Morphotectonic evaluation of the Delhi region in northern India, and its significance in environmental management

B. L. Kaul · M. K. Pandit

Abstract This paper deals with the morphotectonic evaluation of the Delhi region in northern India to understand its impact on land use and urban development. To accommodate heavy urbanization and population rise (being the capital of India), the area has undergone tremendous environmental degradation resulting from a mismatch between adopted land use and morphotectonic considerations. The geomorphic and drainage signatures of the region have evolved out of interaction of varied geological parameters including neotectonic activities. We have evaluated the changes in the drainage pattern of the Yamuna River in the Delhi region to underline its significance in geomorphic evolution and subsequent land use and/or land suitability. The Yamuna River has shown variations both in channel position and geometry over the last two centuries. The observed migration pattern of the river (shifting of confluences, position and disposition of palaeochannels, etc.,) cannot be attributed to normal river phenomenon and appears to have been effected by neotectonic changes. In addition, some case studies are discussed to underline the significance of geomorphic factors in urban development.

Keywords Neotectonics · Yamuna migration · Environmental management · Delhi region · India

Received: 25 August 2003 / Accepted: 4 June 2004
Published online: 2 July 2004

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Introduction

The geomorphic setting is an expression of the prevailing geology of the area and plays a vital role in land-use planning and environmental management. The landforms and drainage are shaped by several factors, including the neotectonic control. The environmental degradation of primary nature can be avoided if land suitability studies are based on neotectonic and other relevant geological considerations. Several factors, like the shifting of streams, tilting of terraces, development of anomalous slopes and seismic impacts are required to be evaluated while planning land use for an urban setting.

The Delhi region (N India) is an example of regrettably ignored geomorphic inputs though essential in planning and urban development. In addition, neotectonic and other geologic factors have also resulted in severe environmental problems. Being the capital of India, the land–water system in this region has been under tremendous stress to accommodate a growing population and rapid urban industrialization of the region. We have initiated morphotectonic studies of the Delhi region to monitor the urbanization-related land use and present our initial results and discuss the implications on urbanization to emphasize the significance of geo-factors in urban planning. For this purpose, the slope studies and detailed analysis of the shifting and migration of the Yamuna River during the last 200 years have been evaluated.

Geological and geomorphologic overview

The Delhi region in northern India is bounded by the Gangetic alluvial plain in the north and east, the Thar Desert in the west, and Aravalli hill ranges to the south. The area can be broadly classified into two main physiographic domains: (1) northern and central undulatory terrain (197 to 260 m a.m.s.l.) and (2) southern upland rocky region with an altitude between 20 and 340 m. a.m.s.l. (Fig. 1). Geologically, the rocky upland area comprises quartzites with intercalations of schist-phyllite, belonging to the Delhi Supergroup (Proterozoic); the whole assemblage is intruded by younger pegmatite

