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A geo-spatial inter-relationship with drainage morphometry, landscapes and NDVI in the context of climate change: a case study over the Varuna river basin (India)

Pawan Kumar Chaubey[1] · Arnab Kundu[1] · R. K. Mall[1]

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Abstract Watershed development and management is essential for the present as well as future constancy of water resources in a river basin. Watershed prioritization, planning and development are depending on the morphometric analysis of a basin. The drainages of a basin are mainly influenced on geomorphic appearances which show a dynamic role for monitoring the basin's hydrology as per topographical characteristics. In this paper, the morphometric study was characterized by set of parameters i.e. linear, aerial and relief aspects of Varuna river basin (India) with the integration of geo-spatial techniques. The mean annual rainfall, Normalized Difference Vegetation Index, Digital Elevation Model and Land Use/Land Cover (LULC) were taken into account for this study. The annual rainfall pattern and its percentage departure were shown by high frequencies of drought conditions while the seasonality index depicts that mostly rainfall occurred in less than 3 months. Moreover, indices such as Standardized Precipitation Index and Standardized Precipitation Evapotranspiration Index were used to conclude past extreme drought conditions (1996–2002, 2010–2017) over the basin. LULC changes were monitored over the south-east and north-west part of river basin during the period 1977 to 2013. The results revealed that an increasing trend of urbanization was monitored due to a decrease in agricultural land by 40.71% in the lower part of the basin. Moreover, the overall study can be helpful to assess the quantitative depiction of basin geometry as well as land use pattern for future development of agricultural growth.

Keywords SPI · Seasonality index · SPEI · Morphometric analysis · NDVI · Rainfall · LULC

✉ R. K. Mall
mall_raj@rediffmail.com; rkmall@bhu.ac.in

[1] DST-Mahamana Centre of Excellence in Climate Change Research, Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, Uttar Pradesh, India

1 Introduction

The Varuna river basin is surrounded by south to north as Vindhyan rocks and Gomati river basin forming the peripheral bulge in the central alluvial plain of the Indo-Gangetic Basin (IGB) [1, 2]. The fine particles like sand, silt and clay formed interfluves surface where river flow deeply incised along narrow valley [2, 3]. Varuna river and its sub-watersheds are one of the foremost controlling drainage systems of Varanasi city as well as controls groundwater flow over the adjoining area [4, 5]. Owing to fast urbanization and in-depth pumping, groundwater is depleting rapidly over parts of the basin [6]. Hence, Varuna river is deteriorating continuously forming as a drain with carrying domestic wastes and sewerage of dense urbanized Varanasi city that sound for instant attention of watershed management in the study area [2, 3]. Tectonic activity and climate change are responsible for drainage modification and transformation over time. The river network forces quantitative morphometric analysis over the interfluves of river basin [2, 7]. Dynamic flow and structural design are mainly controlled by geomorphic parameters of basin [8].

A natural disaster in an aspect of extreme climate events such as drought shows large impact over the water resources [9, 10]. However, Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) are the tools for computing the severity of drought events which are statistically based on the

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probability distribution of long-term precipitation time series. Subedi et al. [11] used multi-scalar drought indices, i.e. SPI, SPEI for long-term drought conditions by rainfall deficit on monthly and annual timescale. Dai [12] analyzed meteorological drought indices in perspective of global warming through observations and different models. Dutta et al. [13] evaluated the SPI based study for meteorological as well as agricultural drought scenario over the semi-arid and arid regions of India.

Watershed prioritization based on morphometric parameters and geo-information techniques were studied by various people [14]. Prakash et al. [15] established a relation between different linear and aerial parameters for morphometric analysis of river basin. The Normalized Difference Vegetation Index (NDVI) is a much-admired tool and has been used by several researchers by their distinctive studies [16–18]. Emiru et al. [19] focused on the long-term impacts of anthropogenic activities on rainfall, LULC and NDVI dynamics over the study region. The NDVI and LULC are important parameters and have been used for determining the urbanization process in the basin. The greenness results were associated with NDVI for the onset date of early spring [20, 21]. Sahoo et al. [22] explained how GIS is essential for land use/land cover transformations, agricultural activities and water resources management in the context of climate change. Rainfall is another important climatic factor varied by Digital Elevation Model (DEM) of the river basin and influenced the NDVI [23–25]. Prakash et al. [2] studied the necessity of scientific approach to the sustainable basin management for the Varuna basin. In addition, Raju et al. [6] examined the high pollutant value of Fluoride and Nitrate (> 1.5 mg/l) over the catchment area of Varuna basin. In due course of time, the streams of the drainage basin of the Varuna river worsened and transforming over a drain, carrying domestic waste or sewerage and industrial debris like toxic, chemical, industrial solid and the municipal solid waste of Allahabad and Varanasi city. Furthermore, the current environmental status of a region and on-going adaptations in terms of big urban growth could be better appreciated by the analysis of spatial and temporal change in land use planning [26].

Decreasing trends of rainfall over the basin could be one of the factors for the low flow of water in the river Varuna. The changes of NDVI in and around Varuna river basin were analyzed. Keeping in view of the above facts, in this paper, it is aimed to carry out as follows:

- Characteristics of rainfall Seasonality Index over the Varuna basin
- Evaluation of drought events by using extreme indices SPI and SPEI
- Long-term changes of rainfall with NDVI
- Morphometric analysis for long-term periods over the basin
- LULC changes in and around the Varuna basin

2 Materials and methods

2.1 Study area

The Varuna river rises at 25°27′N and 82°18′E near Mau Aima (Pratapgarh district, Uttar Pradesh), flows east to south-east for approximately 128 km, and joins the Ganges at 25°19′46″N to 83°02′40″E in downstream at Varanasi, Uttar Pradesh, India. The study area lies between the 25°21′46.89″N to 25°21′44.88″N latitudes and 82°55′22.708″E to 82°58′28.33″E longitude (Fig. 1). The basin is the influent or tributary of the Ganga River that has current direction from west to east before joining the Ganga at the Saray Mohana near Rajghat, Varanasi, Uttar Pradesh, India.

2.1.1 *Geological, geomorphological and hydrological setting over the Varuna basin*

Geologically, Varuna river basin belongs to the Indo-Gangetic plain underlain by Quaternary alluvial sediments of Pleistocene to recent age and has clay-kankar with meander river deposits [6]. The geomorphology suggests that the Varanasi district is highly agriculture dependent area at lower Varuna basin located in the central Ganga plain. The agricultural and urbanization activities have a significant influence on the quality of groundwater over the study region [6]. Hydro-geologically, the Varuna basin suggests that in close proximity to surface groundwater only under water table condition, while deeper aquifers occur in semi-confined to confined conditions. In the basin, aquifer level remains semi-confined and confined condition. Rainfall is the only source to recharge groundwater in the Varuna basin [6].

