CHAPTER - III

Geomorphology
GEOMORPHOLOGY

General Statement

The study on geomorphology was carried out with village level resolution as part of Ph.D. program for Aligarh, Mathura districts Uttar Pradesh and Bharatpur district, Rajasthan, in parts of Yamuna basin. The landforms of the geomorphic zones have been described and drainage morphometry is presented for the study area.

Geomorphic Zones

The Yamuna basin in the study area has been divided into eight geomorphic zones based on geomorphic landforms, topographic elevation, using photographic and geotechnical elements etc.

The area comprise the following geomorphic zones:

1. Structural Hills and Valleys of Delhi Supergroup
2. Vindhyan Plateau
3. Burried Pediment
4. Varanasi Older Alluvial Plain
5. Aligarh Older Alluvial Plain
6. Older flood plain of Yamuna basin
7. Recent Flood Plain of Yamuna River and tributaries
8. Aeolian Deposits

1. Structural Hills and Valleys of Delhi Supergroup

The hills and ridges of the Bayana, Ajabgarh and Alwar groups of Delhi Supergroup form hogback and cuesta outcrops aligned in NE-SW to ENE-WSW directions in the northern and southern parts of the Bharatpur district (Fig. 3). The cuesta, hogback and erosional valleys are prominent geomorphic elements which constitute this zone:

a. Cuesta

Cuesta ridges (Lobeck, 1939; Thornbury, 1954) in the Bayana Group are aligned in a linear pattern in ENE-WSW direction developed near Deeg in the north and around Bayana in the southern part of the district. The geomorphic unit is identified on TM FCC output by its dark tone, linear pattern, isolated hillocks, parallel pattern of first order channels and scanty or no vegetation. The Cuesta topography has been controlled by gently dipping strata with moderate resistance to erosion and exhibits asymmetrical ridge profile.

b. Hogback ridges

The hogbacks (Cotton, 1944, 1952; Lobeck, 1939; Thornbury, 1954) occur as NE-SW trending steep ridges of Delhi Supergroup with symmetrical profile defining the main architecture of the Aravalli ranges, forming natural
fortification on the western boundary of the Bharatpur district in Pahari and Kaman Tahsils.

The dip slopes and obsequent slopes are nearly symmetrical and smooth. In the TM FCC the ridges are defined by tonal banding, linear forms, parallel drainage and symmetrical profile. Vegetation cover is scanty and resistance to erosion is high. The continuity of the ridges at places is punctuated by faults or joint controlled drainage. These are seen prominently in the Pahari and Kaman Tahsils. The Kaman ridge terminates at Barsana in Mathura district, while the Pahari hogbacks continue northwards in Haryana and Delhi states, in south these merge with the I alsot Hills of Rajasthan.

c. Erosional Valleys

The erosional valleys are developed within the Bayana Hill ranges and in Pahari and Kaman Tahsils of Bharatpur District, in association with the structural hills. These are characterized by depressed topography, carved out of soft lithologies in the rocks of Delhi Supergroup. The erosional valleys are sandwich within the hogback zone and exhibit restricted agricultural practice, centripetal drainage and form rib and furrow topography due to low to moderate resistance to erosion of the lithologies constituting the Erosional Valleys.
2. Vindhyan Plateau

The Vindhyan Plateau in the southern part of the Bharatpur district forms the monolith overlooking the Varanasi Older Alluvial Plain of Bharatpur and Banganga valley. This zone is defined by Cuesta hills of the Upper Bhandar Sandstone and hogback ridges of Rewa Sandstone of the Vindhyan Supergroup. The hogback ridges strike in ENE-WSW direction in a linearly stretched belt aligned parallel to the Great Boundary Fault which separates the Vindhyan Plateau from the rocks of Bayana Group and Delhi Supergroup.

The cuesta hills occupy higher topographic elevation in the Vindhyan Plateau and range in elevation from 220 m to 318 m. These are characterized by structurally controlled drainage, the drainage density is medium to low, resistance to erosion is moderate to high, the Cuesta in the Vindhyans are remnants of inliers of palaeo-planar surfaces in the area (Iqbaluddin, 1996a). Besides, these hogback and Cuesta hills, the Vindhyan Plateau is also characterized by association with loess and ravines.

3. Buried Pediment

This geomorphic zone occupies a significant area in the north, south-west and north-eastern parts of the district fringing the structural hills of Delhis and Vindhyan plateau in Pahari, Kaman and Bayana Tahsils. The zone is characterized by undulating topography, accidented slope, thin alluvial cover,
higher elevation as compared to the Aligarh Older Alluvial Plain and favourable soil conditions for agricultural practice.

This zone is identified on the remotely sensed data by light to medium tone, sharp contact with the adjacent geomorphic zones, irregular boundary outline and partly internal drainage with low drainage density.

