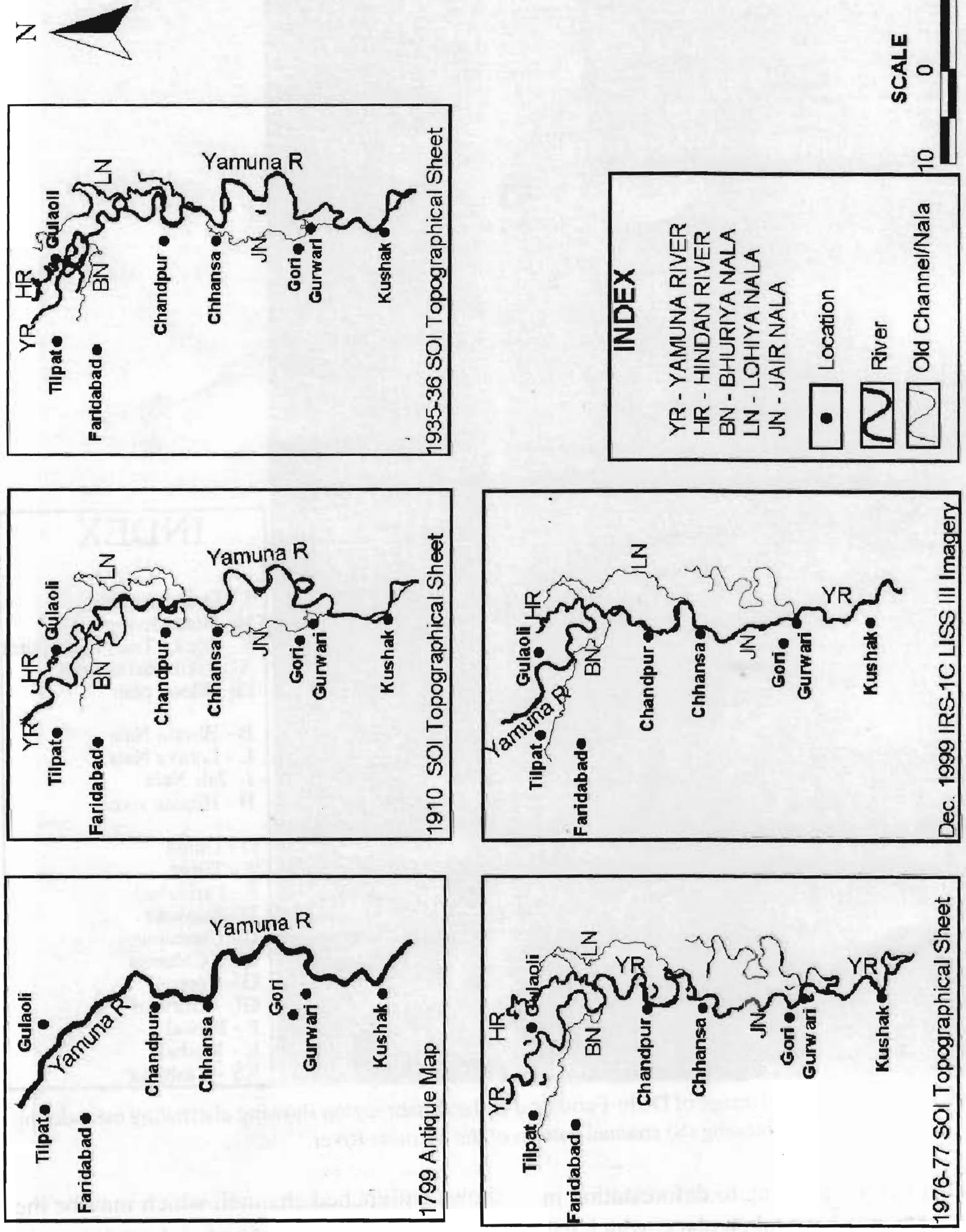

Fig. 4. Channel changes in the Yamuna River (1799-1999).

Yamuna river in the Faridabad region has made the area prone to subsidence (Saini *et al.*, 1994).

