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Morphometric and Hydrological Analysis of Hindon River, Uttar Pradesh, India: using Remote Sensing and GIS Techniques

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ABSTRACT

The term morphometric analysis is used for quantitative measurement of landforms to understand the geohydrological characteristics of a drainage basin. Using remote sensing and GIS technology, we identified morphological features and analyzed the characteristics of the Hindon River basin. The river originated in Saharanpur and merged into Yamuna River near Noida, Uttar Pradesh. In this study, Shuttle Radar Topography Mission (SRTM) and Digital Elevation Model (DEM) are used to measure morphological features such as area, alignment, and undulating aspects. The basin morphometry components were drawn using automated extraction tools developed through ArcGIS 10.8 software. Various thematic maps and morphological analysis such as drainage density, slope, undulations aspects, etc., and morphological measurement such as river order, river length, divergence ratio, river frequency, form factor, circulation ratio, respectively etc. were prepared and analysed using the same GIS tool. The basin land cover map was created from the latest available Landsat satellite data (). The basin has a dendritic drainage pattern of up to 5th order, which is mainly controlled by the physiographic and lithological conditions of the area. The shape coefficient ratio is 0.22 while the expansion / contraction ratio is 0.53, indicating that the basin shape is elongated. The results observed in this study can be used for field suitability analysis of soil and to prepare water protection and storm water harvesting structures in the area. Morphological analysis of the Hindon River basin in the study not only provides a well-designed description of the basin's topography, but also helps in identifying and resolving the critical environmental concerns that arise due to the basin modernization.

Keyword: Hindon River, Morphometric, Yamuna River, Watershed

1. Introduction

Morphological analysis is a mathematical representation of the earth surface (Clarke et al., 1996). Watershed morphometry studies provide information on a variety of features and characterize the drainage system of the basin in terms of features (Radiant et al., 1964; Dubey et al., 2015). In the context of the Indian river system, National Institute of Hydrology (1993) studied morphometric analysis of different watersheds and used different mathematical formulas to base on linear, air, and undulating aspects (Dubey et al., 2015).

Quantitative morphometry analysis of the basin can provide information on the hydrological properties of rocks found in the basin. Watershed drainage maps provide a reliable indicator of the relationship between rock permeability and rock type, structure, and their hydrological state (Singh et al., 2014). Remote sensing and GIS based drainage basin assessment has been carried out by number of researchers, scholars and scientists for different landscapes and it is proved to be a very systematic tool for generation of detailed and updated information for characterization of drainage basin parameters (Grohmann et al., 2004; Korkalainen et al., 2007; Hlaing et al., 2008; Javed et al., 2009; Singh et al., 2014; Pankaj and Kumar, 2009).

The recent development in drainage morphometric assessment through geospatial technology for drainage system mapping and their periodic monitoring in GIS environment concluded the utilization of space borne satellite images for extraction of streams and their related features (Singh et al., 2013, 2014; Saha and Singh, 2017). Drainage characteristics of many river basins and sub basins in different portions of the earth have been studied using conventional methods (Horton et al., 1945; Strahler et al., 1957, 1964; Krishnamurthy et al., 1996). Nowadays, GIS based assessment using Shuttle Radar Topographic Mission (SRTM) data has given a detailed, fast, and a low-cost way for analysing hydrological structures (Smith and Sandwell, 2003; Grohmann et al., 2004). The processed DEM was used successfully for generating the stream network and other supporting layers (Mesa et al., 2006; Magesh et al. 2011). Digital elevation models (DEMs) for this region were created to incorporate morphometric parameters such as catchment area, drainage density, drainage sequence, undulations, direction, length, and network diameter.

The geographic and topographical features of the catchment area are important for hydrological studies, including assessment of groundwater potential (Rai et al., 2014). Geology, undulations and climate are the main factors in river systems that function at the basin level (Rastogi and Sharma, 1976). Geographic Information Systems terrain and morphometric parameters of several evaluation methods are used today.

This study aims to use morphometric analysis including linearity, area, and undulation morphometry characteristics to give a an insight into the geo-hydrological features of the drainage basin which ultimately used in the identification of groundwater potential zones and overall supervision of the basin emphasizing more on the status of groundwater. This study will also be useful in preparing the management plan of the Hindan river basin.