4. Varanasi Older Alluvial Plain

This geomorphic zone corresponds to the Older Alluvium Group of the Indo-Gangetic plain (Krishnan, 1982). The word Alluvium is derived from the Latin word for "Flood", it is more or less stratified deposit of gravel, sand, silt clay or other debris moved by streams from higher to lower ground. The term Alluvium was widely used in Central Europe for the Holocene stage as distinct from "Diluvium" which is Pliestocene in age. In the Indian context the term Alluvium has been used for the Quaternary deposits which are genetically related to fluvial dynamics. During the Pleistocene glaciation in India most of the rivers from the northern provenance had little discharge due to glaciation. However, the southern provenance of Vindhyan Uplands supported a very well developed drainage network, which poured the sediments during the Pleistocene in the depression between Himalayas in the north and Vindhyans in the south. The alluvial deposits of the Indo-Gangetic plain which have a mix source with dominant clastic supply from the Vindhyan Uplands during the Pliestocene sedimentation are referred as
Varanasi Older Alluvial Formation and constitute geomorphologically the Varanasi Older Alluvial Plain (Iqbaluddin, 1996a).

The Varanasi Older Alluvial Plain is characterized by uniformity in characters, gentle to moderate slope and extensive agricultural activity. The unit occupies large parts of Aligarh, Mathura and Bharatpur districts and higher topographical level with elevations ranging from 196 m to 182 m above M.S.L. This geomorphic unit can be identified on TM FCC by its bright to medium tone, irregular boundary outline and association with agricultural practice. The local water logging conditions are also prevailing in this unit and it can be easily picked up by dark tone on TM FCC image. The soils of this zone exhibit dominantly sandy nature comprising 67.36% sand with admixture of clay and silt and the texture of the soil is medium to fine (Fig. 2).

![Fig. 2. Clastic assemblage in Varanasi Older Alluvial Formation](image-url)
5. Aligarh Older Alluvial Plain

This geomorphic zone occupies considerable area in the Aligarh, Mathura and Bharatpur districts and is characterized by the extensive development of paleo-channel deposits of an earlier north flowing drainage system (Fig. 3, Plate 22, 23). The Aligarh Older Alluvial Plain represents the depositional history of an earlier drainage system, which originated from the Vindhyan Uplands in the south and had a regional slope towards north. This paleo-drainage system was first recognized in the Aligarh district (Samdani, 1990; Iqbaluddin, 1992). The drainage density is coarse with dendritic to sub-dendritic pattern (Fig. 3, Plate 22, 23).

This unit is easily picked up on LANDSAT TM FCC Image of bands 2, 3 and 4 by its bright hue and intensity, irregular boundaries, sharp contacts, development of paleo-channels. The association of saline/alkaline patches is the characteristic feature of the Aligarh Older Alluvial Plain, locally known as Usarland which exhibit bright tone on TM FCC.

The natural vegetation on this geomorphic surface is poor but it is under heavy agricultural practice for seasonal crops. The main vegetation include the fruit orchards, sporadic Babul, Neem, Jamun, Mango and Guava plantations etc.

Lithologically of this unit consists of admixture of sand, silt and clay, texture is fine to very fine (Fig.4) and color of the alluvial material is gray to
yellowish brown. Stratigraphically the unit corresponds to Older Alluvium Group (Das Gupta & Gupta, 1992).

The zone represents almost uniform plain with elevation ranging from 178 m to 190 m. The scars and paleo-channels of the north flowing paleo-drainage are characteristic elements, picked up on LANDSAT TM FCC outputs.

a. Paleo-channels
The paleochannels correspond to the north flowing paleo-drainage (Fig. 3, Plate 22, 23), which originated from the south and predates the Newer Alluvium (Iqbaluddin et al., 1994). This paleo-drainage was sub-dendritic with medium to high drainage density. The paleochannels are recognized on the TM FCC data by their medium to dark hue, curvilinear pattern, uniform texture and continuity beyond the district boundaries of Mathura and Aligarh. The groundwater conditions along these paleo-channels are good to very good & hydrochemically the water is potable.

b. Scars
These are the remnant of the highly sinuous paleo-drainage system (D1), which were cut-off from the main channel. These are recognized northeast of Nadbai and north of Bharatpur (Fig. 3) by arcuate shape, uniformity in tone, isolated occurrence and depressed relief, characterized by loss of hydraulic continuity with parent channel, it is characteristic element of Aligarh Older Alluvial Plain.
6. Older Flood Plain of Yamuna Basin

The former levels of the valley floor of flood plain located at more or less constant heights above the present flood plain of Yamuna river has been mapped as Older Flood Plain in Yamuna basin. The unit represent composite surface formed by coalescence of depositional terraces which are homogeneous in lithological characters and have short aerial extent. The terraces constitute the flood plain deposits of Yamuna and its tributaries and have been distinguished into $T_2$ and $T_1$ level terraces in the Aligarh and Mathura districts. The surface occurring above the present day river channel has been designated as $T_1$ terrace. Chronologically, $T_2$ terrace is older than $T_1$ but both $T_1$ and $T_2$ correspond to Newer Alluvium Group (Das Gupta & Gupta,1992; Thussu et. al.,1992; Iqbaluddin,1994).
a. \(T_2\) Terrace

This unit occupies a higher topographical level compared to \(T_1\) terrace. It is developed on the eastern bank of the Yamuna as a linear and continuous tract (Fig. 3).