 DOI 10.1007/s00254-004-1111-3

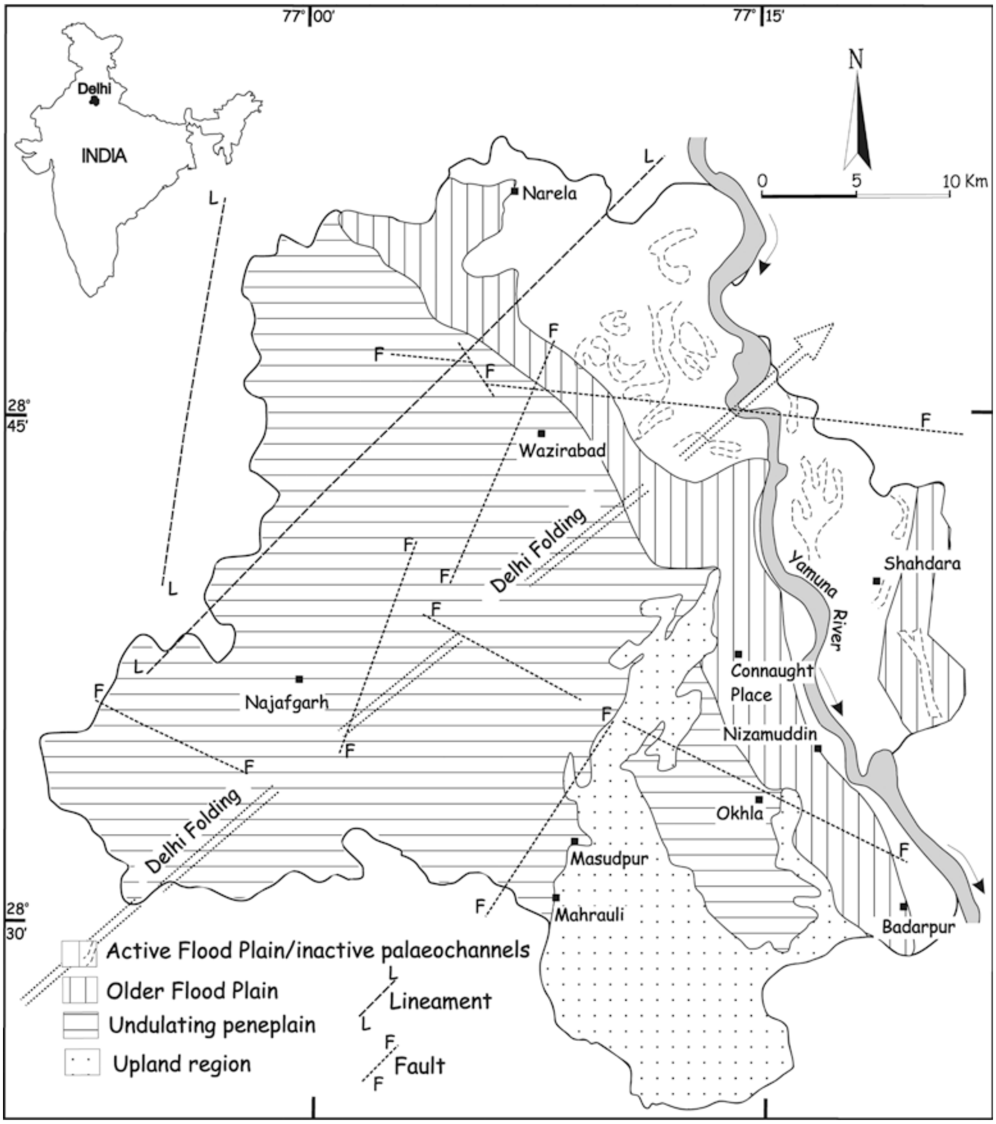

Fig. 1
Geomorphological map of the Delhi region showing major geomorphological domains and tectonic features (adapted from Kaul 2000). *Inset map* of India shows location of the Delhi region in northern India

and quartz veins (Heron 1953). The rocks in the central part extend as a NE–SW-trending ridge (known as the Delhi Ridge or the Delhi Shahabad Ridge) up to Wazirabad in the NE (Fig. 1). The northern and central gently undulatory plain comprises alluvial and fluvio-alluvial material at places with small aeolin mounds of Quaternary to Sub-recent age. The perusal of satellite photographs allows the identification of some major lineaments and faults, corroborating major tectonic disturbances in the geological times that have resulted in uplifting and down-faulting of blocks. All major tectonic units are aligned NE–SW, corresponding with the Aravalli-Delhi tectonic trend. The area has a highly undulatory bedrock configuration, as reflected from the geophysical data published in the Geological Survey of India (GSI) and Central Ground Water Board (CGWB) reports (Dimri and others, unpublished report; Burman, unpublished report). The depth of bedrock between the Delhi (Shahabad) Ridge and the Yamuna River varies from 0 to 30 m b.g.l. The bedrock depth is over 100 m b.g.l. further east and within the flood plains of the Yamuna River. In the northern part, the bedrock has not been encountered, even up to a depth of 340 m b.g.l.

