Mega-geomorphology and sedimentation history of parts of the Ganga–Yamuna plains

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Mega-geomorphological units in parts of the Ganga–Yamuna plains have been mapped using IRS-LISS III remote sensing data. The study highlights the differences in geomorphic setting of this part of the Gangetic plains with that in more eastern parts, and this is manifested in fluvial landforms. A 20 m incised bank section at Kalpi in the Yamuna plains has also been examined and preliminary interpretations about the general stratigraphy are presented. The fluvial sequence manifests several hiatuses in the sedimentation record represented by palaeosol units.

THE Gangetic plains consist of many distinct types of fluvial systems, each formed by different river channel systems. Each of these 'systems', has characteristic (mega-) geomorphic 'units' and these units themselves consist of different geomorphic 'elements'. These terminologies may be used in a hierarchal sense. As a sequel, it is emphasized that the entire Gangetic plain is not uniform, as is envisaged by some workers. The dominance of one process over the other will be controlled by the geomorphic setting of the area, and of course, the geological setting, including neotectonic activities, if any. The paper presents the first level geomorphologic maps for the Ganga–Yamuna plains prepared using digital remote sensing data (IRS LISS III) and supported by field investigations. Field mapping of the exposed sections have been interpreted for deriving a general sedimentation history of the region.

Two windows in the Ganga–Yamuna plains have been taken up (Figure 1). The first window is around Kanpur representing the central Ganga plain, where fluvial sedimentation is considered to be influenced by uneven basement formed by extension of Bundelkhand–Faizabad ridge and neotectonics. The course of the Ganga river in this region has been described as a zone of subsidence that demarcates the boundary between the tectonically uplifted block situated on the southern bank of the river with north-facing escarpment and the northern block with extensive floodplain. A reconnaissance hydrogeomorphic map of this region using Landsat images identified three distinct divisions as upland tract, ravinous tract and floodplain[1].

The second window is around Kalpi region about 100 km SW of Kanpur city and represents the Yamuna plain. The Yamuna river cuts across the Kanpur–Jhansi road at Kalpi and has a very wide, sinuous section at this site, and once again the southern bank has developed very high escarpments. The river channel is distinctly braided in spite of high sinuosity and the floodplain is characterized by ravinous tract. Gullying action is widespread in the region and the incision is very deep (8–10 m). No systematic geomorphological study is available for this region and the first level geomorphological mapping has been carried out to understand the alluvial history of the region and possible tectonic implications suggested by earlier workers[2,3].

IRS-1C LISS III imagery of May 1997 was used for the present work. Four bands of the digital data were extracted first and a base map was prepared from topographic sheets. After georeferencing and resampling of data, visual enhancement techniques such as contrast stretching, filtering, band ratio, colour composite, etc. were applied on the image to obtain information about the various features present in the region. A digital elevation model (DEM) was generated and the image was draped over it to get a three-dimensional view. The edge enhancement filters like Sobel and Kirsh were applied and followed by thresholding to extract linear features. Further, all visually enhanced and edge extracted images were used to identify and digitize geomorphic elements which were overlaid to obtain a geomorphologic map of the region. This geomorphologic map was divided into