The \(T_2\) terrace ranges in elevation from 188 m to 176 m above M.S.L. This geomorphic unit can be recognized in the remotely sensed data from its tonal contrast with the Varanasi Older Alluvial Plain. It is medium to dark tone, occurring as continuous and prominent linearly stretch persistent belt, along the banks of Yamuna river. Meander scars are the characteristic land forms associated with this surface. The vegetation cover present on \(T_2\) terrace include seasonal crops, mango, guava and ber orchards. Besides trees like babul, neem, sheesham etc. have provided vegetal cover to the unit.

b. \(T_1\) Terrace

\(T_1\) terrace occurs as a continuous linear stretch between \(T_2\) terrace and the Recent flood plain of Yamuna river. It represents the paleo-flood plain deposits of Yamuna river and is developed along the banks of River Yamuna. \(T_1\) terrace is separated from the Recent Flood Plain and from \(T_2\) terrace by break in slope, which vary from 1m to 3m. The nick points have been erased by extensive agricultural activity along the unit. This surface is homogenous in character and do not show much difference with \(T_2\) terrace. At places it is difficult to draw boundary between \(T_2\) & \(T_1\) terraces in the remotely sensed data output due to tonal similarity. It is a narrow and continuous zone and the cut-off meanders, representing the change in river courses and a sluggish low energy environment are characteristic elements associated with \(T_1\) terrace. It
occupies a lower topographical level than $T_2$ terrace. The natural vegetation in the form of grasses and bushes is found in abundance, landuse is restricted for cultivation during the lean season and Rabi crops are generally sown along with seasonal vegetables.

c. Older Flood Plain of Banganga River
A younger set of abandoned paleo-channels south of Bharatpur and Nadbai define the earlier channel courses of the river Banganga and are helpful in reconstructing the channel migration of the Banganga river. These features show that Banganga is gradually shifting from north to south and the scars of the individual channels of this river are well picked up on TM FCC outputs (Fig. 3). In the digital data outputs these are recognized by light tone, uniform texture, linearity of tone, sharp contact, development of channel sinuosity etc. (Plate - 1, 22, 23) The water-table along the paleochannels is shallow but quality is not good. The landuse pattern is defined by agricultural activity. The Banganga paleo-channels are separated from the north flowing paleo-drainage by the roughly east-west trend of these channels. The Nadbai-Bharatpur water divide separates the Banganga paleo-channels in the south from the northeasterly flowing paleo-drainage of Aligarh Older Alluvial Plain.

7. Recent Flood Plains of Yamuna
Geomorphologically, a flood plain is among the most dynamic of topographic surfaces. This dynamic quality is due to its inter-relatedness to the dynamics of a whole system of processes that constitute a stream system. Leopold and
Wolman (1957) suggest that the active flood plain is an area subjected to inundation by the annual flood (highest discharge in each year). The uniform frequency of flooding suggests relationship between the height of a flood plain and the stream that built it. Following Leopold and Wolman (1957) in the present study the area occupied by the present day river channel and adjoining areas (low lying plain), which is locally called "Khadir" has been included in the Recent Flood Plain of Yamuna. The Recent Flood Plain of Yamuna river has been demarcated on the basis of periodic inundation levels.

This geomorphic unit is easily identified on TM FCC image due to its dark color, irregular shape, sharp geomorphic boundaries, presence of point bars/ channel bars, development of Ox-bow lakes and cut-off meanders. Khadir is sparsely populated with temporary settlements and rare agricultural practice of seasonal crops like Zaid.

The Recent Flood Plain of Yamuna is under dynamic state and form active alluvium. The development of point bars/ channel bars, cut-off meanders etc. indicate that the river has built up its flood plain by lateral accretion process. The Recent Flood Plain of Yamuna correspond to Recent Alluvial Group.

a. Recent Flood Plain of Tributaries of Yamuna River
This includes the flood plain deposits of the Banganga and Gambhir rivers, which correspond to Quaternary period. These rivers are characterized by their overall sinuous courses. The Banganga and Gambhir rivers locally become braided and the two finally confluence in the north-west of Rupbas town forming a low lying plain adjacent to Vindhyan Plateau in the south.
The Banganga Recent Flood Plain is recognized on the remotely sensed data by its dark to medium hue, sharp contact with adjacent geomorphic zone, irregular boundary outline, low settlement density, restricted landuse pattern, association of point bars/channel bars, gully erosion, scars, badland topography, sand bars, etc.

The Banganga river possibly indicate a drainage anomaly defined by the higher channel width in the western part (proximal end), as it enters from the adjacent Sawai Madhopur district, the channel width decreases at the distal end as it flows towards east (Fig. 3). This anomaly clearly indicates that there has been reversal in the drainage which was from east to west in contrast to the present day west to east flow (Iqbaluddin et.al., 1997). The drainage mutation in the area has possibly taken place in the Quaternary. The frequent floods in the Bharatpur district may be attributed to the drainage mutation in the area.