Geomorphology

The area can be divided into four major geomorphological domains, each characterized by its distinguishing parameters: (1) northern and eastern undulatory terrain (older floodplain) constituting T_2 and T_1 terraces, at places, with palaeochannels/inactive channels, marshes and meander cutoffs, (2) eastern active floodplain, (3) western peneplain area with minor hillocks and structural sags and (4) southern upland area with strike ridges, dissected hills, badland with rills and ravines (Fig. 1). The northern and eastern areas are largely occupied by older alluvium (Sub-recent in age) with minor aeolian mounds in the northwest, whereas the eastern active floodplains are occupied by Newer Alluvium (Recent in age). The southern rocky upland, in addition to rocks and residual soils, also has older alluvium from local ephemeral streams and badland with large clay bluffs. The western undulatory terrain has fluvio-alluvial material, at places, with aeolian mounds.

Slope morphometry

The Delhi region (Fig. 2) exhibits a very gentle southerly master slope as indicated by the southerly flow of the Yamuna River, except at some places where the slopes have been locally reversed. The general slope in the region east of the Yamuna River is westerly. Similarly, the change in slope direction is also noticed west of the Yamuna-adjoining Okhala Barrage. Adjoining the tectonic junction east of Connaught Place, the slopes gently swerve around the structural knot. The slopes in the southwest show a major change to the northeast, developing an anomalous character. The depth to bedrock and tectonic uplifts in the southwest have resulted in development of anomalous slopes and consequent modifications in drainage. The southerly and westerly flowing drainages change to the northeasterly direction in the western part of area and join the northeasterly flowing Najafgarh drain (Fig. 2).

Seismotectonic setup

Major tectonic elements recognized in the area are the Delhi-Shahabad Ridge in the east, and NE-trending Delhi folding (Fig. 1). The basement configuration of bedrock, in general, structural sags in the southwest, and tectonic knot/junction in the east, as well as some of the major lineaments and NNE and WNW-trending faults are suggestive of several weak zones in the region. The area has witnessed earthquakes of local and Himalayan origin and falls in seismic zone IV as defined by Indian Standards Institute (Kaul 2000). The epicenter concentration points are along the tectonic junction and largely fall on the NE-SW trend line. The isoseismals have more or less NE–SW-trending axis, with ellipsoids predominantly narrowing towards the NE (Kaul 2000), thereby indicating the potentially seismic hazardous area to be largely coinciding with the trend of Delhi folding. Observed morphotectonic changes, such as the development of anomalous slopes, tilting of terraces, shifting of confluences, migration of the river, sudden off-sets, changes in base level, merging of floodplains etc. can be attributed to seismic activity and neotectonic changes in Recent geological times.