2.2 Datasets

The data for current research is obtained from CGIR-CSI, ESRI, USGS, NOAA, Toposheet map (SOI), Earth Explorer (USGS) etc. LULC maps were prepared based on Landsat-MSS/TM/ETM + satellite imageries for 1977, 1990 and 2013. LULC pattern was analysed for 40 years period of time. NDVI analysis has been carried out using Landsat satellite and ArcGIS environment. The morphometric analysis was studied by SRTM-DEM with 90 m spatial resolution in GIS environment (Fig. 2a–e). The rainfall pattern and Seasonality Index (SI) were estimated

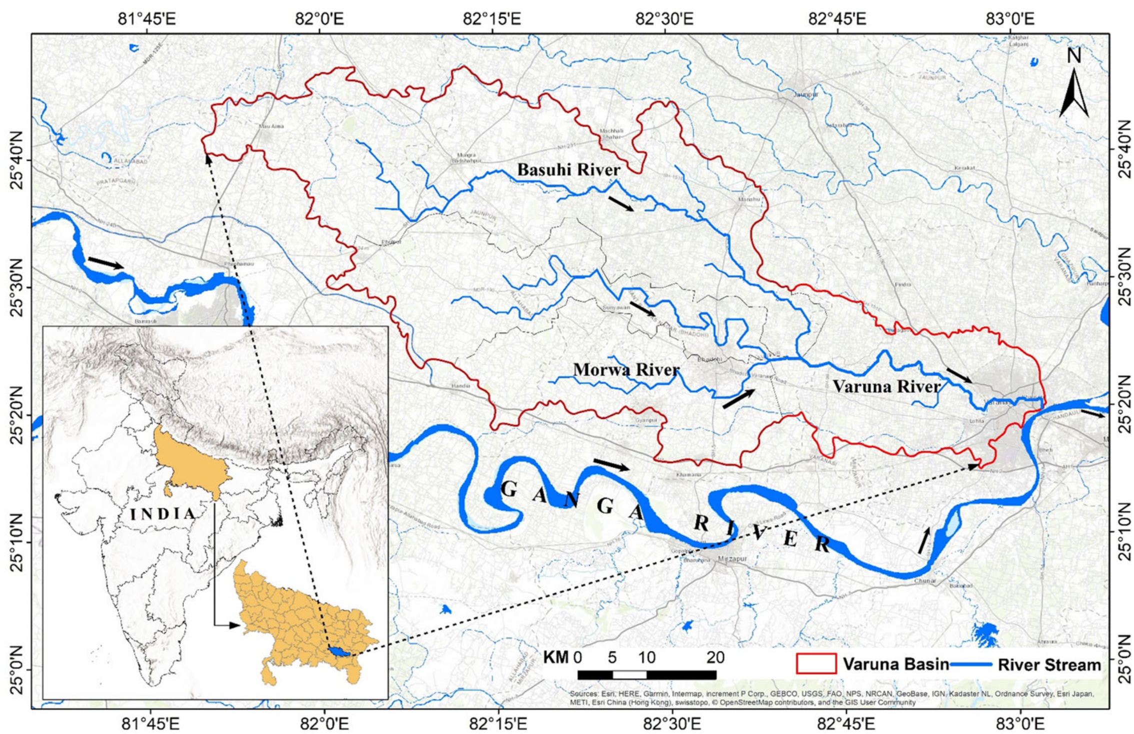


Fig. 1 Varuna river basin and its sub watersheds

using the long-term (1960–2013) rainfall data obtained from the India Metrological Department (IMD) over the Varuna river basin (Fig. 3a–d). We were taken the Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) for assessing dryness condition derived from IMD and Tropical Rainfall Measuring Mission (TRMM) monthly rainfall over the basin (Table 1).

2.3 Methodology

2.3.1 Climatic approach

2.3.1.1 Extreme indices To examine the metrological drought stages caused by scarcities in rainfall over the river catchment area there has been two drought indices such as Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) are used as the probability distribution of long term rainfall time series [27]. SPI and SPEI have been calculated by using the R package based on gamma distribution to 4 and 6 months running mean of rainfall timescales. Estimated SPI values were higher than − 3 are considered as extremes drought events while values between − 1 and − 2 are considered as moderate extreme events.

2.3.1.2 Departure The departure ($Departure_i$) of rainfall for an individual year was expressed as:

$$Departure_i = \mathrm{rf_i} - \overline{\mathrm{rf}} \quad (1)$$

where ($\mathrm{rf_i}$) = Annual rainfall for an individual year; ($\overline{\mathrm{rf}}$) = Average of long term annual rainfall.

2.3.2 Seasonality index (SI)

SI which helps in determining the monthly rainfall distribution on temporal scale calculated by equation:

$$\mathrm{SI} = \frac{1}{\mathrm{R}}\sum_{n=1}^{12}\left|\overline{\mathrm{X_n}} - \frac{\overline{\mathrm{R}}}{12}\right| \quad (2)$$

here $\bar{\mathrm{X}}_\mathrm{n}$ = mean rainfall of month n and $\bar{\mathrm{R}}$ = mean annual rainfall.

2.3.3 Geospatial approach

2.3.3.1 Normalized difference vegetation index (NDVI) The NDVI is calculated by the quantity of reflectance in near-infrared and red bands of the electromagnetic spectrum and is a proficient indicator for assessing vegetation dynamics. NDVI is calculated by the reflectivity of the bands channel of Landsat imagery that is Red (R) (0.64–

