Journal of Geomatics Vol 10 No. 1 April 2016

Morphometric changes of the Varuna river basin, Varanasi district, Uttar Pradesh

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(Received: Jan 10, 2015; in final form: Dec 02, 2015)

Abstract: The Varuna is one of the important interfluves rivers joining the Ganga river near Varanasi city. The morphometric analysis of the Varuna river basin has been carried out. It covers an area of about 3622 km^2 of the Ganga plain. The dendritic drainage pattern diagnosed in the area exhibits homogeneous permeable substratum and gentle gradient. Spatio temporal changes (Land Use and Land Cover i.e. LULC) of the Varuna river basin, in Varanasi district, using Landsat multispectral imageries spanning 38 years (1972, 1988, 2002 and 2010) are also studied. The LULC patterns illustrate that in early 80's the basin is largely covered by the salt affected waste land. Later on the salt affected waste land area is reduced and area of agricultural land and built-up area has increased. The study underlines the necessity of a scientific approach for the sustainable river basin management, with the help of the hydrological conditions, recent climatic anomalies and geological control of the basin.

Keywords: Gangetic plain, Interfluves, Varuna river, Morphometric analysis, Confluence-shift

1. Introduction

The interfluves (doab) surfaces of the Gangetic plain, forming a part of Indo-Gangetic fore land basin system (Singh et al., 1996), are the most important, tens to hundreds of kilometer wide geomorphic surfaces and witness the oldest living civilization of the world. These plains are drained by numerous snow fed and alluvium fed rivers. Interfluve river basins undergo morphometric changes and transformation of channel patterns and their degradation and aggradations in response to varying set of climate and tectonics influencing the base level of the rivers through time (Denizman, 2003). According to Mesa (2006) geomorphic parameters are important and necessary to explore the basinal dynamics and basin architecture. The present study is targeting on quantitative approach of watershed and landscape development of the Varuna river, a tributary of Ganga river, with the help of remote sensing and GIS data. The river is flowing deeply incised in to the interfluve surface having a rather narrow valley (Shukla, 2013). Interfluve surface making the base level of the rivers is made up of silt, sand and clay horizons. Varuna river basin is a part of the central alluvial plain of the Ganga basin (Singh, 1996; Shukla and Raju, 2008) bounded by the Vindhyan rocks in the south forming the peripheral bulge. For watershed management practices and geotectonic control over the drainage basin through morphometric analysis has been attempted by several workers in the recent past (Sreedevi et al., 2004; Pati et al., 2006; Pati et al. 2008; Thomas et al., 2010; Sarmah et al., 2012). Channel characteristics of the interfluves alluvial river replicate the stability of bank material and erosive power of the stream and any small changes in geomorphology (or spatio temporal shift) in the river basin signify a consequence of variation in sediment load, sediment-water ratio and slope of the basin as a result of prevailing climate and neotectonics (Schumm et al., 2000; Raj, 2007). There are many small and large rivers such as Ganga, Yamuna, Brahmputra, Kosi, Gomati rivers and several others have shown changes in their channel courses through Quaternary-Holocene times in response to changing set of climate and tectonic conditions (Wells and Don, 1987; Srivastava and Singh, 1999; Kotoky et al.,2005; Roy and Sinha, 2005; Shukla et al., 2012, Shukla, 2013).

The focus of the study, the Varuna river emanates at 25°27′ N & 82°18′E near Mau Aima (Pratapgarh district, Uttar Pradesh) flows east-to-southeast for about 183km, and makes confluence with the western bank of the Ganga river at the 83°2'40.088"E 25°19'46.387"N near Raj Ghat bridge, just downstream of the Ganga in Varanasi city (Fig.1). The Varanasi city is one of the oldest living civilizations in the world and important pilgrim city of India with a population of about 1.5 million. The name Varanasi itself is believed to have been derived after the name of the rivers Varuna and Assi. Varuna river is one of the foremost controlling drainage system of Varanasi city (Khan et al., 1988). Assi river has deteriorated to become a drain, carrying domestic waste and sewerage of Varanasi city, and calls for immediate attention for its reclamation (Shukla, 2013). The study also analyses spatio-temporal changes in Land Use Land Cover (LULC) of the Varuna river basin based on available Landsat imageries. Moreover, the current environmental status of a region and ongoing modifications in terms of urban growth could be better appreciated by analysis of spatial and temporal change in land use planning (Turner et al., 1993).