LONGITUDINAL PROFILES

Channel, left bank and right bank profiles for the stretch from Delhi to Kashipur (Faridabad district) along the Yamuna River are presented in figure 2. It may be mentioned here that meandering channel beyond the downstream of Chhansa is abandoned and the river at present flows through straighter path known as Jair Nala located between Chhansa and Gurwari. The Channel profile indicated has therefore been constructed through Jair Nala. The other profiles are also plotted accordingly. Channel profile (fig. 2A) shows a general fall towards downstream from about 202 m to about 180 m. There are three major falls indicated on the profile at Chhansa, Gori and Gurwari. The fall at Chhansa corresponds to change from meandering to straightening in channel (inset of fig.2). Minor falls have been noticed in Gori-Gurwari region (figs. 2B and 2C). Similar falls are evident in the left and right bank profiles. These falls indicate possibility of minor subsidences in the subsurface, indicated by meander loop adjustments on slopes. Observations on toposheets of 1935-1936 and 1976-1977 clearly indicate a shift in areas from thickly forested vegetation to agriculture and urbanization. This has added into incision of channels after 1935-1936, reduction in amplitude of meanders and a shift from meandering to straight channels (as evident in the downstream of Chhansa, where the river has shifted westwards to flow along the straight Jair Nala). Such effects in channel changes due to land use changes have been documented in northeastern Puerto Rico (Clark and Wilcock, 2000; Hession *et al.*, 2003). Thus it can be noticed that Chhansa is a sensitive area from where the meander pattern is changing whether on the upstream side or downstream side.

HYDROGEOLOGIC TRANSECTS

Hydrogeologic transects (A-A, B-B and C-C, insets of figs. 5, 6 and 7) plotted along and across the Yamuna river are presented in figs. 5, 6 and 7. The hydrogeologic picture for each transect has been described as follows:

Transect A-A

This represents the subsurface hydrogeologic picture in the western vicinity of the Yamuna river to a depth of about 130 m (fig. 5). As evident from the figure that the depositional sequence starts from clay and kanker and extends upward with coarse sand to fine sand. The sequence in the top is blanketed by clay. Thick aquifers are formed in medium to coarse sand mostly all along the section, however maximum thickness has been observed in Bhopani-Nachauli region (section 3-4, fig.5) and in Gori-Chandhat region (section 13-14, fig. 5). It is interesting to find that through 3-4 regions the major lineaments with NE-SW trend pass through, where the Yamuna river shows compressed meanders (inset fig. 5). In the downstream along section 13-14 the more thickness of sand (about 80 m) can be attributed to tectonic subsidence as evidenced by knick points in long profiles at Gori and Gurwari (fig.2).

Transect B-B

This transect represents the longitudinal section in the close vicinity towards the east of the Yamuna river (inset, fig. 6). The depositional sequence is represented by alternating clay and sand bodies, which pinch out laterally. In general, the sand bodies show fining upward sequence. The maximum thickness of aquifers formed in medium to fine sand is evident in section 3-4 (fig. 6) in Bodha-Bhagpur region. This region also appears to be a zone of subsidence, where the compressed meanders of the Yamuna river join with the Hindan river.