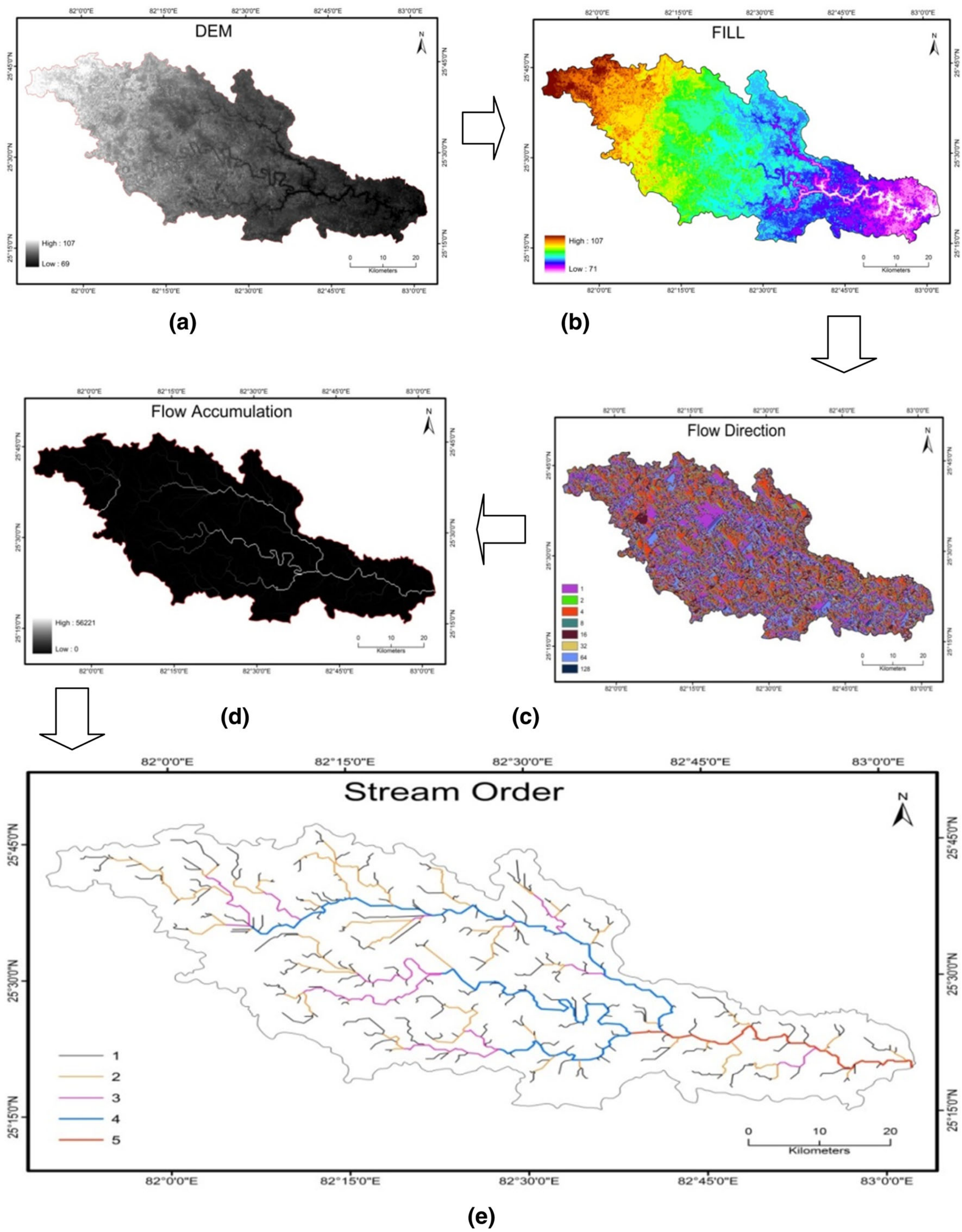


Fig. 2 Extraction of stream network by spatial-hydro procedure in **a** DEM **b** Fill **c** Flow direction **d** Flow accumulation **e** stream order over the Varuna basin

0.67 μm) and near-Infrared (NIR) light (0.85–0.88 μm) [20, 28] (Eq. 1).

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{R})}{(\mathrm{NIR} + \mathrm{R})} \tag{3}$$

NDVI mainly ranges from − 1 to + 1 where the areas devoid of any vegetation give a negative value or a value close to zero means no vegetation and a value close to + 1 (0.8–0.7) represents healthy vegetation [20].

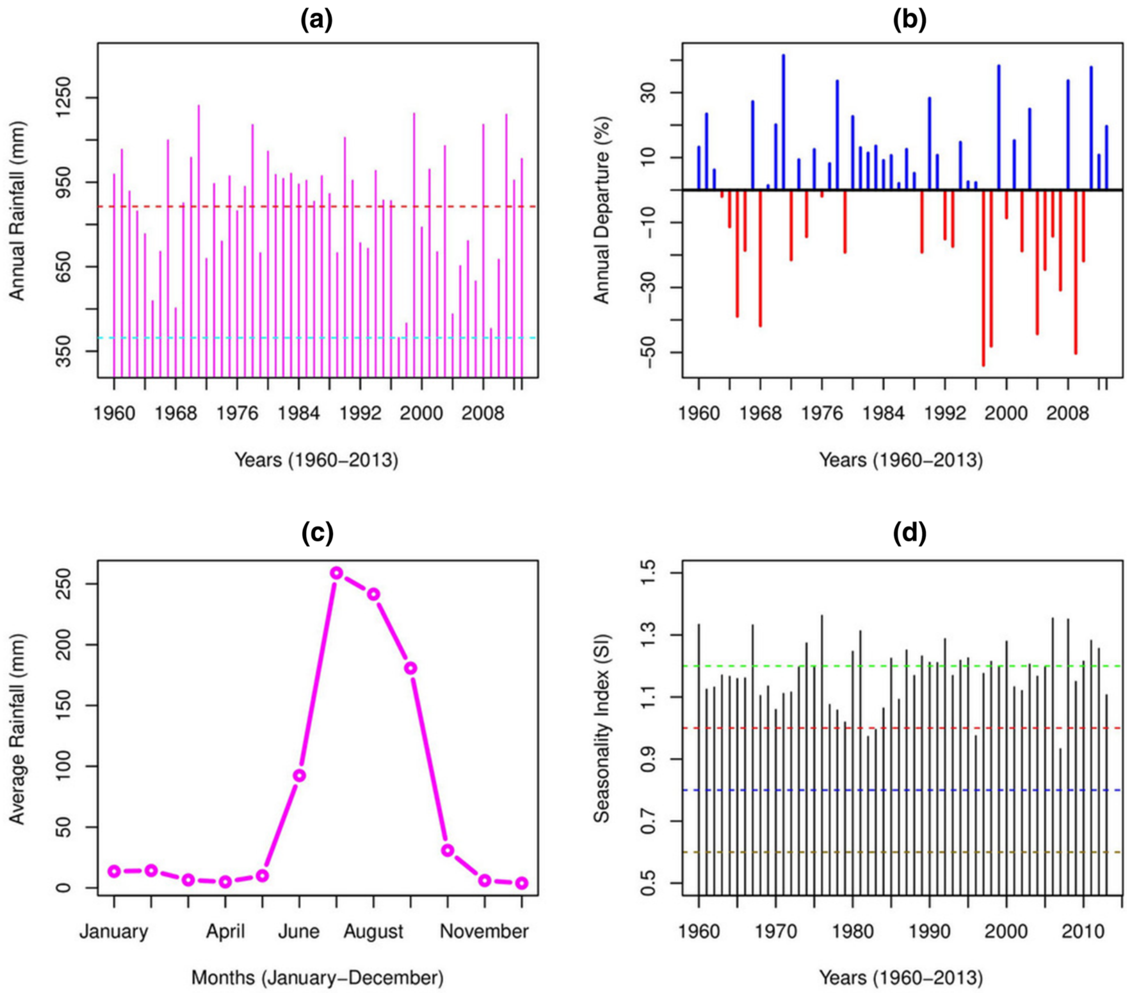


Fig. 3 Rainfall characteristics over Varuna River basin **a** Annual rainfall series **b** annual rainfall departure series **c** annual cycle **d** seasonality index

Table 1 Specification of data sets

Sl. no.	Product	Period	Spatial resolution	Web link
1.	SRTM-DEM	2000	90 m	http://srtm.csi.cgiar.org/
2.	Landsat-MSS/TM/ETM+	1977, 1990, 2013	60 m/30 m	https://earthexplorer.usgs.gov/
3.	*Rain gauge products* IMD	1960–2013	0.25 × 0.25	http://www.imd.gov.in
4.	*Satellite-based precipitation* TRMM 3B42v7	1998–2017	0.25 × 0.25	https://earthdata.nasa.gov/

2.3.3.2 Drainage morphometry The study examined the quantitative river morphometry integrated with geo-spatial tool over the Varuna river basin. Basin morphometry clarified the size and drainage geometry to the devolution of water and sediment load through the stream. The degree of drainage basin depends on the quantity of water yield, length, shape and relief affected the rate of water discharged from the river basin [29]. The morphometric interpretation was estimated by parameters like stream order (S_u), stream length (L_u), bifurcation ratio (R_b), basin length (L_b) as linear aspect, Sinuosity Index (S_i), drainage density (D_d), stream frequency (F_s), elongation ratio (R_e), circularity ratio (R_c) as aerial aspect and major relief parameters viz. relief ratio (R_{hl}), Dissection Index (Di_s), Ruggedness number (R_n) were calculated using mathematical formulae [30].