2.Methodology

2.1 Study Area

The Hindon River begins in the lower Himalayas from kaluwala khol, barsani fall, Mohand range, shivalik woodland division, Saharanpur area. The stream streams for 291 KMs through six areas (Saharanpur, Muzaffarnagar, Meerut, Baghpat, Ghaziabad and Gautambudh Nagar) After rigorous ground-truthing and talking to locals we found out that it originates from four villages Kothari Bahlolpur,kaluwala pahadipur,kaluwala jahanpur ,naglamafi these are adjacent village where 1st order stream originates all these four streams are also part of Shivalik reserve forest which has shakumbri range and Mohan range. then three rivers originate kaluwala nadi,nagdehi nadi, shahnsara nadi, then there is a fault line where all water goes inside it and after which all river dries out but after 7 km springs pops out. now it has two main feeders which are dhamola nadi which originates from springs , nagdehi nadi joins kaluwala nadi then which is called after a place called khajnawa this river kaluiwala is called hindan. after baghpat it meets kali west and krisni river in a place called barnawa and it terminates at Gautam Budh Nagar to Yamuna basin The Hindon River has two principle feeders, the Hindon River which starts at Kairi Village and joins the Hindon at Barnawa Village, and the Kali River (West) which begins at Dhanakpur Village and joins the Hindon River at Pithlokar.

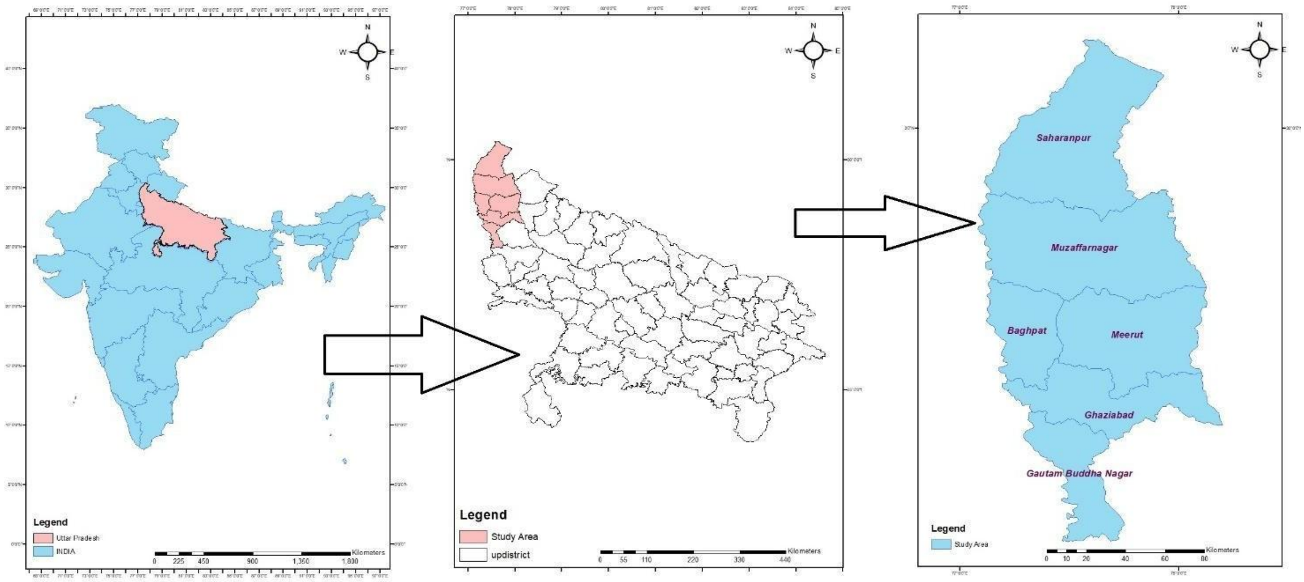

Fig 1: Study Area

2.3. Data and Materials used

Table 1: Data Used

Types of data/software	Details of data/software
SRTM DEM	90 m, Year 2014
Landsat 8 satellite imagery	Dated 30/01/2021
ArcGIS software	ArcMap 10.8

SRTM data is used to extract the network of water body with spatial resolution of 90 meters. Using hydrology tools from ARCGIS 10.8 and performing process like fill, flow direction, flow accumulation, stream order etc. Landsat 8 data is used to calculate NDVI value using band 4 and band 5.

Landsat 8 data of November 2021 is used for calculation of NDVI for Hindan river basin. Band 4 Red (30m resolution) and Band 5 (30m resolution) NIR is used for NDVI calculation.

We will be using ArcGIS software 10.8 for performing morphometric analysis, extracting, mosaicking image and calculation of NDVI.