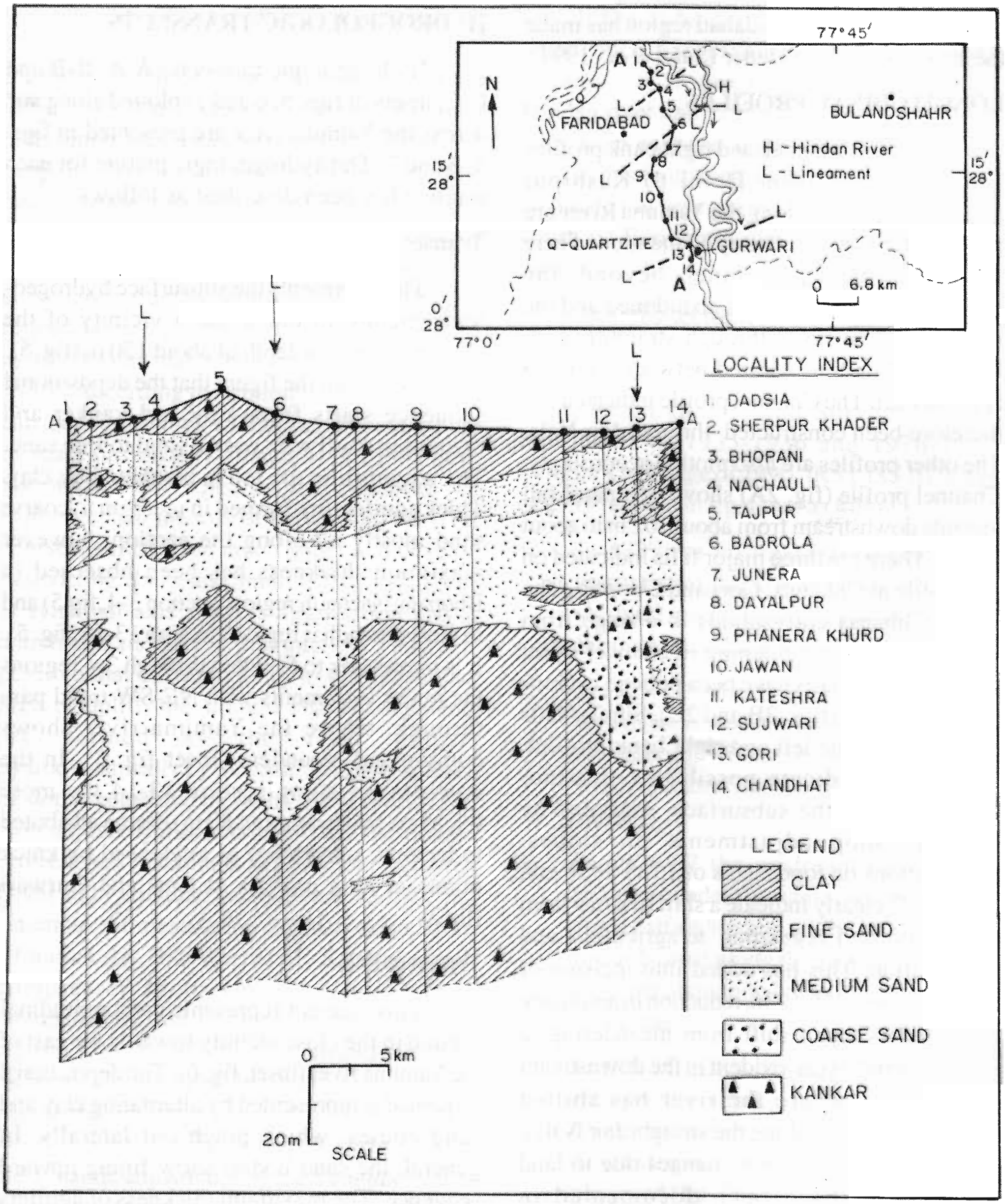

Fig. 5. Hydrogeologic transect along the Yamuna River from Dadsia to Chandhat in Faridabad region.

Similar high thickness zones are observed in Jewar-Mehandipur (Section 13-14 fig. 6) region. This zone lies to the east of Gori-Gurwari region, where the subsidence giving rise to thick deposit of sand has already been observed. However, in this section being towards east the intercalation and interfingering of clay has exceeded.