2.3.3.3 Land use/land cover (LULC) Generally, LULC represents the thematic classifications of the earth's exterior that capture biotic and abiotic assets and that are strictly stressed to the environmental circumstance of land areas which helps for the conservation of land and water resources management in a basin [2, 21]. The most notable changes include reductions in breadths of the river streams with increases in built-up areas and industries over the SE to NW direction due to the continuous degradation of the cultivated land and water bodies.

3 Results and discussion

3.1 Rainfall distribution

Annual rainfall over the basin was heterogeneous with large variation in temporal distribution with annual average 863.9 mm (Fig. 3a). The maximum rainfall was observed 1222 mm in 1971 while minimum rainfall was 397.8 mm in 1997. The high variability in the temporal distribution of rainfall was intermittent relation with runoff over the basin. Figure 3b showed the annual percentage departure of rainfall over the basin, and it was calculated by subtracting the annual rainfall for an individual year (rf_i) with an average ($\overline{rf}$) for the period of 54 years (1960–2013). The $Departure_i$ of rainfall for an individual year was computed from Eq. (1). The blue ticks represented the surplus rainfall while red one presented the percentage deficit of rainfall with mean annual rainfall (1960–2013). It was found that since 1988, there was a percentage deficit of rainfall in drier periods. Also, large intensity of rainfall departures was observed with most of the years having more than 30% departure. Figure 3c showed annual trends of rainfall (average) of IMD data over the basin. The rainfall peaks were raised in the month of July and August (an average of < 250 mm $month^{-1}$) and started decline in September. The summer monsoon months (June–July–August–September) were shown a large variability of rainfall from very low to high with respect to all India average ISMR rainfall [31].

3.2 Seasonality index (SI)

Seasonal climate variability was carried out using Seasonality Index (SI) [32] which helps in determining the monthly rainfall distribution on the temporal scale (Eq. 2).SI varies on scale of 0 to 1.83 where zero represents the minimum value reflecting an equal distribution of rainfall among all the months while maximum value 1.83 represents total rainfall in 1 month only. Figure 3d represents the SI histogram which depicts that rainfall over Varuna generally occurred in 3 or fewer months. The rainfall regime showed minimum SI (0.93) value reflecting seasonal with long drier periods in 2007 while maximum (1.36) was found in 1976. Most of the year showed SI having > 1.0. Moreover, the basin was more prone to dry periods rather than surplus water condition leading to more frequency of drought.

3.3 Evaluation of dryness condition using climate extremes indices

Hydrological and meteorological drought condition mainly originated owing to variability in weather and climate state over timescales, caused by below-average rainfall in a certain region. Standardized Precipitation Index (SPI) is a widely used index to characterize meteorological drought in the aspect of rainfall on a range of timescales [27]. Figure 4 showed climatic extremes which defined as statistical indices for the climate impact analysis. As per Mckee et al. [33], estimated SPI from IMD showed severe drought events over the catchment area during monsoon season ($SPI\_4 < -3$) i.e. 1972, 1984, 1996–1998, 2001–2003, 2005–2007, and 2009–2010 while TRMM indicated the recent droughts stage of the study area, i.e. $SPI < -2$ include: 2002, 2007, 2016–2018 (Fig. 4a, c). Our purpose was to calculated both rainfall with potential evapotranspiration using SPEI which acted as a widely extension of the SPI. Annually, SPEI was estimated by IMD, and TRMM derived datasets that indicated the prolonged droughts as $SPEI < -1.5$ from 1996 to 2018 which was led to the longest hydrological drought (i.e., soil moisture deficit) over the basin (Fig. 4b–d).

3.4 NDVI analysis

The spatio-temporal variation of NDVI was high in western and northern part of the Varuna basin while the decreasing trend was observed in the south-east region of the basin. The rainfall variation as climate indicators plays a vital role in the changes of vegetation cover in the basin. NDVI value indicates the vegetation dynamics in the middle and lower catchment of the basin which was crucial for the ecological stability of the whole watershed. The leading vegetation types were agricultural land and grassland which can sturdily control the eco-environmental status of the basin [24]. Though the basin has experienced a change in its landscape and the majority of the W3 and W2 watersheds were manifested with healthy vegetation due to