Table 2: bands of Landsat 8 and its resolution

Landsat 8			
Spectral Band	Use Area	Wavelength	Resolution
Band 1	Coastal/ Aerosol	0.433-0.453 µm	30m
Band 2	Blue	0.450-0.515µm	30m
Band 3	Green	0.525-0.600µm	30m
Band 4	Red	0.630-0.680µm	30m
Band 5	Near Infrared	0.845-0.885µm	30m
Band 6	Short Wavelength Infrared 1 (SWIR 1)	1.560-1.660µm	30m
Band 7	Short Wavelength Infrared 2 (SWIR 1)	2.100-2.300µm	30m
Band 8	Panchromatic	0.500-0.680µm	15m

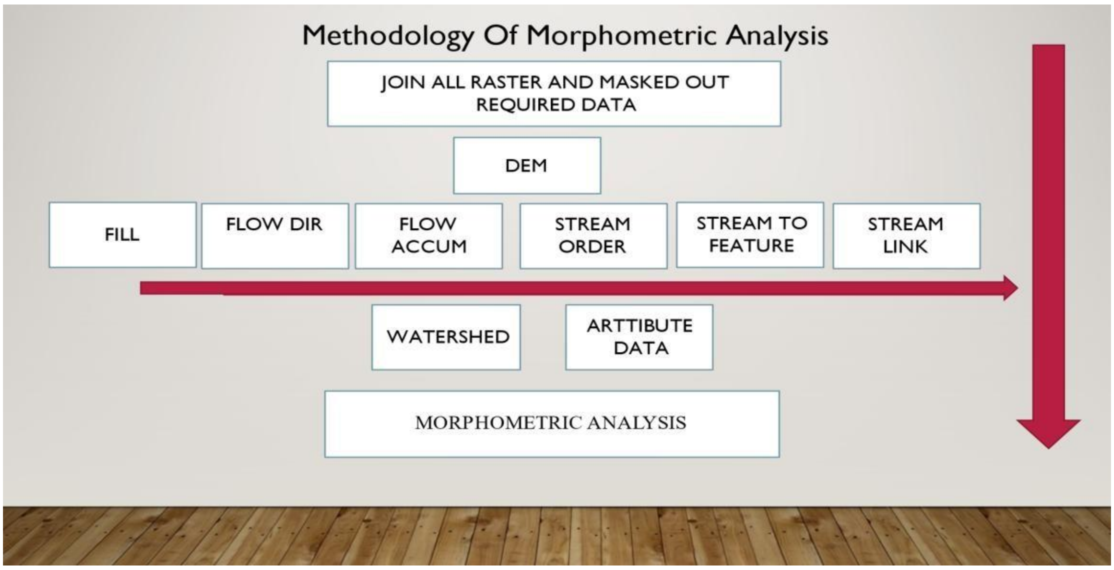

Fig 2: Methodology of Morphometric analysis

Methodology analysis of a river involves DEM data, since we are using SRTM (2014) data which is the best data for performing morphometric analysis of river. Arc GIS 10.8 Hydrology tools are used here to find out all orders of river. The tools which are listed above to find stream order are explained below in brief-:

Fill-: Fills sink in a surface raster to remove small imperfections in the data.

Flow direction-: Creates a raster of flow direction from each cell to its downslope neighbor, or neighbours, using D8, Multiple Flow Direction (MFD) or D-Infinity (DINF) methods.

Flow accumulation:- Creates a raster of accumulated flow into each cell. A weight factor can optionally be applied.

Stream order -: Stream Order Assigns a numeric order to segments of a raster representing branches of a linear network.Accoding to Strahler or shreve.

Stream to Feature Converts a raster that represents a linear network into features that represent the network.

Stream Link Between intersections, assigns unique values to parts of a raster linear network.

Waatershed Any surface area from which rainwater runoff is collected and drained through a common point is referred to as a watershed. It's the same thing as a drainage basin or catchment region. A watershed might be as small as a few hectares for tiny ponds or as large as hundreds of square kilometres for rivers. Sub-watersheds can be found within all watersheds.

Method of stream ordering (optional)

The method used for assigning stream order.

- STRAHLER—the method of stream ordering proposed by Strahler in 1952. Stream order only increases when streams of the same order intersect. Therefore, the intersection of a first-order and second-order link will remain a second-order link, rather than creating a third-order link. This is the default.
- SHREVE—the method of stream ordering by magnitude, proposed by Shreve in 1967. All links with no tributaries are assigned a magnitude (order) of one. Magnitudes are additive downslope. When two links intersect, their magnitudes are added and assigned to the downslope link.

So the tools used in Later we will use table 2 Morphometric parameter and find out various parameters like drainage network, basin geometry, and Drainage texture analysis and relief characterization.