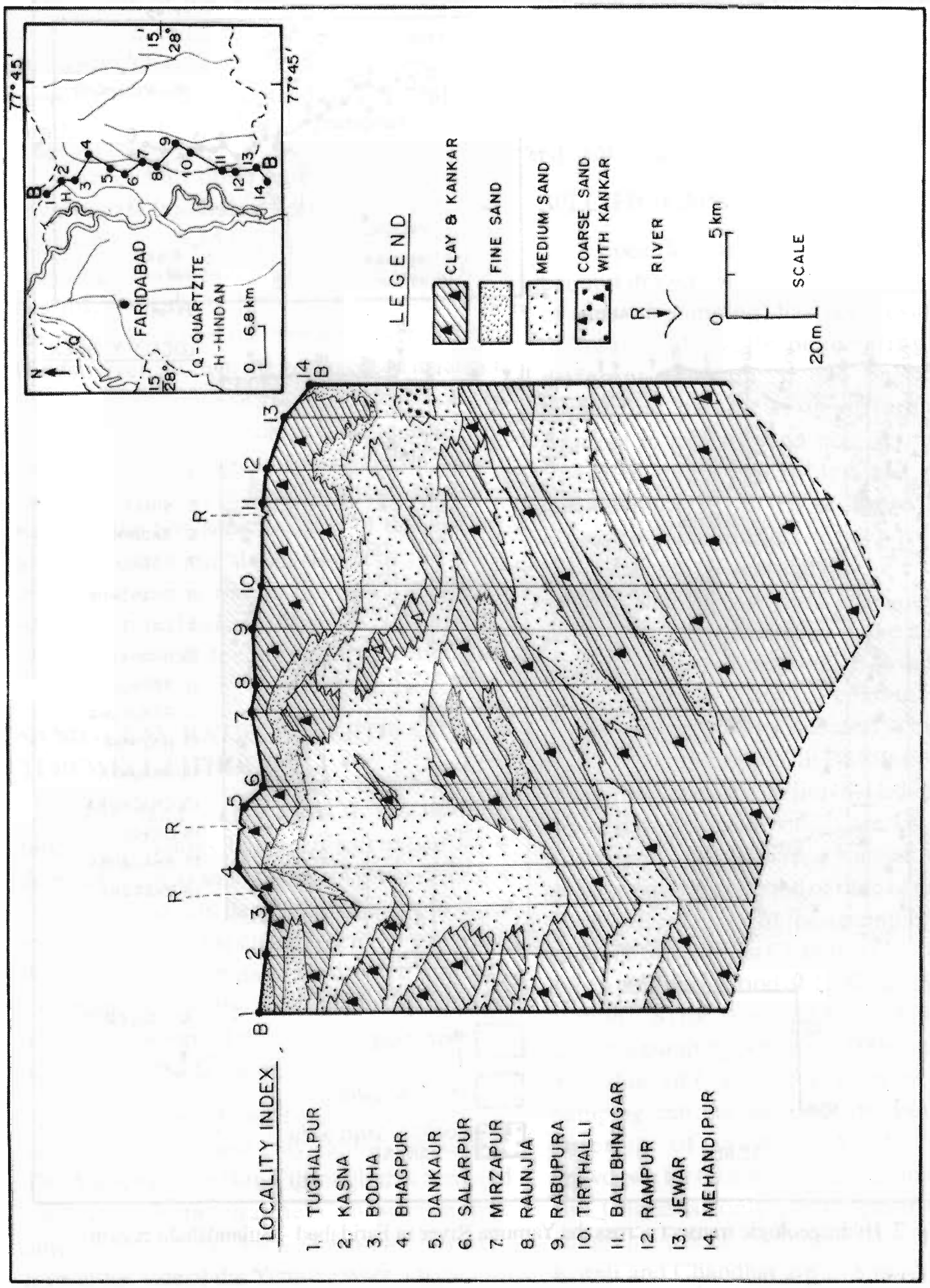

Fig. 6. Hydrogeologic transect along the Yamuna River from Tughalpur to Memandipur in Bulandshahr region

Transect C-C

This represents the section across the Yamuna river in Bhankri (Faridabad district) – Pharana (Bulandshahr district). The aquifers in thick sand bodies are formed in Chandpur-Latifpur region (section 8-9, fig.7). In general, the aquifers are thick and extensive laterally with increasing intercalation of clay towards