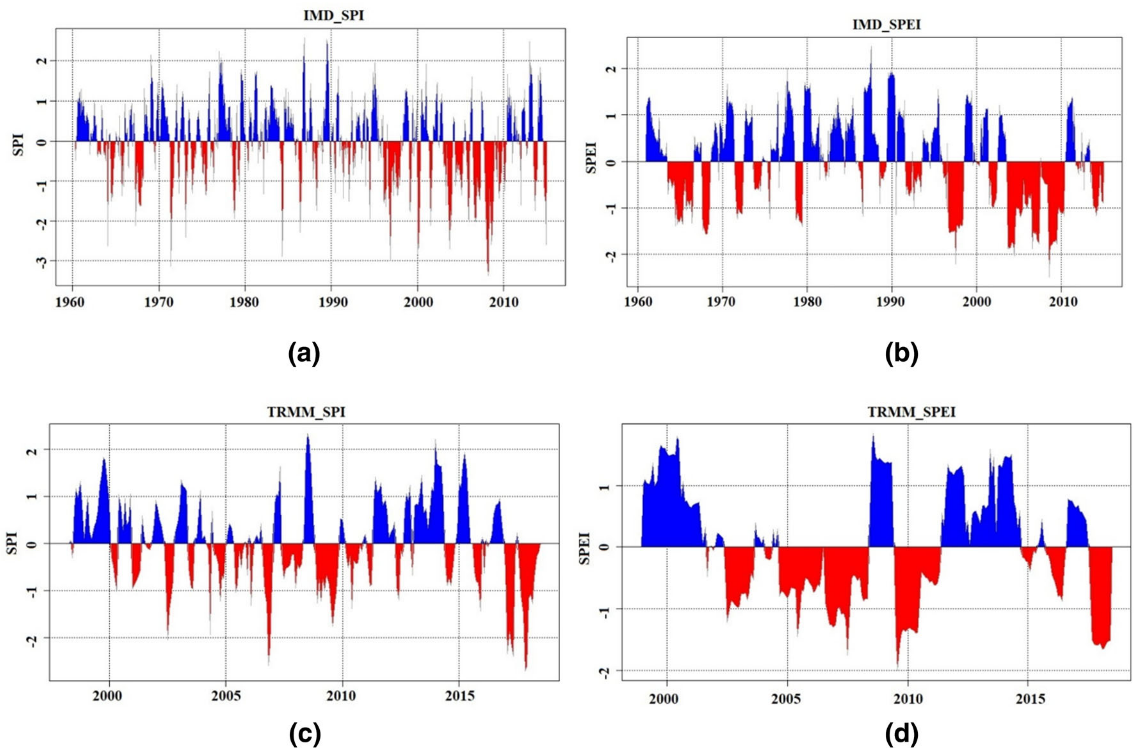


Fig. 4 Standardized precipitaion index (SPI) and standardized precipitation evapotranspiration index (SPEI) estimated based on 4 (monsoon) and 12 (annual) months running mean for IMD (1960–2015) (**a**–**b**), and TRMM (1998–2018) (**c**–**d**) respectively

the existence of grass and agricultural cropland in the basin. The central western part of the basin had shown a positive trend of NDVI. While the eastern part of basin areas shown a negative trend of NDVI values due to the areas are covered with industrial waste materials mixed with settlements, industries, agricultural practices, barren lands indicating the imperviousness (Fig. 5a, b). Furthermore, the NDVI values found in the range between + 0.83 to − 0.05 and + 0.49 to − 0.07 of 1990 and 2017 respectively, that show the decrement of average gap 0.78 to 0.32 indicates 40.71% of vegetation cover in the Varuna river basin [using Eq. (3)]. This variation influences by the sharp negative trends (− 0.06) of rainfall in between the years 1963 to 1969, 1971 to 1977 and 2003 to 2013 (Fig. 6). The less NDVI can decline the local ecosystem stability, which can accelerate soil erosion, resulting in the reduction of river or water quality [16].

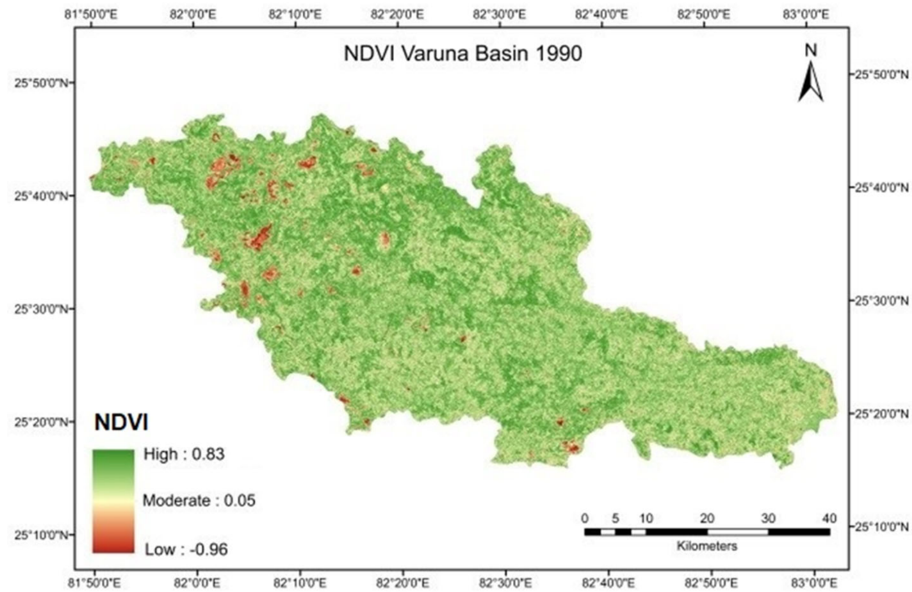
3.5 Drainage network analysis of Varuna basin

3.5.1 Linear aspects (La)

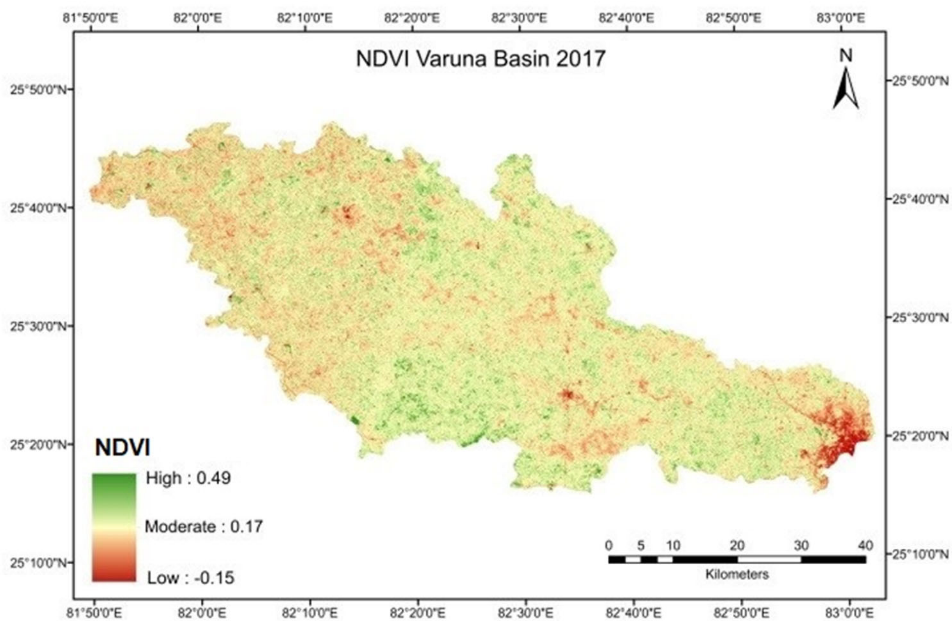
The stream segment of the Varuna river has been identified as 292 with 5th Stream Order (Su) whereas watersheds Basuhi and Morwa river as 4th order were estimated as per Strahler [34] method (Table 2). A large number of first-order streams over the study area indicated the intensity of permeability and infiltration [35]. Stream Length (Lu) was calculated and characterized regions with abrupt slopes and better textures based on Horton's law. Bifurcation Ratio (Rb) was estimated from 3 to 4.5 (Table 2), as a degree of branching within the hydrographic network [36, 37] and this type of anomalies was reliant upon geological and lithological development of the drainage basin [34, 38]. Low Mean Bifurcation Ratio (Rbm) of the main channel (0.98) designed that drainage pattern over the basin was typical without any structural disturbances [37–39]. Bifurcation index be able to provide useful information on erosive processes and the degree of evolution of basin [36]. Rho Coefficient (ρ) (0.16) was a significant parameter relating drainage density to physiographic development of a watershed [40] (Table 2).