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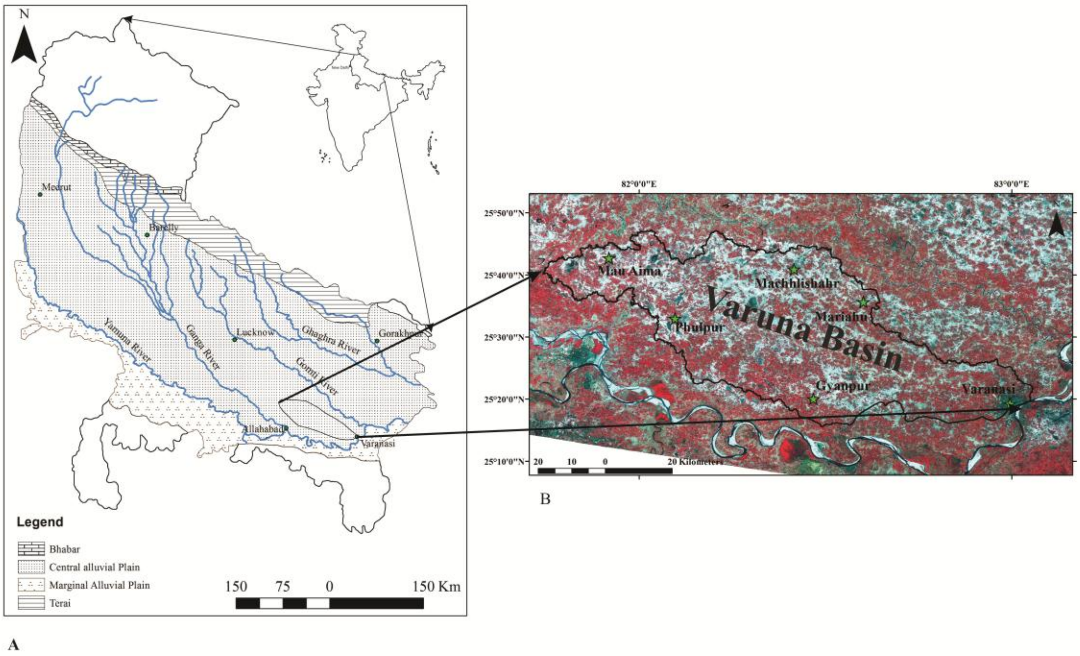

Figure 1: Location map of the Varuna basin (a) Map showing subdivision of Ganga plain in Uttar Pradesh (modified after Singh, 1996); (b) Landsat imagery (MSS Path 153 and Row 42 of 1972) representing Varuna river basin

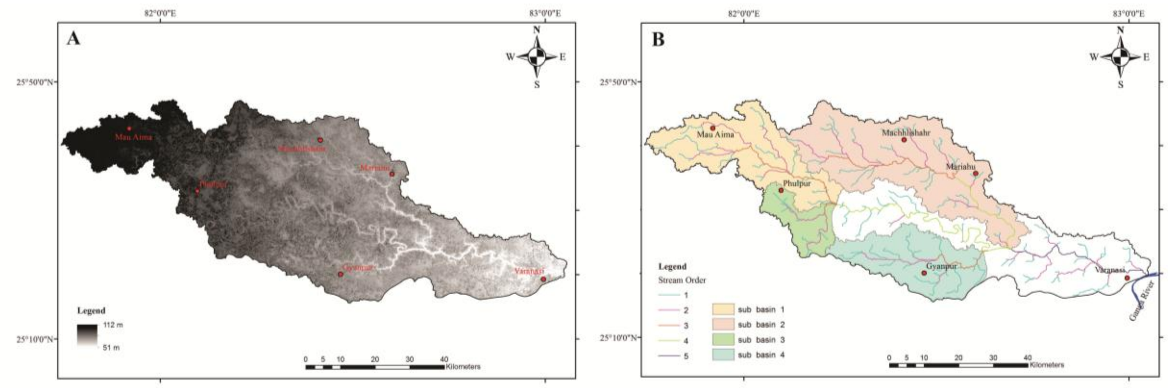

Figure 2: Varuna river basin (a) DEM (digital elevation model) from SRTM data; (b) Drainage pattern and 4 sub basins