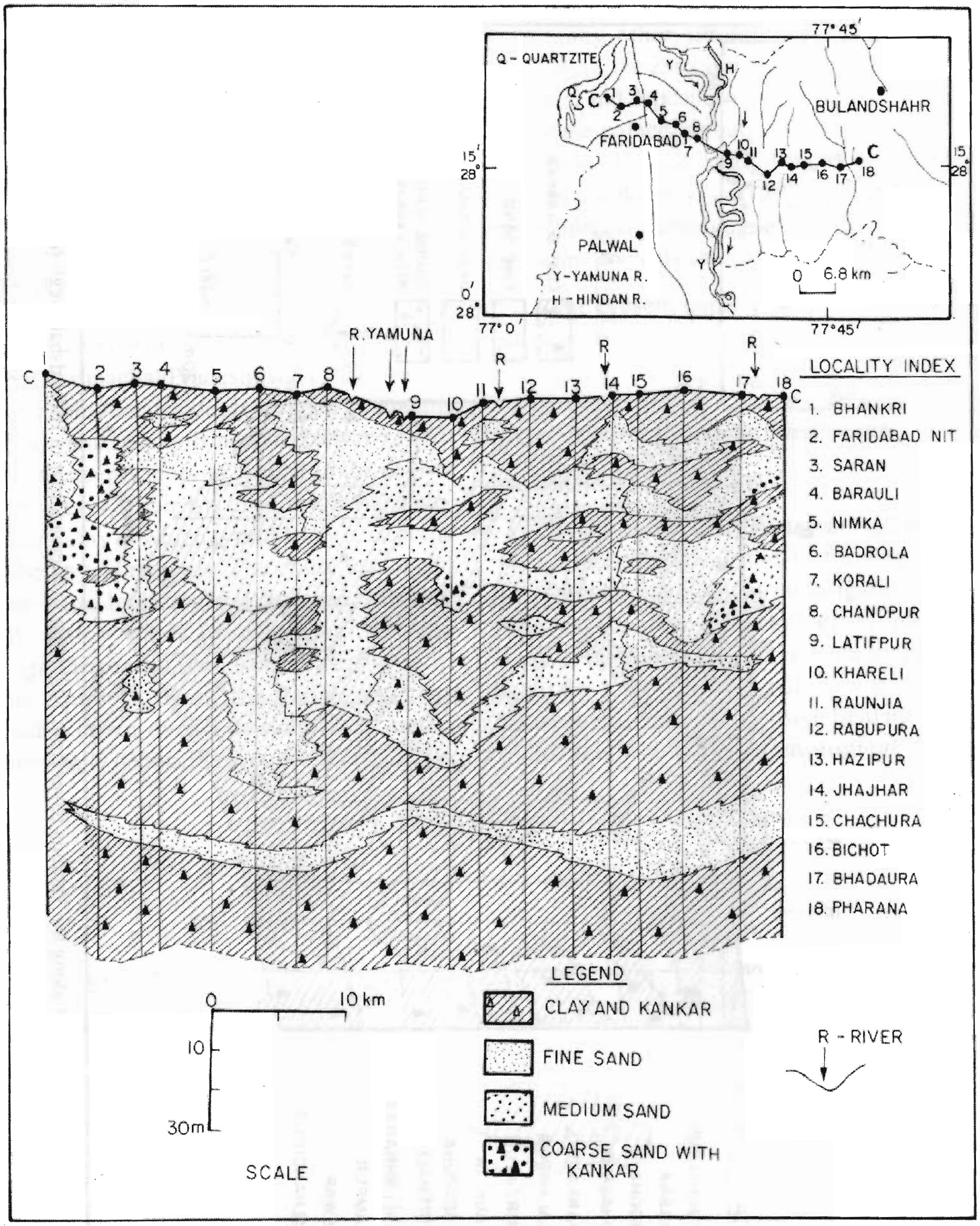

Fig. 7. Hydrogeologic transect across the Yamuna River in Faridabad - Bulandshahr region

east (Section 9-16, fig. 7). The increased thickness in 8-9-10 sections can be attributed to the presence of the Yamuna channels, however, the 8- 9 sections is also a zone of subsidence as observed in terms of compressed meanders and where the Hindan river also joins the Yamuna river from east. This has been further observed that there is in general the dominance of abandoned channels on the eastern side of the Yamuna and the Hindan rivers, which indicate tectonic tilting towards the west. The channels show asymmetric meandering evidence in sand bodies at shallow depths.