3.5.2 Aerial aspects (Aa)

Length of the Main Channel (Cl) had been examined (178 km) in the GIS platform (Table 3). Moreover, the length of the basin (Lb) was estimated 128.63 km, as the longest dimension equivalent to the main drainage line, i.e. distance between origins to the mouth of the river [41]. The highest value of lemniscates (k) was calculated as 4.80 (Table 3), which revealed that watershed captures the



(a)



(b)

Fig. 5 NDVI changes through **a** 1990 to; **b** 2017

maximum area with a large number of higher stream order [42]. As per Horton [43], Form Factor (Ff) was estimated at 0.21 and indicated that basin shape was elongation in nature (Table 3). Furthermore, the estimated value of Elongation ratio (Re) (0.52) was useful for hydrological consequences in contrast to circular catchments [44]. In the present study, the texture ratio of the basin was 0.54 (Table 3). Dimensionless Circularity Ratio (Rc) (0.24) signified that watershed was not much elongated in shape (Table 3). The compactness coefficient (Cc) was 2.04. As per Melton [45], Fitness ratio (Rf) (0.42) was the ratio of main channel length to the length of the watershed perimeter, which measured topographic fitness [46]. The wandering ratio of the basin was estimated 1.38, while its sub-watersheds were 1.26, 1.68 and 1.44 respectively, which specify that river outright and the basin was plain in nature (Table 3). Sinuosity Index (Si) of the Varuna river basin (1.44) was estimated by Muller [47] and its sub-

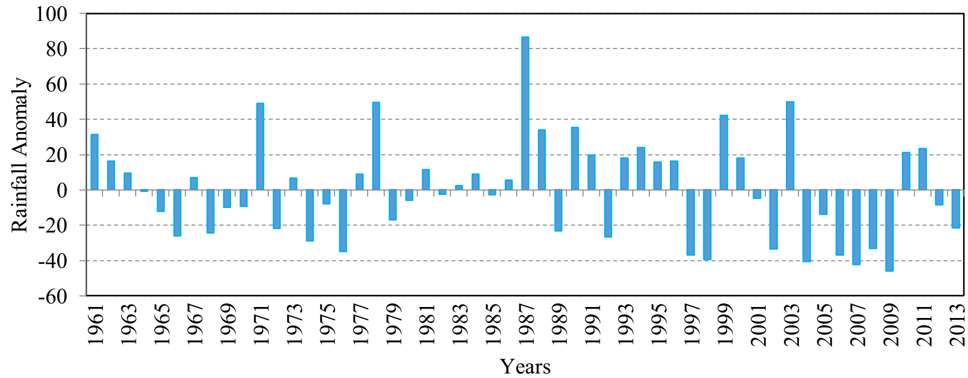


Fig. 6 Anomaly of annual rainfall (1960–2013) over the Varuna basin

Table 2 Linear aspect of the study area

Stream property	Formula	Reference	Maine river channel	W 1 (Basuhi)	W 2	W 3 (Morwa)
Stream order (u)	Hierarchial rank	Strahler [34]	5.00	4.00	4.00	4.00
Stream length (Lu)	Length of the stream	Horton [36]	1282.14	564.18	240.73	211.04
Mean stream length (Lsm)	Lsm = Lu/Nu	Strahler [34]	4.39	3.89	4.38	4.59
Stream length ratio (RL)	RL = Lu/Lu − 1	Horton [36]	0.62	0.79	0.70	0.68
Bifurcation ratio (Rb)	Rb = Nu/Nu + 1	Schumm [41]	3.92	4.99	2.98	2.59
Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all order	Strahler [37]	0.98	1.25	0.75	0.65
Rho Coefficient (ρ)	RL/Rb	Horton [36]	0.16	0.16	0.24	0.26
Direct bifurcation ratio (Rdb)	Rdb = Ndu/Nu + 1	–	3.02	3.22	1.84	1.75
Bifurcation Index (R)	R = Rb − Rdb	–	0.89	0.53	1.14	0.84

watersheds W1 (1.22), which indicated that Basuhi river had moderate meandering in nature while W2 and W3 (Morwa river) had 1.69 and 1.50 respectively (Table 3). Hydraulic sinuosity index (HSi) and Topographic (TSi) value were calculated, 37.24% and 62.76% respectively. It was observed that TSi decreased with altitude and Hsi has increased both significant parameters in defining the stage of river basin development as well as the controlling aspects of sinuosity. The basin was identified as very coarse Drainage texture (Dt) (0.69), that reflected climate, a permeability of rocks, vegetation, etc. [48]. Channel or Stream frequency (Fs) (0.08) helped to analyse the erosional processes over the study area. Drainage density was 0.37 km/sq. Km. with moderate drainage concentrations. Constant Channel maintenance (1/D) specified that the relative size of landform units in a drainage basin and had a specific genetic connotation [37]. Low values of Drainage density (Dd) were very susceptible to flood and channel erosion [39, 42]. Varuna drainages were identified as a dendritic drainage pattern (Table 3). The high value (5.37) of Length of overland flow (Lg) revealed high values in the lower stage (old age).

3.5.3 *Relief aspects (Ra)*

Low relief ratio (Rhl) over the basin (0.30) and its sub-watersheds Basuhi (0.14) and Morwa (0.86) showed a less resistant with low degree of gradient [39]. Absolute relief (Ra) was estimated about 107 m, which indicated the difference in altitude between specified site and sea level [42] (Fig. 7b) (Table 4). Channel Gradient (Cg) was estimated (0.14) as total drops (horizontal distance) in elevation from source to mouth of the basin (Table 4). As per Strahler's [56] method, low value (0.01) of Ruggedness Number (Rn) showed enlargement of the basin relief as practically combined with slope sharpness and its length. Furthermore, Melton Ruggedness Number (MRn) (0.65) showed relief ruggedness in the watershed [29, 57]. Dissection Index (Dis) (0.36) revealed a deficiency of vertical dissection or erosion, i.e. domination of flat plane over the basin (Table 4). Moreover, Gradient Ratio (Rg) (0.30) was an essential indicator of channel slope, which allowed evaluation of the runoff amount [39, 42, 46, 58].