Table 3: Morphometric parameter

Sl. No.	Morphometric Parameters	Formula	Reference
A	Drainage Network		
1.	Stream Order	Hierarchical Rank	Strahler (1952)
2.	Total Stream order	Sum of Stream order	
3.	Stream number (Nu)	Nu = N1+N2+ ……. +Nn	Horton (1945)
4.	Stream length (Lu) (KM)	Length of the stream	Strahler (1964)
5.	Stream length ratio (Lur)	Lur =Lu/(Lu-1)	Strahler (1964)
6.	Bifurcation ratio (Rb)	Rb= Nu/Nu+1	Strahler (1964)
B	Basin Geometry		
7.	Basin Perimeter (P)	GIS software analysis	Schumm (1956)
8.	Basin Length (Lb) (KM)	GIS software analysis	Schumm (1956)
9.	Basin Area (KM2) (A)	GIS software analysis	Schumm (1956)
10.	Form factor Ratio (Rf)	Ff = A / Lb2	Horton (1932)
11.	Elongation Ratio (Re)	Re= 2√(A/π)/L	Schumm(1956)
12.	Shape Factor Ratio (Sf)	Sf=Lb2/A	Horton (1945)
13.	Circularity Ration (Rcn)	Rcn = A / P	Strahler (1964)
14.	Relative Perimeter (Pr)	Pr = A / P	Schumm (1956)
C	Drainage Texture Analysis		
15.	Drainage Density (Dd)	Dd = Lu / A	Horton (1932)
16.	Stream Frequency (Fs)	Fs = Nu / A	Horton (1932)
17.	Drainage Intensity (Di)	Di = Fs / Dd	Faniran (1968)
18.	Length of overland flow (Lo)	Lo= 1/Dd×2	Horton (1945)
D	Relief Characterization		
19.	Maximum Basin Height (Z) (m)	GIS software analysis	
20.	Minimum Basin Height (z) (m)	GIS software analysis	
21.	Total Basin relief (H) (m)	H = Z - z	Strahler (1952)
22.	Relief Ratio (Rhl)	Rhl = H / Lb	Schumm (1956)
23.	Relative Relief Ratio (Rhp)	Rhp = H * 100 / P	Melton (1957)
24.	Ruggedness Number (Rn)	Rn = Dd * (H / 1000)	Patton & Baker (1976)
25.	Melton Ruggedness Number (MRn)	MRI = H / A^0.5	Melton (1965)

3. Result and Discussion

Here, we have 3 Dems who are mosaic together because the basin area is large. (As you can see in fig 3). Then we have used arc hydrology tools to find outflow direction, which will be necessary to find out-stream orders. (As you can see in fig 4).So the final outcome is there are total 5 stream orders in Hindon river basin (as you can see in fig 5).Total area cover by stream is 5204 KM and Mean Bifurcation ratio (mbr)is 2.7307.