An overall observation on the basis of asymmetric meander belt and associated subsurface shallow channel sand bodies showing typical pinch and swell behaviour possibly indicates a differential subsidence in the region between the Yamuna river and the Hindan river, more in the compressed meander zone as compared to less asymmetrical meander zone. Differential subsidence associated with laterally migrating asymmetrically meander belt has been observed in the South Fork Madison River in the SW Montana due to tectonic tilt and due to tectonic slopes developed by fault movement giving rise to changes in meander pattern of the Mississippi river in New Madrid (Alexander and leeder, 1987; Leeder and Alexander, 1987).

SAND - CLAY RATIO IN VERTICAL TUBEWELL LITHOLOG

The sand - clay ratio in the vertical tubewell lithologs has been calculated for a depth of 90 m as sand bodies in general are not found beyond this depth. This has been done in order to assess the channel activity assuming that more the thickness of sand, more would be the channel activity. The increased channel activity represented by sand - clay ratio would also signify the areas of subsidence.

As evident from figure 7 that on the section 8-9, the sand-clay ratio is about 4.6. The Yamuna river flows through this area and its meandering channels show dynamic adjustment to subsidence. The sand-clay ratio is on either side of the Yamuna river, varies 1.43 to 0.6 (Section 6-7, fig. 7) on the western side and 1.14 to 0.57 (Section 9-10, fig. 7) on the eastern side. In the transects from north to south (fig. 5), the sand-clay ratio is maximum in Bhopani- Nachauli region as 31.66. At Bhopani the sand extends to a depth of about 100m showing alternating fine and coarse sequence ultimately fining upward. It may be mentioned here that the major lineaments (fig. 3) trending NE-SW pass through this region.

SPECIFIC CAPACITY DATA

Specific capacity (C) defined as discharge per unit drawdown, taken for a certain period of time of pumping, has been evaluated for different tubewells penetrating through different aquifers. It can be taken as a supporting parameter to differentiate the aquifers in tectonic and non-tectonic zones. Specific capacity values are normally anomalously high in tectonic zones as estimated in the aquifers of marginal Gangetic alluvial terrain (Bajpai and Gokhale, 1990). The same is also evident from the hydrogeologic sections in the present area in the zones along the tectonic lineaments, which have thick sand accumulation in a vertical column, otherwise away from such zones the sand is intercalated with clay. For example, in Dayalpur-Katesara-Sujwari-Chandhat (Section 8-11-12-14, fig.5), the specific capacity values are very high. At Dayalpur C = 583.76 m^2/d, at Katesera C = 432.06 m^2/d for sufficient period of time of pumping, at Sujwari C = 288 m^2 /d for a pumping period of about 10,000 min., at Chandhat C = 1074.24 m^2/d for a pumping period of 1500 min. Similarly in section 7-8 (fig.7) around Korari C = 254.2m^2/day for a pumping period of 1000 min. However, the values of C arrived at different periods of pumping can not be used for comparing the potential of aquifers. As the values of drawdown for 60 minutes are available for Korali and Chandhat only ,their specific capacity values have been compared. The C values for Korali and Chandhat are 278 m^2/day and 440 m^2/day respectively and the aquifers in both these sections are extensive and hydraulically interconnected, it can be inferred that aquifer potential is high at Chandhat as compared to that at Korali. As already indicated that subsidence zone exists to the south of Gurwari, which is situated towards north of Chandhat (fig. 5).