8. Aeolian Deposits

Sand dunes and the loess deposits are reported from the Ndbai, Nagar, Bayana and Rupbas Tahsils (Fig. 3). These sand dunes comprise > 85% sand, the grains are fine sub-angular to angular and forming 6-8 m high heap of sand. Texturally the sand is very well sorted to well sorted, fine to medium grain, possess high porosity, devoid of any biocover and has internal drainage. These are the aeolian features which have been brought to the area by wind action, but do not show the direction of the wind. In the remotely
sensed data outputs these reflect uneven texture, irregular shape and outline and are spatially associated with the Aligarh Older Alluvial Plain, Vindhyan Plateau and Bayana Hills, occurring as obstruction dunes and sand spread.

**Drainage**

The present day drainage of the Aligarh, Mathura and Bharatpur districts represented by Ganga and Yamuna and their tributary streams is referable to D3 system in terms of morpho-chronology. It is developed as superimposed drainage over a paleo-flood plain of a major river system which emerged from the Vindhyan Plateau and flowed towards north in the Central depression around Meerut in the Indo-Gangetic Plain.

The Yamuna drainage basin in Aligarh, Mathura and Bharatpur districts is separated by major drainage divides following the Upper Ganga Canal in the east and the Aravalli Mountain range in the west (in Bharatpur) which separates it from Luni basin of western Rajasthan.

This paleo-drainage (D1 and D2) predates the Newer Alluvium (see Joshi & Bhartiya, 1991; Iqbaluddin, 1996a; Iqbaluddin, et. al., 1997). The palaeo-drainage has two cycles D1 and D2. The D1 drainage has a higher sinuosity than D2. The D1 drainage represent the mature stage and D2 drainage represents the rejuvenated phase characterized by linearity of channels. The relief mutation in the area during the Holocene period resulted in partial filling
of the paleo-flood plain by sediments which in the Indian Stratigraphic nomenclature have been assigned as Newer Alluvial Group. Radio Carbon dating of coeval sediments carried out from Ganga valley has indicated age 11040 ± 190 Y.B.P. (Joshi and Bhartiya, 1991) and from Yamuna Basin an age of 9960 ± 80 Y.B.P. has been indicated by 14C- method (Singh et al., 1997) for the paleo-drainage.

**Drainage Morphometry**

For purpose of morphometric analysis the D3 drainage system of Yamuna basin has been subdivided into micro-watersheds on the basis of micro-relief, slope, drainage characteristics and spatial relationship of the lower order channels with major rivers. The morphometric analysis has attempted quantification of micro-watershed in terms of Stream order, Stream number, Bifurcation ratio, Stream length, Mean stream length, Stream length ratio, Stream frequency, Drainage density, Texture ratio, Basin area, Basin elongation, Basin circulatity, Maximum basin relief, Relative relief, Ruggedness number, Infiltration number for each micro-watershed.

The Yamuna Basin has been sub-divided into twelve micro-watersheds, which have been designated as Y1, Y2, Y3, Y4, Y5, Y6, Y7, Y8, Y9, Y10, Y11 and Y12. Seven micro-watershed have been recognized in Aligarh (Y1 to Y7) and in Mathura district one micro-watersheds Y8 has been recognized. The Bharatpur district on the right bank of Yamuna Basin has four micro-
watersheds which have been assigned as Y9, Y10, Y11 and Y12 to facilitate the description. Table -12 presents the list of the micro - watersheds and Table- 13 gives their morphometric parameters.

Table - 12 Micro-watersheds in the study area

| a. Sengar Nadi Micro-watershed   | Y1   |
| b. Aligarh Drain Micro-watershed | Y2   |
| c. Somna Nala Micro-watershed   | Y3   |
| d. Karwan Nadi Micro-watershed  | Y4   |
| e. Jamon Nadi Micro-watershed   | Y5   |
| f. Patwaha Nadi Micro-watershed | Y6   |
| g. Dehar Nadi Micro-watershed  | Y7   |
| h. Yamuna Sub-basin             | Y8   |
| i. Banganga Sub-Basin           | Y9   |
| j. Gambhir Sub-Basin            | Y10  |
| k. Kakund Sub-Basin             | Y11  |
| l. Kaman Sub-Basin              | Y12  |

a. Sengar Nadi Micro-watershed (Y1)

The Micro-watershed Y1 covers about 909 km$^2$ area in parts of Lodha, Jawan, Dhanipur, Sasni, Akrabad and Hasain blocks of Aligarh district. The morphometry of the study area drained by Sengar Nadi in the Aligarh district is presented in Table - 13. The Y1 micro-watershed has twenty seven streams which include twenty four of 1$^{st}$ order, two of 2$^{nd}$ order and one stream of 3$^{rd}$
order. The Bifurcation Ratio $R_{b1}$ for 1st and 2nd order is 12 and $R_{b2}$ for 2nd and 3rd order is 2.0; Length of Stream Segment $L_1$, $L_2$ and $L_3$ for 1st, 2nd and 3rd order streams are 143.25 km, 17.5 km and 66.5 km respectively; the Mean Stream Length is 5.98 km, 8.75 km and 66.50 km for 1st, 2nd and 3rd order streams respectively; Stream Length Ratio $R_2$ and $R_3$ is 1.46 and 7.6; The Drainage Density $(D)$ is 0.25; Stream Frequency $(f)$ 0.029; Texture Ratio $(T)$ is 0.196; Form Factor $(F)$ is 0.017; Basin Circulatity $(R_c)$ is 0.297; Basin Elongation $(E)$ 291.66 km. Relative Relief $(R_{hp})$ is 0.106; Maximum Basin Relief $(H)$ is 8 m; Ruggedness Number $(H_{dd})$ of the basin is 3.73 for the Y1 micro-watershed.