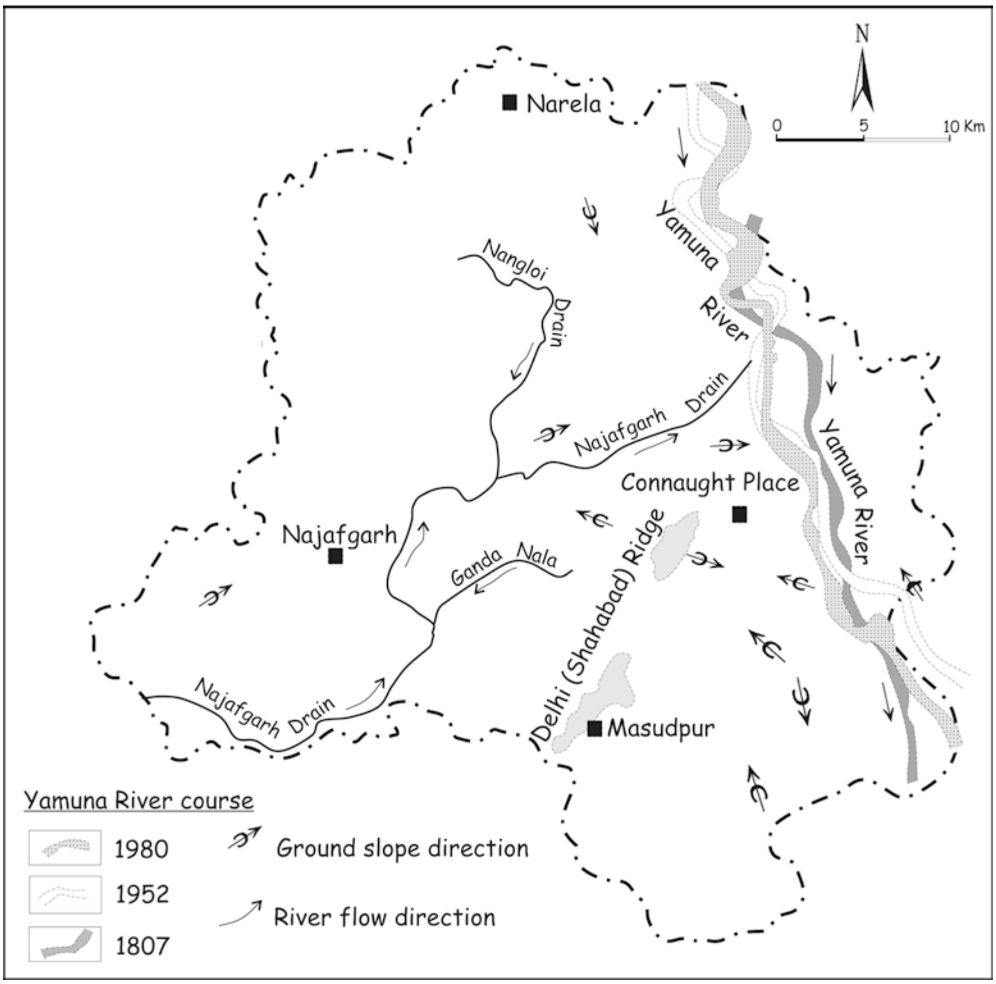

Fig. 2
Map of the Delhi region showing slope characteristics, surface drainage, and temporal migration of the course of the Yamuna River between 1807 and 1980. (Compiled from Survey of India and other published maps)

Temporal migration of the Yamuna River

The topographic maps of the Delhi region for 1807 and 1980 indicate temporal variation both in channel geometry and the position of the Yamuna River, reflecting block-wise elemental changes (Fig. 2). The river shows a fairly wide migration zone, i.e., nearly 8 km in the north (Narela-Wazirabad area) and 5 km in the south (Okhla area). The width of the migration zone in the central part, adjoining the tectonic junction, is rather narrow. The migration is E–W, oscillatory, and block-wise, with changing periods of time. The river during 1807 was flowing nearly 2.8 km east of Badarpur, whereas during 1952 it was 4.8 km east of the same place. The river in the north prior to 1952 was flowing just east of Narela, as evidenced by large palaeochannels/abandoned channels, meander cut offs, terrace sediments and other geomorphic features. The river during the same period has been east of Wazirabad with a sudden offset to the east, whereas during 1980, in the same area, the river moved westward in an almost straight course. The morphology of the river during 1807 has been highly meandering with several channels to the west. In the adjoining Wazirabad, during the same period, it followed a straight course. In 1952 the course of the river south of Okhla shows easterly shift whereas the same section in 1980 shows a westerly shift. In Badarpur area and further south (outside Delhi region), the river course in 1952 shows a highly complex and convolute morphology whereas the same section in 1980 shows simple meanders (Kaul 2000). The river during the same period, downstream of Nizamuddin, exhibits merging of its floodplain with Hindon River.

The geometric and base level changes, at places being depositional, cannot be ruled out. However, the overall pattern of migration, together with other factors, i.e., the shifting of confluences, the presence of palaeochannels/inactive channels, etc., cannot be attributed to general river phenomenon only. The shifting of confluences with the Hindon River in the southern parts, with the central tectonic junction area of least migration, being unaffected, emphasize a significant role of neotectonic activity in shaping the geomorphology and drainage morphometric patterns in the region. The identified stretch under the migration zone shows activation/reactivation and abandoned channels resulting in changes in geometry of the floodplain in the region.