CONCLUSIONS

1. Marginal Gangetic alluvial terrain in Delhi-Faridabad region shows signatures of uplift and subsidence, reflected in anomalous meandering pattern of the Yamuna river.
2. The alluvial and hard rock terrain along the Yamuna river shows the influence of lineaments trending NE-SW, NW-SE and E-W as visible on Landsat TM image. These trends affecting the river channel have been observed in Bouguer gravity anomalies also by earlier workers (Mishra and Laxman, 1997; Sharma *et al.*, 1999).
3. Bouguer anomaly section (N-S) plotted in Delhi-Barsana region shows a graben structure with the deepest point at Hodal (Faridabad region) as indicated by the gravity value of - 65 mgal.
4. The sinuosity measurements along the straight channel segments give values of 1.15 and 1.41, the same along the segments of compressed meanders give value of 3.1. The occurrences of alternating straight and meandering channels possibly correspond to the areas of uplift and subsidence in the subsurface. This is indicated by anomalously thick sand, deposited at Nachauli (70 m) and Chandpur (70 m) and Gori (85 m) in a vertical column. All these regions show subsidence in faulted graben structures. Besides tectonics, the channels show straightening and meandering with loops (1799) and overall meandering (1922). However, it appears that due to fast urbanization and shift from thickly forested vegetation to agriculture, the river has adopted a straight course in the downstream along Jair nala (Survey of India toposheet, 1976-77).
5. The depositional sequence to a depth of 90 m shows fining upward sequence starting from coarse sand and kankar to fine sand in the near surface. This indicates initially more subsidence, which reduces upwards.
6. The longitudinal profiles indicate knick points, which are in conformity to the areas of change from straightening to meandering and meandering to straightening.
7. High sand-clay ratio in vertical tubewell lithologs indicate areas of more channel activity, as in Bhopani-Nachauli region, the value is 31.66, otherwise the value ranges from 0.57 to 1.14.
8. Specific capacity data also represents anomalously high values in tectonic zones, where the subsidence has resulted into thick disposition of aquifers. The values range from 288 m^2/d to 1074.24 m^2/d, otherwise in areas of no tectonic influence, the specific capacity values range from 0.51 m^2/d to 0.77 m^2/d.

ACKNOWLEDGEMENTS

Authors are thankful to authorities of Central Ground Water Board and State Ground Water Departments of Delhi, Haryana and Uttar Pradesh to provide tubewell lithologs and library facilities. Useful discussions with Dr. I.B. Singh and Dr. A.R. Bhattacharya, Department of Geology, University of Lucknow, are gratefully acknowledged. The authors are thankful to reviewers for improving the manuscript.

REFERENCES

Agarwal, K.K., Singh, I.B., Sharma, M., Sharma, S. and Rajagopalan, G. 2002. Extensional tectonic activity in the cratonward parts (peripheral bulge) of the Ganga plain foreland basin, India. *Int. Jour. Earth Sci.* **19**: 897-905.

Alexander, J. and Leeder, M.R. 1987. Active tectonic control on alluvial architecture. In: Ethridge, F.G., Flores, R.M., Harvey, M.D. (eds). *Recent developments in fluvial sedimerntology. Soc. Econ. Palaeontol. Mineral Spec. Publ.* **39**: 243-252.

Bajpai, V.N. 1983. *Hydrogeological studies of the Marginal Gangetic Alluvial Terrain in Uttar Pradesh.* Unpublished Ph.D. Thesis, I.I.T. Kanpur, 272 p.

Bajpai, V.N. and Gokhale, K.V.G.K. 1986. Hydrogeomorphic Classification of the Marginal Gangetic Alluvial Plain in Uttar Pradesh, India using Satellite Imageries, *Jour. Geol. Soc. India*, **28**: 9-20.

Bajpai, V.N. 1989. Surface and subsurface evidence of neotectonics and aquifer disposition in central alluvial terrain of Kanpur - Unnao region in Uttar Pradesh, India. *Photonirvachak. Jour. Indian Soc. Remote Sensing*, **17**: 47-53.

Bajpai, V.N. and Gokhale, K.V.G.K. 1990. Aquifer evaluation in Marginal Gangetic Alluvial Terrain of Uttar Pradesh, India. *Proceedings International Conference on Groundwater Resources and Management,* A.I.T., Bangkok: 61-70.

Bajpai, V.N. 1992. Intense development of ravines in Yamuna- Chambal region : causative factors. *Proceedings of Group discussion of Neotectonics and sedimentation in Indogangetic basin*, Kumaun University, Nainital: 16-18.

Bakliwal, P.C. and Sharma, S.B. 1980. On the migration of the river Yamuna. *Jour. Geol. Soc. India*, **21**: 461-463.

Burnett, A.W., and Schumm, S.A. 1983. Alluvial-river response to neotectonic deformation in Louisiana and Mississippi. *Science*, **222**: 49-50.