b. Aligarh Drain Micro-watershed (Y2)

An area of about 487 km$^2$ between Somna Nala and Sengar Nadi separated by natural water divides in parts of Khair, Chandaus, Lodha, Jawan, Iglas, Hathras, Sasni and Mursan blocks of Aligarh district has chocked drainage. The natural drainage has been missing. The hydraulic escape has been provided for the surface run off through drain constructed which is referred as Aligarh drain. The micro-watershed has total of nine streams which include eight of 1st order and one of 2nd order. The Bifurcation Ratio $R_{b1}$ for 1st and 2nd order is 8.0; Length of Stream Segment $L_1$ and $L_2$ for 1st and 2nd order streams are 32.5 km and 68.0 km respectively; Stream Length Ratio $R_2$ is 16.79; The Drainage Density $(D)$ is 0.205; Stream Frequency $(f)$ 0.018; Texture ratio $(T)$ is 0.057; Form Factor $(F)$ is 0.048; Basin Circulatity $(R_c)$ is 0.249; Basin Elongation $(E)$ 140.31 km. Relative Relief $(R_{hp})$ is 0.102;
Maximum Basin Relief \((H)\) is 16 m; Ruggedness Number \((HDd)\) of the basin is 3.28 for the Y2 micro-watershed.

c. Somna Nala Micro-watershed (Y3)

The Somna Nala Micro-watershed (Y3) covers about 634 km\(^2\) area in parts of Chandaus, Lodha, Khair, Sasni, Gonda, Hatras, Iglas and Mursan blocks of Aligarh and Hathras districts which are drained by Somna drain, which discharges into Karwan Nadi. The Y3 micro-watershed has eight streams which includes five streams of 1\(^{st}\) order, two of 2\(^{nd}\) order, one stream of 3\(^{rd}\) order. The Bifurcation Ratio \(Rb1\) for 1\(^{st}\) and 2\(^{nd}\) order is 2.5 and \(Rb2\) for 2\(^{nd}\) and 3\(^{rd}\) order is 2.0; Length of Stream Segment \(L1, L2, \text{ and } L3\) for 1\(^{st}\), 2\(^{nd}\) and 3\(^{rd}\) order streams are 62.75 km, 23.25 km and 35.25 km respectively; Stream Length Ratio \(R2, R3\) are 0.92 and 3.03 respectively; The Drainage Density \((D)\) is 0.19; Stream Frequency \((f)\) 0.012; Texture Ratio \((T)\) is 0.54; Form Factor \((F)\) is 0.043; Basin Circulatity \((Re)\) is 0.365; Basin Elongation \((E)\) 148.31 km. Relative Relief \((Rhp)\) is 0.101; Maximum Basin Relief \((H)\) is 15 m; Ruggedness Number \((HDd)\) of the basin is 2.85 for the Y3 micro-watershed.
d. Karwan Nadi Micro-watershed (Y4)

The Karwan Nadi Micro-watershed (Y4) covers about 548 km² area in parts of Chandaus, Gonda, Iglas and Mursan blocks of Aligarh district and 61.22 km² area of Sadabad Tahsil in Mathura district which are drained by Karwan Nadi which in Mathura district is locally referred as Jharina stream. The micro-watershed has twenty three streams which include nineteen of 1st order, three of 2nd order and one stream of 3rd order. The Bifurcation Ratio Rb1 is 6.33, Rb2 is 3.0, Rb3 for 3rd order is 1; Length of Stream Segment L1, L2, and L3 for 1st, 2nd and 3rd order streams are 90.0 km, 30.5 km, 73.75 km respectively; Stream Length Ratio R2 and R3 is 2.95 and 0.41 respectively; the Drainage Density (D) is 0.318; Stream Frequency (f) 0.0394; Texture Ratio (T) is 0.102; Form factor (F) is 0.021; Basin Circulativity (Rc) is 0.248; Basin Elongation (E) 168.10 km. Relative Relief (Rhp) is 0.078; Maximum Basin Relief (H) is 13 m; Ruggedness Number (HDd) of the basin is 3.77 for the Y4 micro-watershed.

e. Jamon Nadi Micro-watershed (Y5)

The Jamon Nadi Micro-watershed (Y5) covers about 320 km² area in parts of Khair, Gonda, Iglas and Mursan blocks Aligarh district which are drained by Karwan Nadi. The micro-watershed has seven streams which include six of 1st order and one of 2nd order. The bifurcation ratio Rb1 for 1st and 2nd order is 6; Length of Stream Segment L1 and L2 for 1st and 2nd order streams are 8.54 km, 26.0 km respectively; Stream Length Ratio R2 is 3.09;
Drainage Density (D) is 0.24; Stream Frequency (f) 0.021; Texture Ratio (T) is 0.081; Form Factor (F) is 0.053; Basin Circulatity (Rc) is 0.191; Basin Elongation (E) 138.38 km. Relative Relief (Rhp) is 0.103; Maximum Basin Relief (H) is 15 m; Ruggedness Number (HDd) of the basin is 3.6 for the Y5 micro-watershed.