So here we have calculated all four aspects of river basin

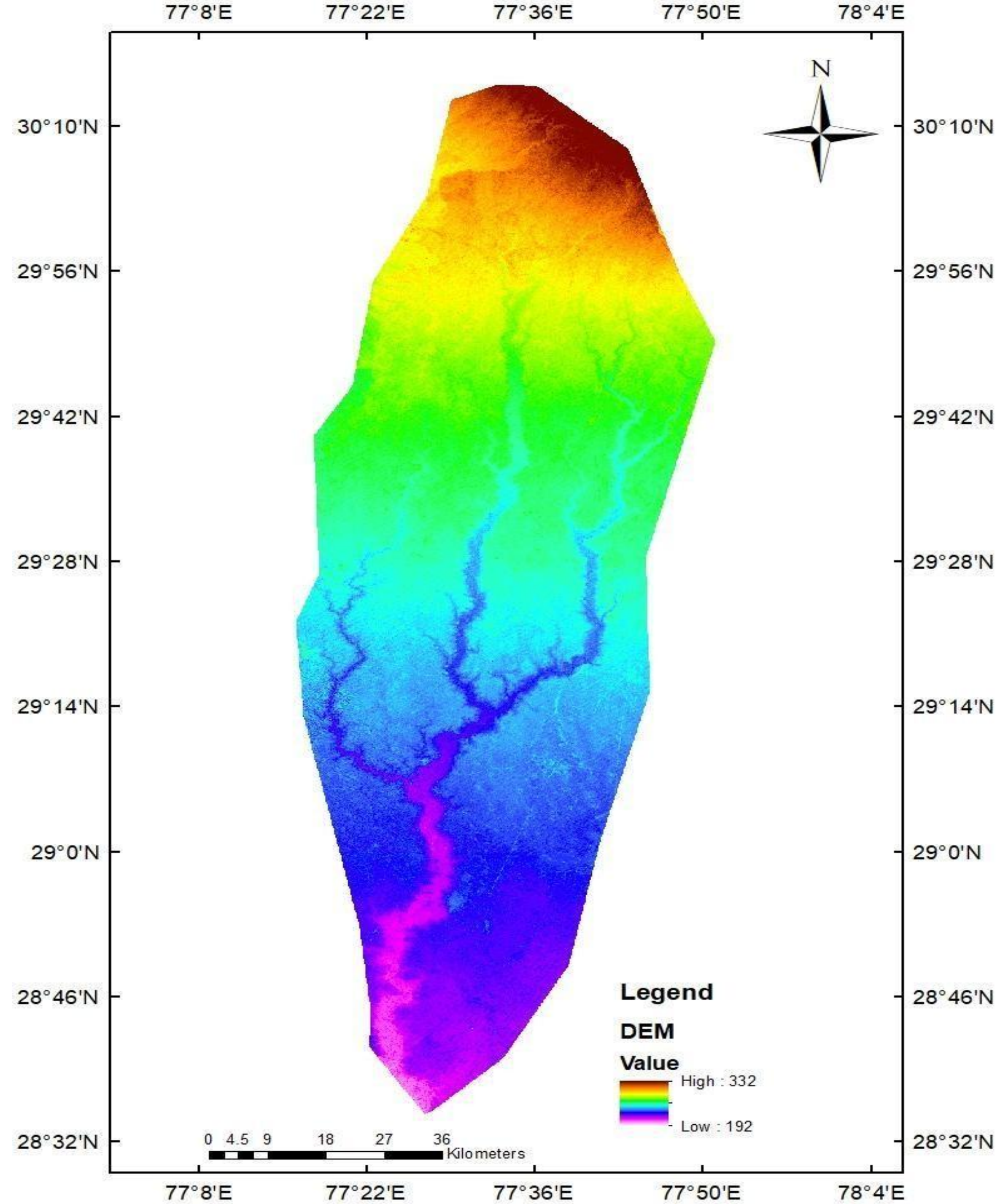

Fig 3: Digital elevation model of Hindon River basin

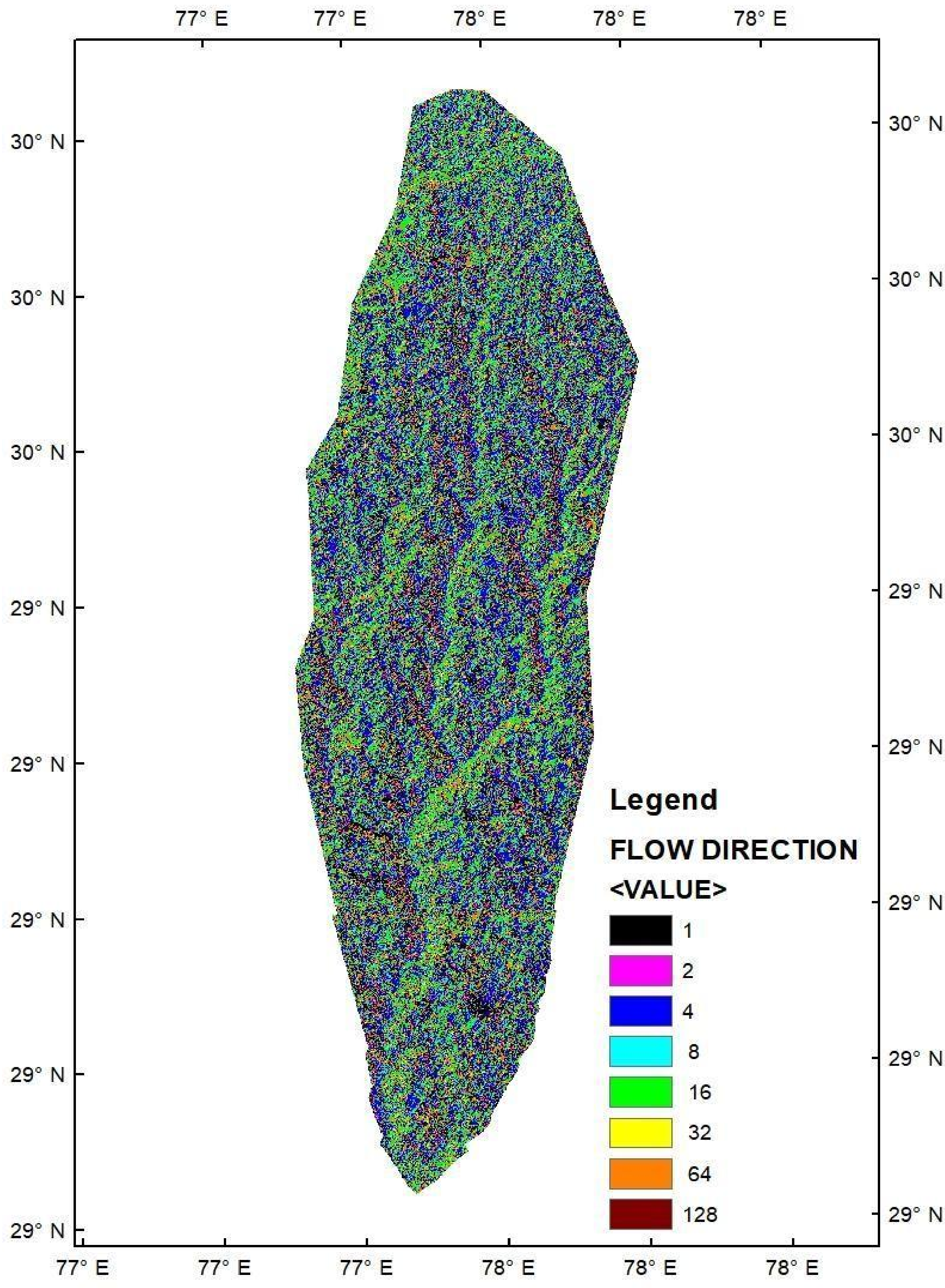

Fig 4: Flow direction of Hindon River

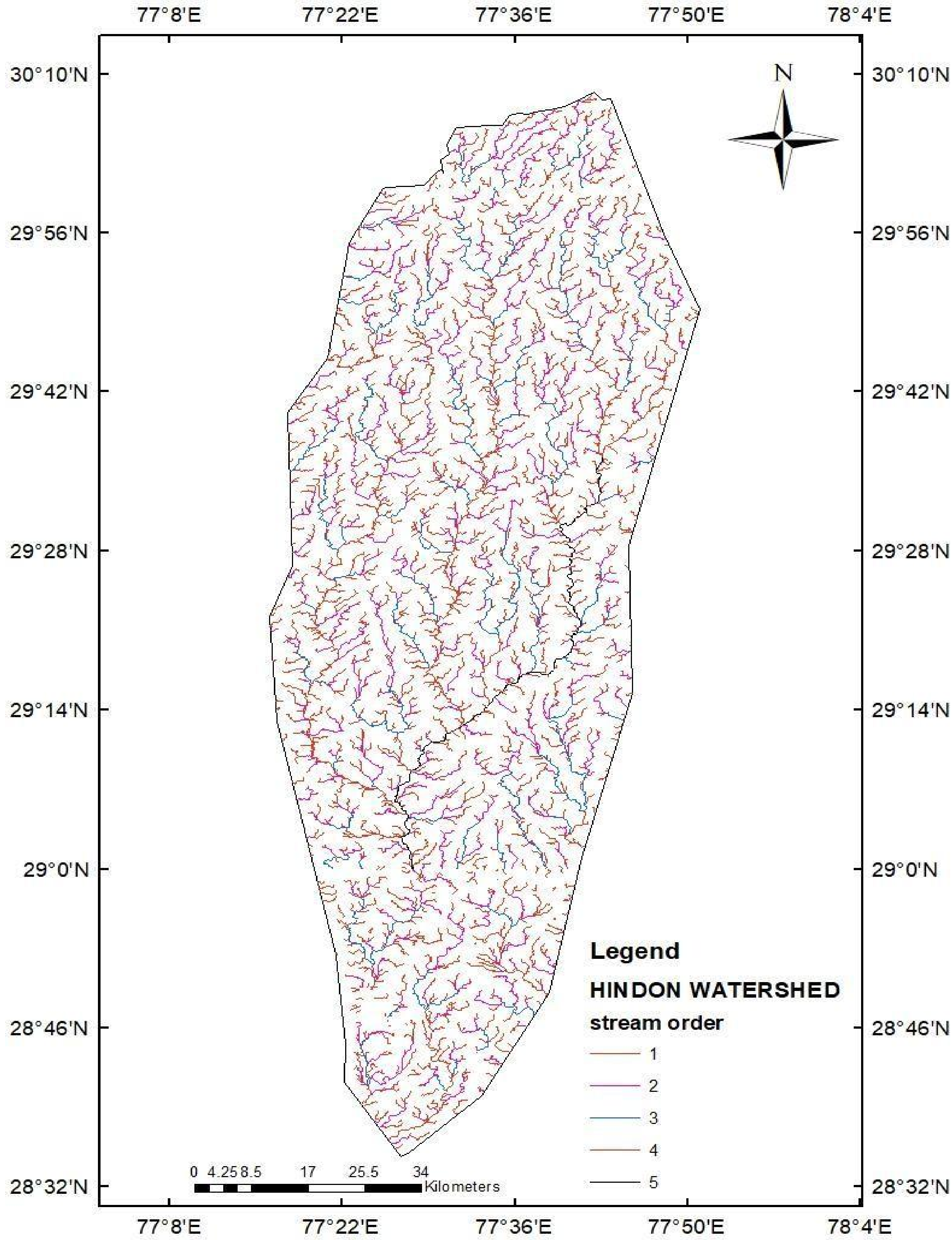

Fig 5: Stream order of Hindon River

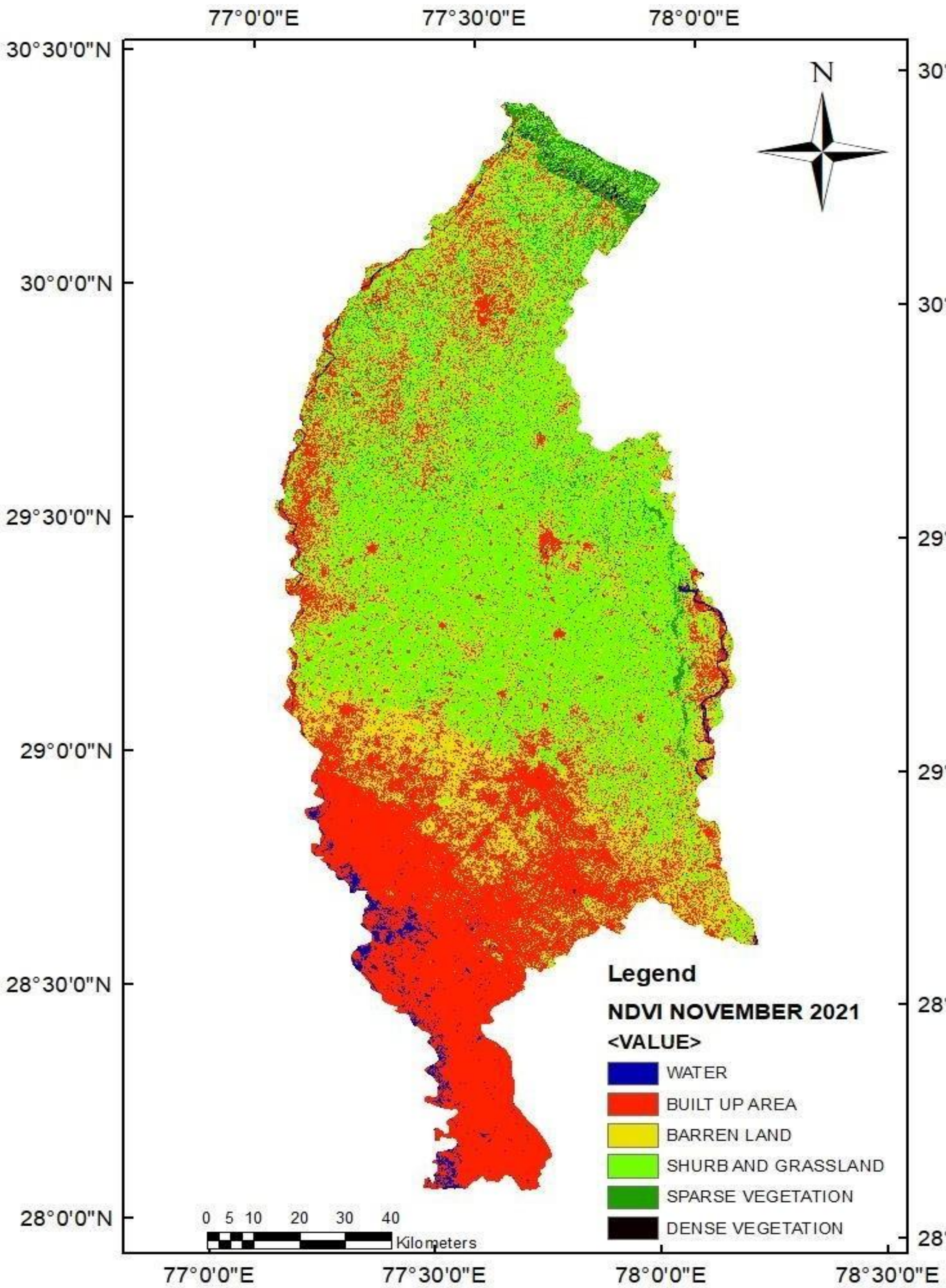

Fig 6: NDVI of Hindon river basin area

NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI)

The normalized difference vegetation index is a simple graphical indicator used to analyze remote sensing measurements on a space platform, assessing whether or not the observed target contains live green vegetation.

NDVI= NIR-RED/NIR+RED
FOR LANDSAT, NDVI=BAND 5- BAND 4/BAND 5+BAND4

As you can see in figure 6, most of the Built-up area is in Ghaziabad and Noida; as a result, the most affected part of the Hindon river basin is in both districts respectively.

Stream Order	Stream number (Nu)	Stream length (Lu) (m)	Mean stream length (KM) (Lsm)	Stream length ratio (Lur)	Bifurcation ratio (Rb)
I	4049	267735	661		2.15946
II	1875	133698	713	0.49936	1.892028