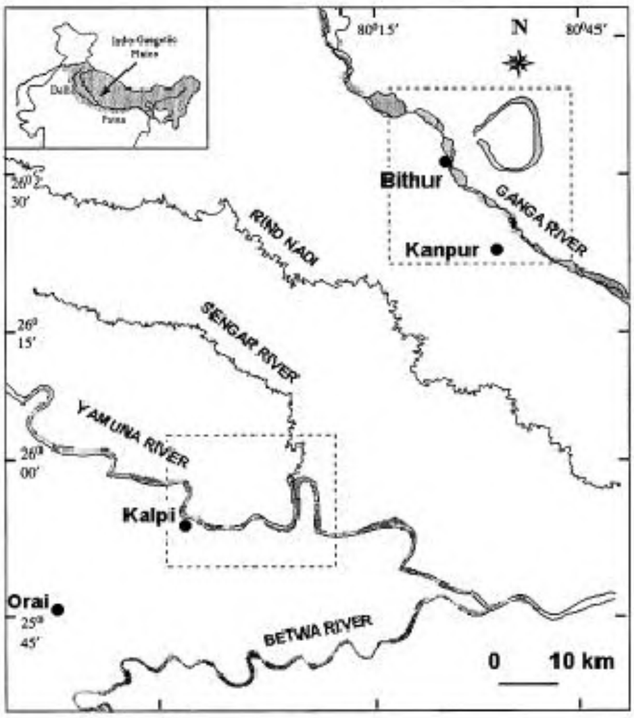

Figure 1. Location map of the study area.

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zones depending on the type of geomorphic elements present. The land-cover information of the region was generated through spectral and textural classification of the satellite images. Finally, interpretations of the geomorphologic history and evolution of the region were made by coupling the information obtained from the processed images, available literature and field observations.

Figure 2 shows a false colour composite (FCC) of the Kanpur window and highlights major geomorphological features. The Ganga river is flowing SE and the city of Kanpur is located at the west bank of the river. The major drainage in this region can be divided into two categories, the mountain-fed[4] (e.g. Ganga) and plains-fed[4] (e.g. Sai, Loni, Morahi, Pandu, etc.). The Ganga river brings its water and sediments from the high mountains in the Himalaya, whereas the plains-fed rivers derive their water from groundwater and essentially redistribute the sediments available within the plains. The mega-geomorphological units identified on the basis of geomorphic elements are (a) present-day Ganga channel, (b) large meander scar, (c) upland surface, including Kanpur city, (d) floodplain, (e) older floodplains, and (f) salt-encrusted zone (Figure 3). The terminology for these units may be preliminary at this stage and they may be revised after detailed sedimentological investigations.

The present-day Ganga river is the most recent surface present trending NW-SE. The Ganga river flows along the topographically lowest points in most parts, except in reaches upstream of Bithur. The river is braided in most parts with low sinuosity. At many places such as Bithur and Jajmau, the river in entrenched and bank sections up to 20 m are exposed.

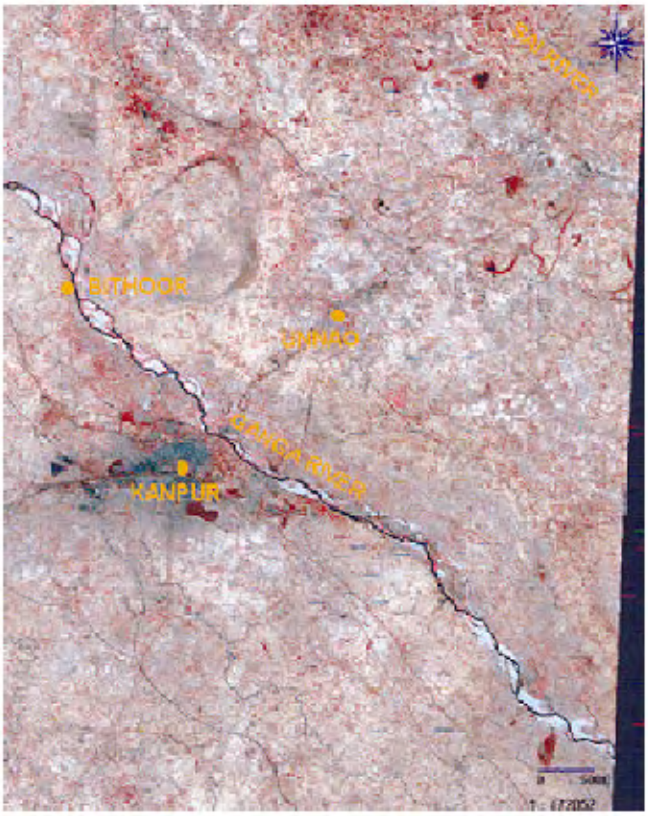

Figure 2. False colour composite of Kanpur window.