f. Patwaha Nadi Micro-watershed (Y6)

The Patwaha Nadi Micro-watershed (Y6) covers about 227 km² area East of Yamuna in parts of Tappal block Aligarh district which is drained by Patwaha Nala. The micro-watershed has only nine streams which include six of 1st order, two of 2nd order and one of 3rd order. The Bifurcation Ratio Rb1 for 1st and 2nd order is 3 and Rb2 for 2nd and 3rd order is 2; Length of Stream Segment L1, L2 and L3 for 1st, 2nd and 3rd order streams are 27.25 km, 17.0 km, 9.75 km respectively; Stream Length Ratio R2 and R3 are 1.87 and 1.14 respectively; The Drainage Density (D) is 0.237; Stream Frequency (f) 0.39; Texture Ratio (T) is 0.116; Form Factor (F) is 0.077; Basin Circulatity (Rc) is 0.474; Basin Elongation (E) 102.35 km. Relative Relief (Rhp) is 0.051; Maximum Basin Relief (H) is 4 m; Ruggedness Number (HDd) of the basin is 0.948 for the Y6 micro-watershed.
g. Dehar Nadi Micro-watershed (Y7)

The Dehar Nadi Micro-watershed (Y7) covers about 192 km$^2$ area in parts of Tappal block Aligarh district which is drained by Dehar Nala & its tributries. The micro-watershed has four streams which include two of 1$^{st}$ order, two streams of 2$^{nd}$ order. The Bifurcation Ratio Rb1 for 1$^{st}$ and 2$^{nd}$ order is 2 and Rb2 for 2$^{nd}$ order is 1; Length of Stream Segment L1 and L2 for 1$^{st}$, 2$^{nd}$ order streams are 10.62 km, 25.50 km respectively; Stream Length Ratio R2 and R3 are 1.95 and 0.22 respectively; The Drainage Density (D) is 0.24; Stream Frequency (f) 0.02; Texture Ratio (T) is 0.057; Form Factor (F) is 0.887; Basin Circulatity (Re) is 0.506; Basin Elongation (E) 68.59 km. Relative Relief (Rhp) is 0.101; Maximum Basin Relief (H) is 0.7 m; Ruggedness Number (HDd) of the basin is 1.68 for the Y7 micro-watershed.

i. Yamuna Micro-watershed (Y8)

The Yamuna Micro-watershed (Y8) forms the dominant drainage network in the Mathura district and covers an area of 1050 km$^2$ in the Central Part of the district. The total number of streams in this micro-watershed is 102, out of which seventy eight are of 1$^{st}$ order, twenty streams are of 2$^{nd}$ order, three of 3$^{rd}$ order and one of 4$^{th}$ order which is the main Yamuna channel. The Bifurcation Ratio (Rb) are 3.9 for 1$^{st}$ and 2$^{nd}$ order, 6.6 for 2$^{nd}$ and 3$^{rd}$ order, 3 for 3$^{rd}$ and 4$^{th}$ order streams. Stream Lengths are 220 km for 1$^{st}$ order, 4 km for 2$^{nd}$ order, 61 km for 3$^{rd}$ order and 45.66 km for 4$^{th}$ order respectively. The Total Length of all the streams is 420.66 km, Mean Stream Length (ML)
are 2.82 km for 1\textsuperscript{st} order, 4.7 km for 2\textsuperscript{nd} order, 20.33 km for 3\textsuperscript{rd} order and 45.66 for the 4\textsuperscript{th} order stream. The Stream Length Ratios R2, R3 and R4 are 1.66, 4.32 and 2.24 respectively. The Drainage Density (D) of the Yamuna sub-basin is 0.40 and Stream Frequency (f) is 0.09 which together indicate a highly permeable sub-soil material and low relief. Texture Ratio (T) is 0.16 representing coarse to medium texture. Basin Elongation (E) and Basin Circulatity (Rc) values are 0.41 and 0.41 respectively, indicating a homogeneous material. Infiltration Number (INF) is 0.23 for Y8 micro-watershed.