III	991	689223	695	0.51550	1.17556
IV	843	402890	478	0.58455	5.69594
V	143	97305	657	0.24151	2.73075
Total = 5	Total = 7906	Total (KM)=5204	Total LSM(KM)=3.204	Total=1.84094	Mean (Rbm) 2.7307

Compactness Coeffcient	Shape Factor Ratio	Fitness Ratio	Length Area Relation	Lemniscate's	Circularity Ration	Relative Perimeter
1.3660	4.5789	0.4450	274.3643	4.57894	16.9104	16.9104

Basin Perimeter (KM)	Basin Length (Lb) (KM)	Basin Area (KM2) (A)	Form Factor Ratio (Rf)	Elongation Ratio (Re)	Circulatory Ratio (Rc)
391	174	6612	0.218390805	0.52731756	0.543487042

Drainage Density (Dd)	Stream Frequency (Fs)	Drainage Intensity (Di)	Length of overland flow(Lo)
0.787053842	1.195704779	1.519215988	0.635280553

Relief Ratio	Relative Relief Ratio	Ruggedness Number (Rn)	Melton Ruggedness Number (Mrn)
0.113402062	8.439897698	0.050134128	0.405833149

Strahler proposed the procedure of stream requesting in 1952. Stream request increments when surges of a similar request are met. The crossing point of a first request and second request connection will stay a subsequent request interface instead of making a third request interface. Hindon waterway