2. Methodology

Shuttel Radar Topogrpaphy Mission (SRTM) data (Fig.2a) (of Sep 30, 2000) and SOI (Survey of India) topographic maps (1:50000) are used for extraction of the drainage network and sub water shed in the study area. Landsat Multispectral Scanning (MSS) data (of Sep 30, 1978) is used for delineation of old valley of the Varuna river and further identified and traced out by handheld 12-channel GPS (make Garmin E-Trax Vista). The paleo channels are identified here on the basis of higher moister content in soils, textural characters on the image and the vegetation pattern in the former river valley. The satellite data were obtained from the Global Land Cover Facility (http://www.landcover.org). Horton's (1945) and Strahler (1965) methods were adopted in the present study for characterization of watershed and drainage network. The morphometric parameters such as linear, areal and relief aspects were extracted using ARC GIS-10.0. Measurements pertaining to the confluence shifting of the Varuna river in time and space have been carried out using the available published data, SOI toposheets, Landsat MSS data and GPS readings.

3. Results

3.1. Morphometry

Morphometric analysis done in the present study incorporates quantitative study of the Varuna river valley, altitude, volume, slope, profiles of the land and drainage basin characteristics of the area concerned (Kondolf and Hervè, 2003).The stream network and the catchment area of the Varuna river with four 4th order sub-watersheds with as are shown in figure 2b.