\textbf{j. Banganga Micro-watershed (Y9)}

The Banganga Micro-watershed (Y9) covers an area of about 259.37 km\textsuperscript{2} in the south Central part of Bharatpur district. The perimeter of the sub-basin is about 86 km and Maximum Basin Length (Lb) is 33.75 km. The total number of streams (Nu) of the various orders is 40, out of which the number of 1\textsuperscript{st} order streams is 31, the number of 2\textsuperscript{nd} order is 8 and that of 3\textsuperscript{rd} order is 1. The Total Length of all the Stream (Lu) is 173.0 km, the length of 1\textsuperscript{st} order channels is 106.25 km, the 2\textsuperscript{nd} order is 49.0 km and of 3\textsuperscript{rd} order is 18.75 km respectively. The Bifurcation Ratios (Rb) between 1\textsuperscript{st}/2\textsuperscript{nd} order Rb1 is 3.87 and between 2\textsuperscript{nd}/3\textsuperscript{rd} order Rb2 is 8. The Stream Length Ratio R2 for 2\textsuperscript{nd}/1\textsuperscript{st} orders is 0.45 and R3 for 3\textsuperscript{rd}/2\textsuperscript{nd} orders is 0.39. The values of Drainage Density (D) is 0.667 and that of Stream Frequency (f) is 0.1154. The Basin Elongation (E) is 0.538, Basin Circulatity (Rc) is 0.44. The value of
Infiltration Number (INF) is 0.102, Form Factor (F) is 0.22 and Overland Flow (Lg) is 0.749.

k. Gambhir Micro-watershed (Y10)

The Gambhir Micro-watershed (Y10) covers an area of about 534.37 Km\(^2\) in the southern and south-western parts of Bharatpur district. The Basin Perimeter (P) is about 141.25 km and Maximum Basin Length (Lb) is 42 Km. The Total Number of Streams (Nu) of various orders is 83, out of which the number of 1\(^{st}\) order streams is 63, the number of 2\(^{nd}\) order is 16, the number of 3\(^{rd}\) order is 3 and 4th order is 1. The Total Stream Length (Lu) of all orders is 289.50 Km, the Length of 1\(^{st}\) order stream is 181.0 km, of 2\(^{nd}\) order is 70.75 km, Length of 3\(^{rd}\) order is 19.75 km and that of 4\(^{th}\) order is 18.0 km. The Bifurcation Ratio (Rb) of 1\(^{st}/2^{nd}\) orders Rb1 is 3.93, that of 2\(^{nd}/3^{rd}\) orders Rb2 is 5.33 and between 3\(^{rd}/4^{th}\) orders Rb3 is 3.0. The values of Stream Length Ratio for 2\(^{nd}/1^{st}\) orders R2 is 0.93, for 3\(^{rd}/2^{nd}\) orders R3 is 0.27 and for 4\(^{th}/3^{rd}\) orders R4 is 0.43. The value for Drainage Density (D) is 0.541 where as for Stream Frequency (f) is 0.155. The Basin Elongation (E) is 0.621 and Basin Circularity Ratio (Rc) is 0.336. The value of Form Factor (F) is 0.302, Infiltration Number (INF) is 0.084 and Overland Flow (Lg) is 0.923.
I. Kakund Micro-watershed (Y11)

The area covered by Kakund Micro-watershed (Y11) is 84.37 km² in the southern part of the district on Vindhyan Plateau. The Perimeter (P) of the basin is 48.5 km and Maximum Basin Length (Lb) is 18 km. The Total Number of Streams (Nu) of various orders is 27, out of which the number of 1st order streams is 20, the number of 2nd order streams is 6 and 3rd order stream is 1. The Total Stream Length (Lu) of all orders is 85.75 km. The Length of 1st order stream is 52.0 km, 2nd order is 26.5 km, and 3rd order is 7.25 km. The Bifurcation Ratios (Rb) of 1st/2nd orders Rb1 is 3.33, that of 2nd/3rd orders Rb2 is 6.0. The value of Stream Length Ratio for 2nd/1st order R2 is 0.5, for 3rd/2nd order R3 is 0.27. The value for Drainage Density (D) is 1.016, where as Stream Frequency (f) is 0.32. The Basin Elongation Ratio (E) of the basin is 0.576 and Basin Circularity Ratio (Re) is 0.45. The values of Form Factor (F) is 0.26, Infiltration Number (INF) is 0.325 and Overland Flow (Lg) is 0.491.

m. Kaman Micro-watershed (Y12)