A very large meander scar is a prominent feature in the Bithur region and this has been identified as a separate geomorphologic unit. At this stage, it is difficult to associate this meander with the present-day braided Ganga system. This certainly points to a river system with a very high water budget and low sediment budget (particularly sand component), which is not the case with the present-day Ganga system. It is also likely that this belongs to an older version of the Ganga (in a more humid climate), which was metamorphosed to the present-day braided system due to reduction in water budget. The increased uplift and erosion in the Himalayan catchment contributed to an increased sediment yield, thereby developing this sand-dominated system. A number of meander scrolls present inside the meander scar points to the gradual migration of the meander belt thereby resulting in tightening of the loop, and finally, channel abandonment through neck cut-off (clearly seen on the FCC).

The upland surface is the highest available topographic surface in the region and reasonably enough, most of Kanpur city is located in this unit. The urbanization of the area makes the identification of geomorphic elements difficult. Field examination of the bank sections along the Ganga river as well as bore-hole records (the most recent one in the IIT campus) indicate that at least 8–10 m of this unit consists of muddy sediments which then grade into fine sand units. Given that such deposits in a fluvial environment normally form in an overbank environment, this points towards the existence of a fluvial system with high water budget and large amounts of suspended load.

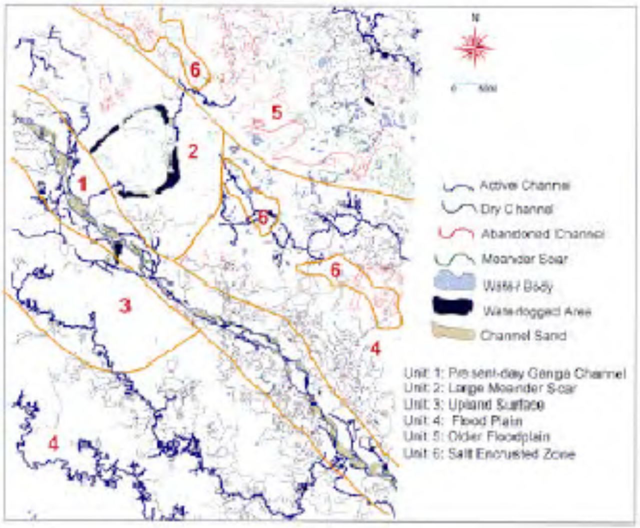

Figure 3. Mega-geomorphological units of the Ganga plains around Kanpur.

This region was later occupied by the present-day Ganga system, which carved its own valley in due course of time. The muddy units resisted lateral erosion and the river was incised at these locations. Right from Bithur to Jajmau, the southern bank of the Ganga river is incised and the areas SW of the Ganga stand out as uplands.

The floodplain unit is very well developed in the reaches downstream of Kanpur city. The topography on both sides of the river is flatter and this zone may well be regarded as the present-day floodplain of the Ganga river. The braiding or the channel multiplicity has also increased, indicating a decrease of the channel slope. The surface material is generally sandy and devoid of vegetation and the unit is clearly distinguished due to its yellowish appearance on the FCC. The eastern part of this unit also shows a wide palaeochannel course running parallel to the Ganga and this may be an earlier course of the Ganga itself. A number of smaller dry channels picked on the satellite image may represent the rain-fed channels which serve as efficient collection system during the monsoon period and divert all the surface run-off to the Ganga. Since they do not have a perennial source of water and also because the surface cover is sandy (meaning high infiltration), they appear as dry channels during the non-monsoon period (image date May 1997).

The older floodplain unit is located at the NE corner of the study area and is marked by spectacular meander belts and a large number of abandoned channels. Most of these meander scars are full of water and some of them show significant algal growth. The source of water in these meander scars is through rainwater and perhaps also through the adjoining Sai river. This belt is separated from the Ganga river by a water divide and occurs in a topographically higher zone than that of the Ganga river. As mentioned earlier, these meander scars seem to point to a larger, highly sinuous river system, presumably with a higher suspended load. The meander scars with a closed loop indicate abandonment through neck cut-off, whereas those with open loops indicate chute cut-off.