Clark, J.J. and Wilcock, P.R. 2000. Effects of land use change on general morphology in northeastern Puerto Rico. *Geol. Soc. America Bull.* **112**: 1763-1777.

Hession, W.C., Pizzas, J.E., Johnson, T.E. and Howitzer, R.J. 2003. Influence of bank vegetation on channel morphology in rural and urban watersheds. *Geol. Soc. America*, **31**: 147-150.

Howard, A.D. 1967. Drainage analysis in Geologic interpretation : a summation. *Bull. Am. Assoc. Pet. Geol.* **51** (11): 2246-2259.

Jianjun, H., Mukang, H. and Ollier, C.D. 1997. A morphometric method to determine neotectonic activity of the Weihe basin in northwestern China. *Episodes*, **20** (2): 95-99.

Kumar, S. 1991. *A Holocene soil chronoassociation and Neotectonics in the Western Gangetic Plains, India.* Unpublished Ph.D. Thesis, University of Roorkee, 292 p.

Leeder, M.R. and Alexander, J. 1987. The origin and tectonic significance of asymmetric meander belts. *Sedimentology*, **34**: 217-226.

Mishra, D.C., and Laxman, G. 1997. Some major tectonic elements of western Ganga basin based on analysis of Bouguer anomaly map. *Curr. Sci.* **73**: 436-440.

Ouchi, S. 1985. Response of alluvial rivers to slow active tectonic movement. *Geol. Soc. America Bull.* **96**: 504-515.

Parkash, B., Kumar, S., Rao, M.S., Giri, S.C., Kumar, C.S., Gupta, S. and Srivastava, P. 2000. Holocene tectonic movements and stress field in the western Gangetic plains. *Curr. Sci.* **79**(4): 438-449.

Ramasamy, S.M., Bakliwal, P. C. and Verma, R.P., 1991. Remote Sensing and river migration in western India. *Int. Jour. Remote Sensing*, **12**: 2597-2609.

Saini, H.S., Mujtaba, S.A.I. and Chopra, K.K. 1994. Integrated multidisciplinary geological, geomormophological and environmental studies including landuse and evalution of natural resources in northern parts of Faridabad district, Haryana. *Geol. Surv. India Rec.* **127**(8): 40-43.

Sharma, K.K., Rao, V.K., and Mallick, K. 1999. Finite element gravity regional and residual anomalies and structural fabrics of northwest Ganga basin. *Jour. Geol. Soc. India*, **54**: 169-178.

Singh, I.B. and Bajpai, V.N. 1989. Significance of syndepositional tectonics in facies development, Gangetic alluvium near Kanpur, Uttar Pradesh. *Jour. Geol. Soc. India*, **34**: 61-66.

Singh, I.B., Ansari, A.A., Chandel, R.S. and Misra, A. 1996. Neotectonic control of drainage system of Gangetic plain, Uttar Pradesh. *Jour. Geol. Soc. India*, **47**: 599-609.

Singh, A.K. and Parkash, B. 1995. Sand distribution in the western part of the Upper Gangetic plain. *Hydrology Jour. IAH*, **18**: 13-24.

Singh, I. B., Jaiswal, M., Singhvi, A.K. and Singh, B.K. 2003 Rapid subsidence of western Ganga plain during Late Pleistocene : Evidence from optical dating of subsurface samples. *Curr. Sci.* **84**: 451-454.

Singh, I.B. and Rastogi, S.P. 1973 Tectonic framework of Gangetic alluvium with special reference to Ganga river in Uttar Pradesh. *Curr. Sci.* **42**: 305-307.

Schumm, S.A. 1993. River response to base level change : implications for sequence stratigraphy, *Jour. Geology*, **101**: 279-294.

Smith, D.G. and Smith, N.D. 1980. Sedimentation in anastomosed river systems: examples from alluvial valleys near Banff, Alberta. *Jour. Sediment. Petrol.* **50**: 157-164.

Tripathi, C., Srivastava, A.K., Srivastava, V.C. and Iyer, R.V. 1986. Changes in the geomorphological setting of Yamuna river – a cause of ravine development. *Geol. Surv. Ind. Rec.* **113** (8): 1-10.