Table 3 Aerial aspect of the study area

Stream property	Formula	References	Maine river channel	W1 (Basuhi)	W2	W3 (Morwa)
Basin length (Lb)	GIS software	Schumm [41] (KM)	128.63	92.3	57	44
Basin perimeter (P) Kms	GIS software	Schumm [41] (KM)	421.60	276.10	176.90	134.48
Basin area (A) SqKms	GIS software	Schumm [41] (Sq KM)	3445.14	1386.75	593.01	460.32
Length area relation (Lar)	Lar = 1.4 * (A)^0.6	Hack [49]	185.55	107.48	64.56	55.46
Lemniscate's (k)	k = (Lb)^2/A	Chorley et al. [50]	4.80	6.14	5.48	4.21
Form factor ratio (Ff)	Ff = A/(Lb)^2	Horton [43]	0.21	0.16	0.18	0.24
Elongation ratio (Re)	Re = 2/Lb * (A/π)^0.5	Schumm [41]	0.52	0.46	0.48	0.55
Circularity ratio (Rc)	Rc = 12.57 * (A/P^2)	Miller [51]	0.24	0.23	0.24	0.32
Compactness coefficient (Cc)	Cc = 0.2841 * P/A ^0.5	Gravelius [52]	2.04	2.11	2.06	1.78
Wandering ratio (Rw)	Rw = Cl/Lb	Smart and Surkan [53]	1.38	1.26	1.68	1.44
Watershed eccentricity(T)	T = ((L^2−W^2))^0.5/W	Black [54]	2.11	3.89	3.20	2.98
Main channel length (Cl) Kms	GIS software	–	178	116.19	95.51	63.34
Valley length (Vl) Kms	GIS software	–	124	95.45	56.56	42.30
Minimum aerial distance (Adm) Kms	GIS software	–	33	10.66	4.34	10.54
Channel index (Ci)	Ci = Cl/Adm (H & TS)	Mueller [47]	5.39	10.90	22.01	6.01
Valley index (Vi)	Vi = Vl/Adm (TS)	Mueller [47]	3.76	8.95	13.03	4.01
Standard sinuosity index (Ssi)	Ssi = Ci/Vi	Mueller [47]	1.44	1.22	1.69	1.50
			i.e. < 1.5	i.e. < 1.25	i.e. > 1.5	i.e. ≤ 1.5
			Sinuous shape	Winding shape	Meandering shape	Twisty shape
Hydraulic sinuosity index (Hsi) %	Hsi = ((Ci − Vi)/(Ci − 1)) * 100	Mueller [47]	37.24	19.65	42.72	39.85
Topographic sinuosity index (Tsi) %	Tsi = ((Vi − 1)/(Ci − 1)) * 100	Mueller [47]	62.76	80.35	57.28	60.15
Length of overland flow (Lg) Kms	Lg = A/2 * Lu	Horton [36]	5.37	4.92	4.93	4.36
Texture ratio (Rt)	Rt = N1/P	Schumm [41]	0.54	0.40	0.25	0.26
Drainage density (Dd) Km/Sq. Km.	Dd = Lu/A	Horton [43]	0.37	0.41	0.41	0.46
Drainage texture (Dt)	Dt = Nu/P	Horton [36]	0.69	0.53	0.31	0.34
Stream frequency (Fs)	Fs = Nu/A	Horton [43]	0.08	0.10	0.09	0.10
length overland flow (Lg) kms	Lg = 1/D * 2	Faniran [55]	5.37	4.92	4.93	4.36
Infiltration number (If)	If = Fs * Dd	Faniran [55]	0.03	0.04	0.04	0.05
Constant of channel maintenance (Kms^2/Km)	C = 1/Dd	Schumm [41]	2.69	2.46	2.46	2.18
Drainage intensity (Di)	Di = Fs/Dd	Faniran [55]	0.23	0.26	0.23	0.22
Drainage pattern (Dp)	GIS software	Horton [43]	Dendritic			

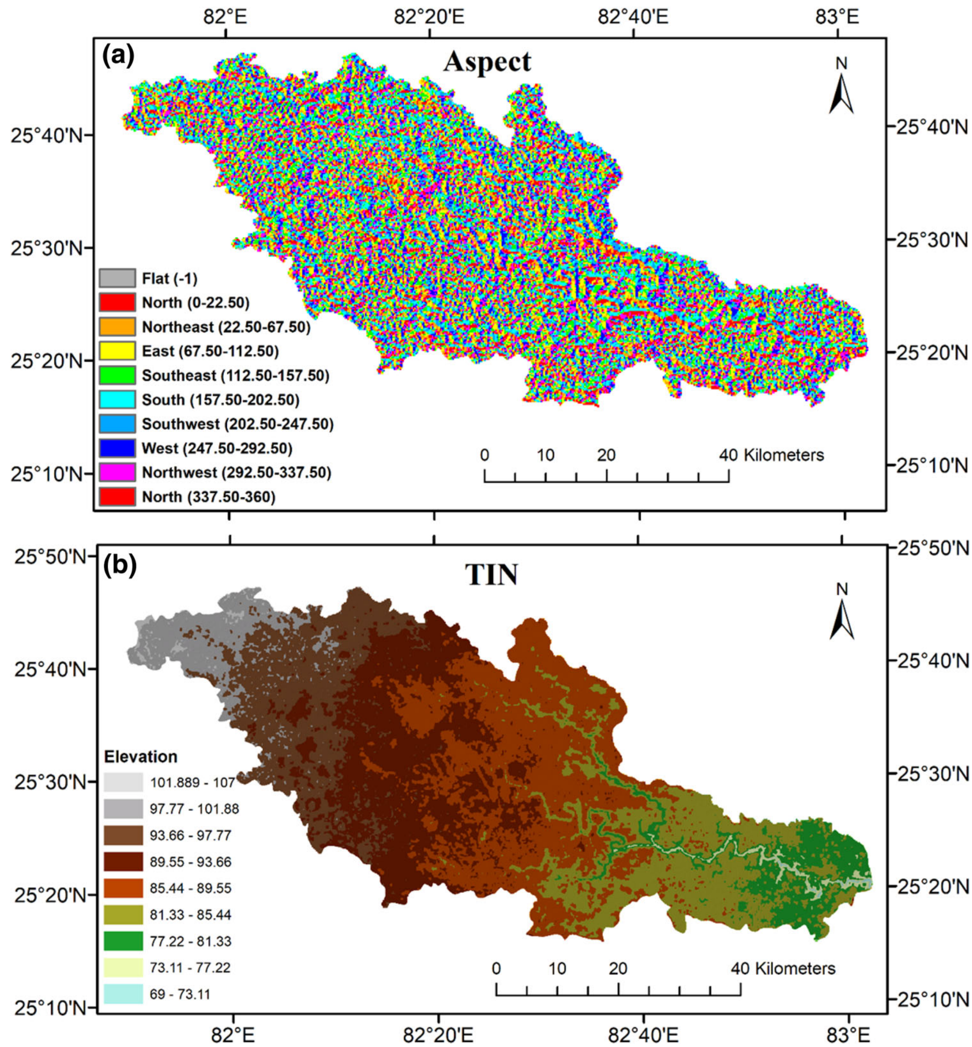


Fig. 7 Extraction of surface characteristic by Spatial-Analyst procedure in **a** aspect; **b** triangulated irregular network (TIN); over the Varuna basin