The salt-encrusted zone appears as remarkably bright white patches within the older floodplain unit in the eastern parts of the study area around Loni nadi and Sharda canal and also in the area north of unit 2. This zone has been interpreted to be a different geomorphic unit. This interpretation is presently based on some available information of the terrain[1,5], but should ideally be verified by ground visits. The presence of salt encrustation is normally related to shallow water-table in the region. The dissolved salts are brought to the surface by capillary action; water evaporates in summer months leaving behind salt encrustations on the surface.

These geomorphic units can also be distinguished topographically. The increasing order of the average height of these units is as follows: Ganga river < large meander scar < floodplain < older floodplain < salt-encrusted zone < upland surface. In classical fluvial geomorphology, this sequence is quite logical and supports the mega-geomorphological division of the area. It is interesting to note that the salt-encrusted zone is lying in a relatively higher topographic zone, which will allow draining of water followed by evaporation and precipitation of salts.

A similar approach was followed for the Kalpi window in the Yamuna plains to map the geomorphic units. The E-W flowing Yamuna river in this window is of meandering nature, with low to moderate sinuosity (Figure 4). To the north, a smaller, highly sinuous and entrenched river, namely the Sengar river, flowing almost N-S joins the Yamuna river near Keotar village (79°56′, 26°09′). The mega-geomorphological units identified in this window are (a) present-day Yamuna channel, (b) floodplain, (c) badland, (d) older floodplain, and (e) salt-encrusted/ waterlogged zone (Figure 5).

The present-day channel of the Yamuna river is the youngest geomorphic unit trending E-W in the Kalpi window. The river cuts a deep section along its right bank. The channel is clearly braided in nature, but has moderate sinuosity.

The active floodplain of the Yamuna is quite narrow, essentially because of the incised section of the channel in this window. Unlike the Kanpur window, this is not a significant unit and highlights the fact that the river does not overspill the banks frequently.

Both the northern and southern banks of the Yamuna river are characterized by badlands and this has been marked as a distinct geomorphic unit in this window. This unit is characterized by extensive gully erosion. Vegetation cover in the badland area is quite variable. Apart from the Yamuna banks, this unit is also distinguishable along the Sengar river albeit to a narrower extent. This unit is quite distinctive for the Yamuna plains and is not present in the Kanpur window of the Ganga plain.

An extensive older floodplain unit has been mapped and this unit is characterized by traces of palaeochannels and meander scars. The frequency and density of palaeochannels are much lesser than in the badland unit. Unlike the Ganga plain, the older floodplain in this window does not display an array of meander belts. Instead alluvium and patches of vegetation/cultivation cover most of the area.

The waterlogged patches/salt-encrusted zones have been mapped as a separate unit and represent the zone of shallow groundwater-table. In the proximal regions, this unit is manifested as waterlogged patches and occur within unit 2 (badland). In distal parts, they occur as salt-encrusted zones within unit 4 (older floodplain).

Major differences emerge between the Ganga and Yamuna plains in terms of geomorphic units, even though they are only 100 km apart. The Ganga plains in Kanpur window manifest features of fluvial dynamics in the past and an array of palaeochannels and meander scars are present. On the other hand, the most characteristic feature of the Yamuna plains in Kalpi window is badland topography marked by extensive gully erosion. This unit is not present in the Kanpur window of the Ganga plains. The other geomorphic units are present in both the plains albeit with variation in terms of frequency and extent of individual geomorphic elements. More detailed investigations, particularly in terms of subsurface stratigraphy and tectonic elements may be necessary to fully understand the variations.