bowl has fifth order of stream and has the absolute length of all requests for streams is 5204 KM. The proportion between the two sets of stream areas; is lower than the following higher demand, called Bifurcation proportion. Assuming the bifurcation proportion of any drainage is low, chances of flooding builds, and the progression of water will aggregate, streams explicitly instead of spreading (Lodhi et al., 2017). The bowl limit is portrayed from SRTM DEM with the assistance of ArcGIS 10.8 programming. Sections of streams determine stream recurrence according to the unit region of a bowl. Drainage thickness is the proportion of absolute stream length of the bowl to-bowl area. The waste thickness of Hindon is 0.78 KM2. Help proportion is the proportion between the bowl alleviation and bowl length. It investigates the landscape inclination of a drainage bowl and indicates the force of erosional processes working on slants.

4. Conclusion

Remote sensing and GIS strategy is a powerful procedure in drainage extraction through DEM information. The hydrological examination completed for the Hindon watershed affirms that the watershed has low help and stretched shape. Drainage organization of the watershed shows as basically dendritic sort which determines the homogeneity in surface and absence of actual control and understands fathoms different landscape boundaries like nature of the spillover, penetration limit, bedrock. So forth, High goal satellite information additionally helps in various geographical and climatic circumstances for better comprehension of the situation with landforms and different boundaries like metropolitan preparation, transportation arranging, biological monetary drafting, natural issues, and water assets the executives. So forth, The outcomes seen in the current work can be utilized for site reasonableness examination of soil and water preservation designs and downpour water collecting nearby. Hence, these boundaries were acclimatized with other hydrological data. Morphometric examination of the Hindon watershed in India offers not just an all-around planned depiction of the bowl landforms and safeguards the contamination of the stream.

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