Table 4 Relief aspects of the study area

Stream property	Formula	Reference	Maine river channel	W1 (Basuhi)	W2	W3 (Morwa)
Relief ratio (Rhl)	Rhl = H/Lb	Schumm [41]	0.30	0.41	0.67	0.86
Relative relief ratio (Rhp)	Rhp = H * 100/P	Melton [45]	9.01	13.76	21.48	28.26
Dissection index (Dis)	Dis = H/Ra	Singh and Dubey [59]	0.36	0.36	0.36	0.36
Gradient ratio (Rg)	Rg = Z − z/Lb	Sreedevi et al. [60]	0.30	0.41	0.67	0.86
watershed slope (Sw)	Sw = H/Lb	Sreedevi et al. [60]	0.30	0.41	0.67	0.86
Ruggedness number (Rn)	Rn = Dd * (H/1000)	Paton and Baker [61]	0.01	0.02	0.02	0.02
Melton ruggedness number (MRn)	MRn = H/A^0.5	Melton [45]	0.65	1.02	1.56	1.77
Channel gradient (Cg) m/Kms	Cg = H/{(π/2) * Clp}	Broscoe [62]	0.14	0.21	0.25	0.38

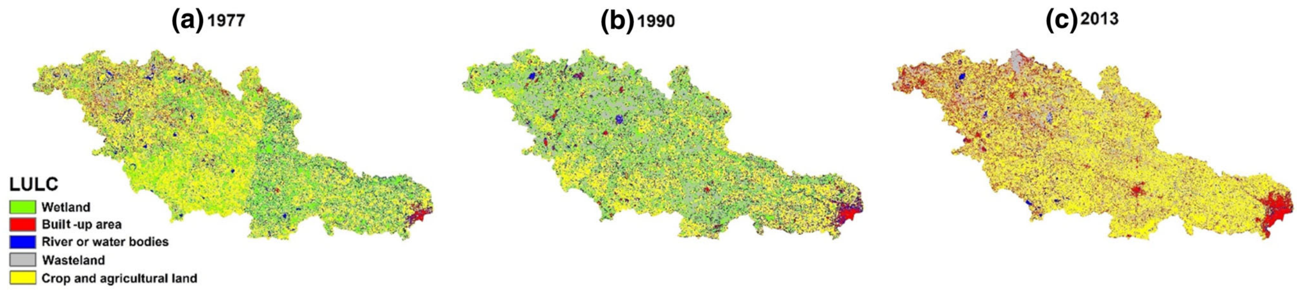


Fig. 8 Spatial and temporal changes of LULC in **a** 1977; **b** 1990; **c** 2013 over the Varuna River from Landsat imagery

3.5.4 Prioritization of Varuna river watershed

The erosion risk evaluation was considered in quantitative morphometric parameters for prioritization of sub watersheds. The quantitative morphometric parameters considered were (1) stream order, (2) stream frequency, (3) length of overland flow, (4) drainage density, (5) elongation ratio and (6) form factor [14, 63]. The linear parameters of morphometric analysis were directly associated with erodibility of sub-watersheds were namely W1 (Basuhi river), W2 and W3 (Morwa river) have been assigned 1st, 2nd and 3rd rank respectively. As the value of linear parameters increases, the susceptibility of soil erosion also increases. According to Gajbhiye [63], the areal aspects were inversely associated with erodibility and vice versa (areal aspects were i.e. form factor, elongation ratio and circulatory ratio). As the value of Ariel parameters increased from low to high, the sub-watersheds W1, W2 and W3 were assigned 1st, 2nd and 3rd ranks, respectively. The compound and its average value were calculated after ranking all linear and aerial parameters in all sub-watersheds. The priority criteria of linear and aerial aspects were based on average value i.e. W1, W2 and W3 as high, medium and low priority, respectively. Our study revealed that the sub-watershed Basuhi river was highly vulnerable for soil erosion and therefore highly recommended for land conservation and soil erosion prevention. Watershed W2 was given second priority for reclamation and conservation process whereas sub-watershed Morwa river was given least priority and examined as low risk of land degradation in sub-basin conservation practices.

3.6 LULC changes

LULC was considerable impacts on hydrologic response at the watershed level of the basin. Quantitative assessment of LULC on runoff was vital for water resources development [64]. In the present study, the remote sensing derived Landsat satellite imageries were classified in five major classes (Crop and agricultural land, River or water bodies, wasteland, Wetland, Built-up area) for 1977, 1990 and 2013. The response of streams current and runoff was rapidly decreased due to spatial–temporal changes of LULC pattern. The changes in wetland and agricultural land were spotted with the increase of the built-up area from 1977 to 2013. In 1977, 29% area was identified as a wasteland, and about 55% area was agricultural land (Fig. 8a). The salt-affected wasteland area was reduced by 18% from 1977 to 1990, and a large amount of reclaimed land was occupied by industrial purpose and urban development, i.e. road construct (built-up areas) also some for agricultural practices (Fig. 8b). The LULC was extremely transformed from 1990 to 2013 (Fig. 8b, c). In these years, the percentage of urbanization was increased exponentially, with the reduction of agricultural land and water bodies. The area of wetland was somehow constant with modest variation while streams and water bodies showed a large variation in time span due to anomalous rainfall from 1960 to 2013 (Fig. 8c).

4 Conclusion

Drainage morphometric analysis is entirely depended upon landform variability of a basin. The Varuna basin is not an exception of that, and its distributional pattern, frequency, density and basin parameters were analyzed by GIS tool. Bifurcation ratio (low) indicated the study area underlined by systematically branched streams. The river basin possessed moderated drainage density which was indicative of permeable material, vegetative cover and moderate to low relief characteristics. Circularity (low) and elongation (high) ratio displayed the basin had an elongated formation. Mean Bifurcation Ratio of Varuna basin was low which designated that drainage pattern of the basin was normal without any the structural disturbances. Estimated prioritization over the study area, resulted in Basuhi sub-watersheds evaluated the highest priority, and this may help for conservation and development of water resource management. The above study was an effort with the integration of morphometry, LULC, Rainfall and NDVI parameters. The NDVI was decreased by 40.71% due to the negative trend of rainfall. As an index of denoting vegetation cover, change of NDVI reflected the condition of vegetation cover over the basin. The rainfall pattern showed temporal heterogeneity, and the frequency of percentage deficit in rainfall occurred very frequently, which might lead to the diminishing of the channel width of river basins. The persistence of similar conditions may consequent in a drain. It indicated drier periods with the decrease in annual rainfall while SI further illustrated a similar pattern. The SI showed low rainfall in less than 3 months which reflected more proneness to drought condition. In addition, statistical multi-scalar indices like SPI and SPEI have reflected the level of meteorological extreme drought actions over the basin. Four month's time scale SPI showed more extreme droughts (1972, 1984, 1996–1998, 2001–2003, 2005–2007 and 2009–2010) and 12 month's time scale SPEI indicated the prolonged droughts since 1996 to 2017. Hence, rainfall was the main factor which influenced vegetation cover as well as LULC of the basin. Thus, this study could find extensive changes of LULC; in terms of loss of natural vegetation cover, uprise of urban growth with industrial garbage, reduction of agricultural land and extension of the road density in and around the basin area. Our study can be recommended to protect river bank erosion and degradation of water quality with the help of civil engineers, planners with suitable action and planning. Moreover, the outcome of this study can be used to build up the proper planning of watershed management.

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