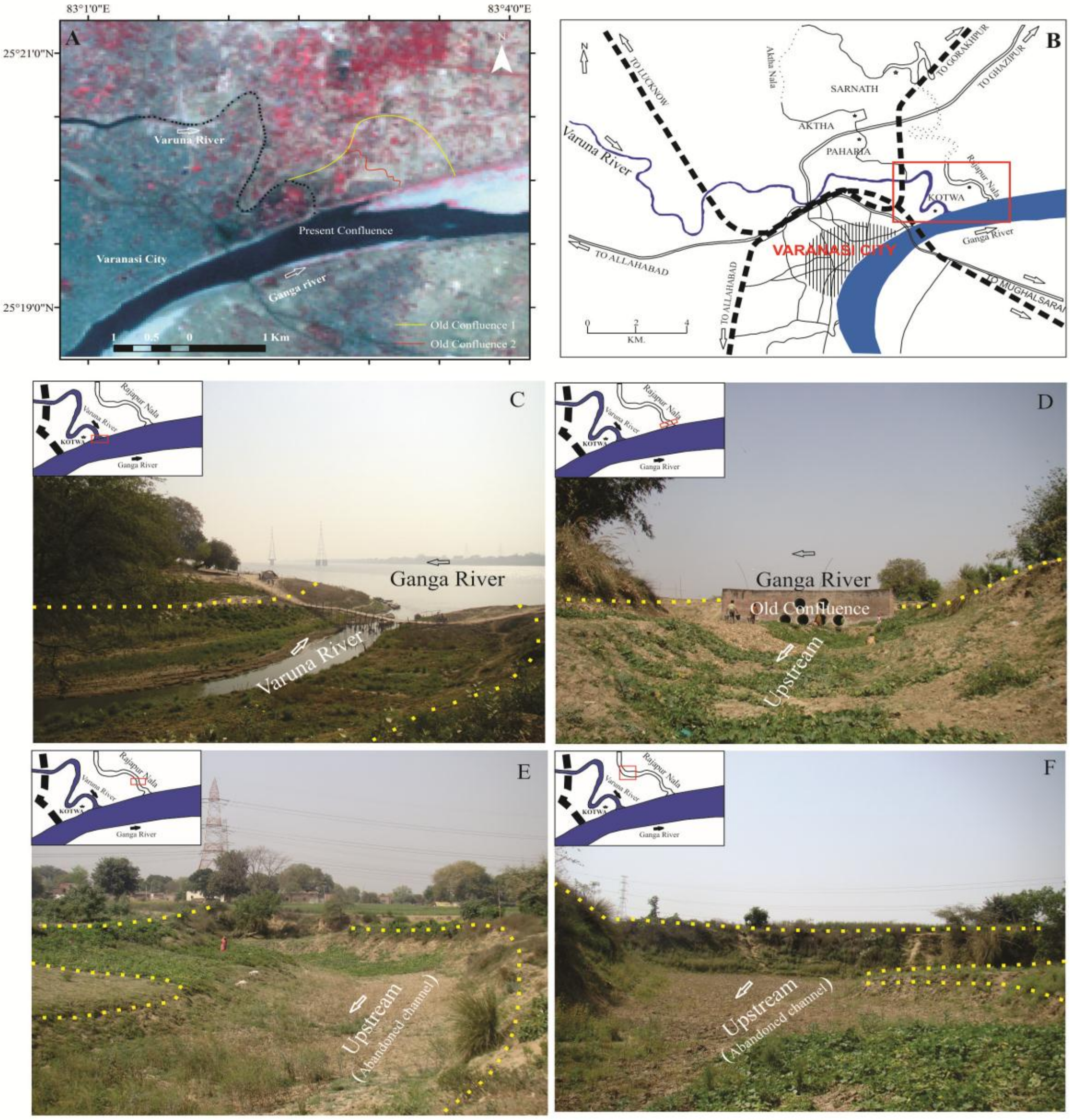

Figure 3: (A) Two discreet southward shifting of the confluence of the Varuna river near Varanasi, traced out in the field with hand GPS; (B) Traces (in doted lines) of the old Varuna River near Sarnath (after Jayaswal et al.); (C) Present confluence of the Varuna river; (D) Old confluence of the Varuna River; (E) Abandoned channel of the Varuna River; and (F)Low lying area showing abandoned channel of the Varuna river

Dendritic drainage pattern is the most common and widespread pattern found in the study area (Fig.2b). The dendritic patterns evolved in the area closely resemble to the area having homogeneous bed materials (mainly Gangetic alluvial) with a very gentle regional slope. The perimeter of the Varuna watershed is 482.07 km (Table 1). The values of the bifurcation ratio (Rb) generally set in between 2.0 and 5.0 for the drainage network. Such network generally develops in consistent lithologies and also signifies the minimum structural control over it. When the values are higher than 10.0, it indicates that structural control has played a dominant role on drainage network development (Mekel, 1970). Low Rb values indicate elongated shape of the basin (Morisawa, 1985). The Varuna river belongs to this category.

The variations among the stream length ratio (Rl) values are directly related to the geomorphology including topography and lithology and hence it governs the erosional stage of the watershed and discharge (Sreedevi et al., 2004). The Rl values in case of Varuna river basin varies between 0.66 and 0.75 (Table 1) and that implies accomplishment of geomorphic maturity. The Rho coefficient is used for determining the storage capacity of drainage network (Horton, 1945). The values of Rho coefficient of the Varuna river and its sub-watersheds vary from 0.14 to 0.26 (Table 1). The higher values of Rho coefficient of SW2 and SW3 (Fig.2b) are indicators of higher hydrologic storage during floods and decreased effects of erosion during elevated discharge.

Drainage density (Dd) is one of the significant indicators of the landform development and presents a numerical measurement of landscape dissection and hence the runoff potential (Smith, 1950). The study area has very low drainage density varying from 0.19- 0.31, and a very coarse drainage texture (Table 1), which implies permeable subsurface conditions (since the basin has chiefly clay and sandy clay subsurface material) and dense vegetation.

Form factor (Ff) is significant factors to envisage the shape of the drainage basin and the flow intensity of watershed with direct relationship to peak discharge (Horton 1945, Gregory and Walling 1973). The value of Ff (Table1) varies from 0.19 to 0.33. Low Ff values (<0.4) are characterized by shorter flow peaks of longer duration which in case of Varuna river seems to be its alluvium fed character and irregular rainfall in the area.

Length of overland flow (Lg) is an important morphometric parameter complementing both hydrologic and physiographic advancement of the watershed (Horton, 1945). The Varuna watershed accounts an Lg value of 1.19, whereas the SW1, SW2, SW3 and SW4 (Fig.2b) are having the Lg values between 1.61 and 2.63 (Table 1). The higher value of Lg of SW2 indicates geomorphic maturity while other sub-watersheds are charecterized by early mature or late youth stage of geomorphic advancement.

The Rc (Circulatory ratio) value of Varuna Watershed (VW) is 0.19, whereas it ranges between 0.15 and 0.23 in other sub-watersheds (Table 1). The low Rc values (<0.6) of the sub- watersheds are probably related to attenuated flood- discharge periods. The stage of evolution of the watersheds can also be explained by the numerical values of Rc of sub- watersheds. The low Rc values of the sub- watersheds, imply youth stages of watershed development.

The numerical value of Re (elongation ratio) for VW is 0.5, signifying an elongated nature of the basin. Re of 4 sub-watersheds varies from 0.56 and 0.65(Table 1). The elongated shapes of sub- watersheds, with the larger basin area, are insisting the role of head-ward erosion in development of lengthy channels.