Further, it is also worth mentioning that the earlier concept of external controls such as sea-level changes[6] does not hold good to explain the geomorphic evolution of the Ganga plain. The idea of sea-level changes and corresponding base-level changes will tend to produce regional scale geomorphic surfaces, which is not the case. In other parts of the Gangetic plains such as north Bihar plains in the east, the geomorphic setting is completely different. For example, the Ganga plain is drained by rivers, which are presently much stable and incised, although they do exhibit features of lateral migration in the past (at least 10^3 years scale). On the other hand, the rivers of north Bihar plains are characterized by shallow, muddy channels, which are much more dynamic in nature and the position of these channels changes in an average of 10^1 years. The morphology of the rivers draining the Ganga plain is also distinctive. Apart from the braided Ganga, all other rivers are highly sinuous, including the palaeochannels, and indicate mature drainage. Such tight meanders are rare in Bihar plains (except some palaeochannels of Burhi Gandak river[7]). Most rivers in Bihar plains are only moderately sinuous and reflect relatively younger drainage, as is also reflected from their migratory nature and frequent overbank flooding[8].

Figure 4. False colour composite of Kalpi window.

Further, the Yamuna river has cut a deep section along its southern bank at Kalpi area, exposed below the road bridge of NH 25. This section along the Yamuna river is about 20 m thick and can be traced laterally for several hundred metres, running roughly in NW-SE direction. The lateral profile of the section was documented with the help of vertical logs at 9 different places along the exposed section. With the help of these vertical logs, a generalized section of the cliff was prepared (Figure 6).

The fluvial sequence at Kalpi is divisible into four units. The lowermost exposed Unit I consists of an association of light-brown medium grained sand, mottled calcareous silt with disseminated rhizocretions, and locally developed, laterally impersistent cross-bedded gravel.

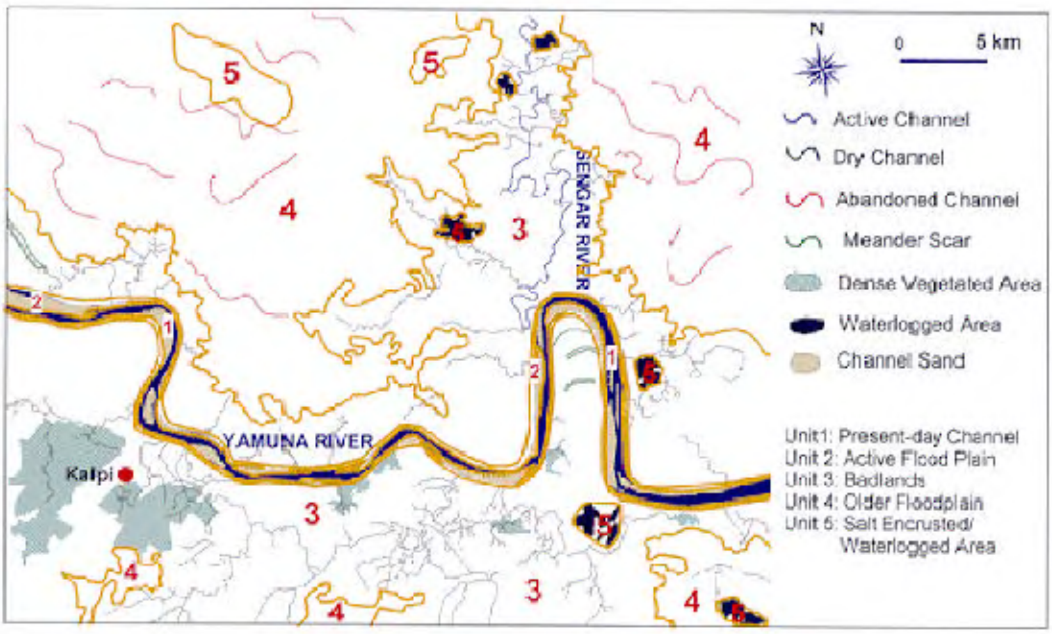

Figure 5. Mega-geomorphological units of the Yamuna plains around Kalpi.