The Kaman Micro-watershed (Y12) covers an area of about 796.87 km² in the northern part of the Bharatpur district. The Kaman Micro-watershed discharges its runoff in Mathura district, whence from it is carried through Govardhan Drain into the Yamuna river near Churmura Ghat. The Basin Perimeter (P) is about 110.25 Km and Maximum Basin Length (Lb) is 46.25 km. The Total Number of Streams (Nu) of various orders is 33 out of which
the number of 1st order streams is 25, the number of 2nd order is 5, the number of 3rd order is 3 and 4th order is 1. The Total Stream Length (Lu) of all orders is 214.25 Km, the Length of 1st order streams is 102.5 km, 2nd order is 30.5 km, 3rd order is 41.25 km and 4th order is 40.0 km. The Bifurcation Ratio (Rb) of 1st/2nd orders Rb1 is 5, that of 2nd/3rd orders Rb2 is 2.5 and between 3rd/4th orders Rb3 is 2.0. The values of Stream Length Ratio for 2nd/1st orders R2 is 0.2, for 3rd/2nd orders R3 is 0.4 and for 4th/3rd orders R4 is 0.5. The value for Drainage Density (D) is 0.269 and Stream Frequency (f) is 0.041. The Basin Elongation Ratio (E) of the basin is 0.689 and Basin Circularity Ratio (Re) is 0.823. The value of Form Factor (F) is 0.372, Infiltration Number (INF) is 0.011 and Overland Flow (Lg) is 1.859.
<table>
<thead>
<tr>
<th>Geomorphic Zones</th>
<th>Image Characters</th>
<th>Lithology/Stratigraphic Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aeolian Deposits</strong></td>
<td>Uneven Texture, irregular shape and outline spatially associated with Aligarh Older Alluvial Plain.</td>
<td>Sand Silt with admixture of clay and mud. medium to fine micaceous sand</td>
</tr>
<tr>
<td><strong>Recent Flood Plain of Yamuna</strong></td>
<td>Dark tone, irregular shape, sharp geomorphic contact development of Ox bow lake, cut off meanders, channel bars and point bars</td>
<td>Sand Silt with admixture of clay and mud. medium to fine micaceous sand</td>
</tr>
<tr>
<td><strong>Older Flood Plain of Yamuna Basin</strong></td>
<td>Medium to Dark tone, linearly stretch belt sharp contact with Recent Flood Plain and Varanasi Older Alluvial Plain. continuous &amp; prominent development of scars which separate it from Varanasi Older Alluvial Plain</td>
<td>Silt and Clay with admixture of Sand and Silt. light Colored mud, clay, silt and sand</td>
</tr>
<tr>
<td><strong>Terrace Zones</strong></td>
<td>Bright tone, irregular boundary outline, sharp contact with Terrace Zones and Varanasi Older Alluvial Plain development of paleo-channels and scars. saline/alkaline soil association is characteristic of Aligarh Older Alluvial Plain</td>
<td>Fine to very fine gray to yellowish brown clay with admixture of sand and silt Aligarh Older Alluvial Formation</td>
</tr>
<tr>
<td><strong>Aligarh Older Alluvial Plain</strong></td>
<td>Uniform tone, arcuate shape, isolated occurrence, depressed relief, loss of hydraulic continuity with parent channel</td>
<td>Fine to very fine gray to yellowish brown clay with admixture of sand and silt Aligarh Older Alluvial Formation</td>
</tr>
<tr>
<td><strong>Scars</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paleo-Channels</td>
<td>Medium to dark tone, curvilinear pattern, Uniform texture</td>
<td>Admixture of Sand and silt. Aligarh Older Alluvial Formation - Older Alluvium Group</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Varanasi Older Alluvial Plain</td>
<td>Light to medium tone, irregular boundary outline. agricultural activity dominant, occurs as oldest unit forming higher level uplands with outliers of Aligarh Older Alluvial Plain</td>
<td>Medium to fine grain. yellowish brown sand with intercalations of silt and clay. Varanasi Older Alluvial Formation - Older Alluvium Group</td>
</tr>
<tr>
<td>Buried Pediment</td>
<td>Light to medium tone, sharp contact with adjacent geomorphic zones, irregular boundary outline, low drainage density and partly internal drainage</td>
<td></td>
</tr>
<tr>
<td>Vindhyan Plateau</td>
<td>Dark tone, linear pattern, structurally controlled drainage, low to medium drainage density, high resistance to erosion</td>
<td></td>
</tr>
<tr>
<td>Structural Hills and Valleys of Delhi Supergroup</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosional Valleys</td>
<td>Centripetal drainage, restricted agricultural practice, rib &amp; furrow topography, low to moderate resistance to erosion - Delhi Supergroup</td>
<td></td>
</tr>
<tr>
<td>Hogback ridges</td>
<td>Tonal banding, linear forms, vegetation cover scanty, parallel drainage &amp; resistance to erosion is high. - Delhi Supergroup</td>
<td></td>
</tr>
<tr>
<td>Cuesta Zones</td>
<td>Bright tone, linear pattern, scattered hill &amp; ridges devoid of vegetal cover, striking NE-SW. sharp contact &amp; topographical level, occur as oldest geomorphic unit - Alwar Group &amp; Ajabgarh Group</td>
<td>Medium to fine grained quartzite with quartz and feldspar.</td>
</tr>
</tbody>
</table>
TABLE - 13 Morphometric analysis of the different micro-watersheds in the study area in parts of Yamuna basin

<table>
<thead>
<tr>
<th>Order</th>
<th>Sengar</th>
<th>Aligarh</th>
<th>Sonna</th>
<th>Karwan</th>
<th>Jamon</th>
<th>Patwaha</th>
<th>Debar</th>
<th>Yamuna</th>
<th>Banganga</th>
<th>Gambhir</th>
<th>Kakund</th>
<th>Kaman</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nu</td>
<td>24</td>
<td>2</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>78</td>
</tr>
<tr>
<td>Rb</td>
<td>12</td>
<td>2</td>
<td>8</td>
<td>2.5</td>
<td>2</td>
<td>6.5</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3.9</td>
</tr>
</tbody>
</table>

where Nu is stream Number, Rb is Bifurcation Ratio, SI is the stream length in kilometers, ML is mean stream length in kilometers, SLR is stream length ratio; DD is drainage density; SF is stream frequency.