Discussion

Neotectonic changes play a vital role in shaping geomorphic setup and drainage patterns, the latter two forming integral aspects of land-use or land-suitability considerations for sustainable development (design, construction, maintenance and socio-hygienic). Morphotectonic and morphometric aspects offer vital inputs in identifying the causes of geoenvironmental degradation and also in providing possible control measures. Such studies also help in identifying land-use suitability for future development. Certain urbanization-related problems in the Delhi region appear to be due to neglect of geomorphic/morphotectonic factors during expansion of the city. The following sections highlight some specific case studies in the light of morphotectonic characteristics of the terrain.

1. Water impounding: The area to the east of Delhi Ridge is one of the heavily populated regions of Delhi and also includes ‘Connaught Place’, the hub of commercial activity. Unfortunately, it is also the site for heavy water impounding during storm showers causing disruption of traffic and normal life (Kaul and Pandit 1997). We attribute this to the localized reversal of ground slope (away from the Yamuna River; Fig. 2) and development of structural sag in this area. The development of anomalous slopes appears to have resulted from Neotectonic tilting of river terraces. In addition, non-availability of sufficient recharge surface has further compounded the problem of water impounding. These features were overlooked while developing the area.
2. Impact of open drains: Unlined open sewerage drains laid in geomorphologically unsuitable areas have resulted in a number of environmental problems. The situation is more severe in the northern parts where the drains run through inactive palaeochannels. In the Najafgarh area, in the west and in some areas east of the Yamuna River, these drains have acted as influent seepage channels, and have polluted shallow aquifers through the infiltration of leachate. The drains were initially designed to transport excess storm shower and sewerage flow. However, due to poor design and improper maintenance and unsuitable geomorphic conditions, these now form pools of stagnant water in northwestern and northern parts of Delhi—potential sources for groundwater pollution and sites for mosquito breeding. These drains join the Yamuna River at its lowest flow level, thus resulting in back-flow due to the rise in water level in the Yamuna River during monsoonal showers. The Najafgarh drain passes through structurally weaker zones that act as channel-ways in unlined sections of the drain and directly pollute the aquifer system in its area of influence.
3. Soak-pit failure: In some of the hinterland regions of Delhi, the old practice of human fecal disposal into soak-pits/septic tanks is being followed. The influent nature of open drains in these areas has changed the geohydrological scenario by shallowing the water table and by development of artificial recharge mounds at several locations. This has led to surface inundation/impoundment on one hand, and pollution of shallow aquifers on the other. The failure of septic tank-soakpit systems, particularly during monsoon, can largely be attributed to water table rise. These problems have arisen by ignoring basic geomorphic parameters like slope-morphometry, groundwater conditions, soil characteristics, subsurface lithology, etc.
4. Three barrages have been constructed on the Yamuna River in the Delhi region, probably without much

morphological considerations. These are either in non-water tight locations or adjoining weak zones. As a result, the Yamuna River has locally developed an influent behavior in contrast to its general effluent nature, as is seen in Kalindi Kunj area.

The foregoing discussion substantiates the neglect of basic geomorphic factors in planning urban development and consequent irreversible urbanization problems. Proper geotectonic evaluation is vital, and needs to be done while planning further expansion to ensure sustainable development. This shall also help in identifying sites for open space and sequential land-use management, urban development including river basin management covering canalization, laying of roads, bridges, barrages, drains etc. The Delhi region, in view of being a potentially seismic hazardous one, warrants the consideration of a seismic risk probability map with microseismic zonation data for identifying areas of tectonic reactivation and neotectonic adjustments. Though it is not possible to quantify the shaking hazard, a generalized view, in conjunction with factors like thickness of covered material/soil cover, its moisture regime, saturation characteristics, subsurface lithology, etc., can help in identifying probable risk areas.

Acknowledgements We thank Prof. R. S. Sharma for stimulating discussion and useful suggestions that have helped in improving this paper.

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