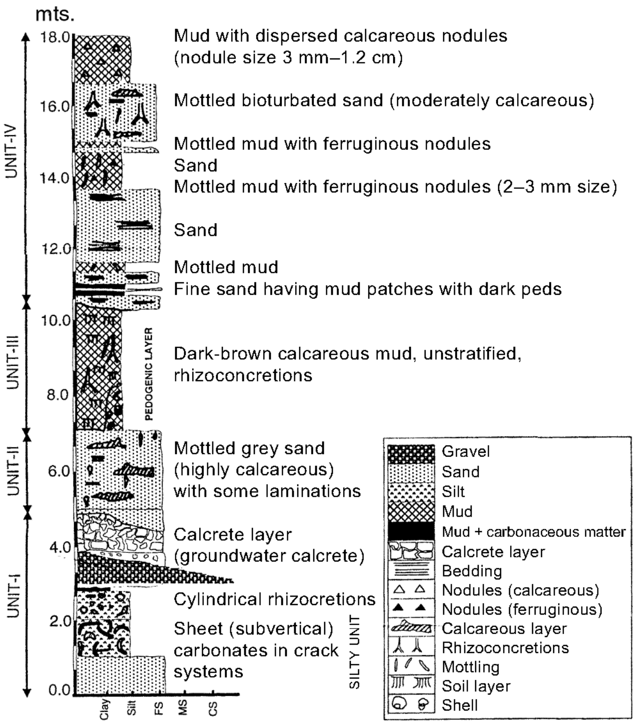

Figure 6. Generalized vertical log at Kalpi section.

The latter consists dominantly of small pebbles of calcrete together with quartzose pebbles. In the westernmost part, few reworked vertebrate bone fragments are also present. A characteristic feature of this unit is the development of variously shaped mottles and rhizocretions. Rhizocretions and mottles occur sub-vertically in places, and extend for more than 10 cm. At some locations, there is an upward increase in the density of calcareous nodules and rhizocretions. In the eastern part, the top of Unit I is made up of a sandy calcrete. It consists of masses of cemented calcareous sand of various sizes and shapes. At places where these calcareous masses are amalgamated, this bed appears knobby and irregular.

Unit II consists of fine-to-medium grey calcareous sand with abundant rhizocretions. Small-scale cross-stratification and syn-sedimentary deformational features are common. The lower part of Unit II contains abundant rhizocretions, which are cylindrical and branching. Also, spherical rhizocretions with internal vein networks of calcite are common. These occur as isolated features. The upper part of Unit II consists of a brown medium-grained sand with abundant laterally discontinuously arranged sheet-like calcareous concretions. In places, these may be associated with cylindrical rhizocretions that show a branching pattern. Unit II is cross-cut by several conjugate fractures that are filled up by calcareous cement. These fractures extend into the lower unit, but rarely into the upper unit.

Unit III is a prominent brown mudstone, which stands out because of its lack of stratification in comparison to the under-and overlying stratified units. This unit is also marked by a strong development of calcareous rhizocretions, vertical fabric and distinct green-grey mottled zones. Rhizocretions include cylindrical, branched, globular and botryoidal and nodular forms. Vertical sheet-like and rod-like calcareous features indicate shrinkage-related fills. In one of the logs this brown mudstone is associated at its base with a dark grey mudstone, which contains molluscan fossils (gastropods and pelecypods). The maximum thickness of Unit III palaeosol is ~ 2.5 m, but thins rapidly both towards the east and west. This unit can be traced laterally over a few hundred metres until it pinches out towards the west.

Unit IV attains a maximum thickness of ~ 12 m and consists of both fine to medium-grained sand and mud alternations at different scales. In some of the logs, sand–mud couplets occur. These show planar contacts mostly, although locally minor basal scours may be present. Horizontally stratified units are a few centimetres thick and may show internal sub-millimetre scale laminations. Sections towards the west show larger bedset thickness together with development of abundant bedding concordant with calcareous concretions. Other sedimentary features which occur in this unit include sub-centimetre sized ferruginous nodules, > 1 m thick medium sand units, thin palaeosol units, very thin carbonaceous mudstone, and mottled, bioturbated moderately calcareous sand.

Variations in the facies assemblages and motifs as well as undulatory contact between the major units suggest that the inter-unit contacts possibly represent genetic surfaces. The contacts mark hiatuses in sedimentation, more notably the upper and lower contacts of the Unit III palaeosol. Work is in progress to develop a detailed stratigraphy of this region and to establish the geochronological framework.

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