Table 1: Mathematical formula adopted for the quantitative measurement and estimated values of the morphometric parameter

Parameters/ Sub-Watershed		SW1	SW2	SW3	SW4	VW
Linear parameters	Unit					
Area	km^2	694.25	1124.3	222.23	523.81	3622.5
Perimeter	Km	237.54	302.46	109.41	149.93	482.07
Basin length (Lb)	Km	52.27	66.51	25.67	42.53	135.57
Linear Aspect						
Bifurcation ratio (Rb) = Nu/N(u+1) Where Nu is number of any given order and N(u+1) is number in the next higher order	Dimensionless	4.03	3.2	2.81	5.33	3.84
Stream length ratio (Rl) = Lu/L(u-1) Where Lu is stream length order u and L(u-1) is stream segment of the next lower order	Dimensionless	0.66	0.67	0.74	0.75	0.68
Rho coefficient (ρ) = Rl/Rb	Dimensionless	0.16	0.2	0.26	0.14	0.17
Areal Aspect						
Drainage density (Dd) = Lt/A Where Lt is the total length of all ordered streams	km^{-1}	0.29	0.19	0.28	0.31	0.26
Stream frequency (Fs) = Nt/A Where Nt is the total number of all ordered streams	km^{-2}	0.05	0.08	0.1	0.05	0.06
Drainage Texture (T) = Dd×FS	km^{-3}	0.014	0.015	0.028	0.015	0.015
Length of overland flow (Lg) = 1/2Dd	km	1.72	2.63	1.78	1.61	1.92
Form factor (Ff) = A/Lb^2	Dimensionless	0.25	0.25	0.33	0.28	0.19
Circulatory ratio (Rc) = $4\pi A/P^2$	Dimensionless	0.15	0.15	0.23	0.29	0.19
Elongation ratio (Re) =	Dimensionless	0.56	0.56	0.65	0.61	0.5

(SW- sub-watershed, VW- Varuna watershed)

3.2. Confluence shift

The confluence shift of the Varuna river is ascertained by analysing the satellite imageries, toposheets (Survey of India) and supported by extensive field effort (Fig. 3). The shifting of the confluence points of the Varuna river is traced out by hand held 12 channels Garmin E-Trax Vista GPS with ± 3 meter accuracy in the field (fig. 3a). The confluence point of the Varuna river has shifted progressively southwards in detached steps by leaving behind older valley signatures like depression with meandering morphology, ponds and meander cut-offs away from the main river channel (Fig. 3b). Two discreet channel shifts have been noticed in the field. First shift is 1.64 km and the second shift is 0.96 km located north from the present day confluence of Varuna with the Ganga river (Fig.3a). The remnant valley of the Varuna river is identified on the basis of width of the abandoned channel/ valley in the field (Fig.3e-f).

It is to be noted that all the tributaries near the Varanasi city along with the Ganga River are deeply incised and at present do not have liberty to leave their valleys and shift (Shukla et al., 2012). Therefore, there are mainly three possibilities for shift of the tributary confluences. The causes are (i) when they were not incised and were freely shifting their channels (ii) in the recent past due to channel piracy by the Ganga river and (iii) periodic and linear change in rainfall.

However, the shift in confluence points of the Varuna river is well comprehended by the dynamic of the main Ganga River channel. Ganga river acts as the base level control for the Varuna river and any change in the dynamics of the former directly affects the later. Before the Last Glacial Maxima most likely in the late Quaternary, rivers were not incised and freely migrating within their broad valleys, shifting laterally for many kilometres (Shukla et al., 2012). The meanders of the present-day Ganga river in the study area around Varanasi appear deformed and elongated, with straight and highly-convoluted reaches, indicating tectonic control over the present-day river channel. Around Varanasi, where presently due to incision (Swamee et al., 2003; Shukla, 2013) the Ganga River is confined within a 1–2 km wide narrow valley, it previously had a much wider valley which was 10–15 km wide. With time it migrated eastward, leaving behind a large abandoned meander belt. The location of Varanasi represents the old flood plain of the Ganga River, characterized by numerous ponds formed due to the abandonment of the channels (Srivastava et al., 2003; Shukla et al., 2012). The incision of the Ganga River seems related to tectonics along a fault line passing in a NE–SW direction, controlling the course of the river and dynamics of tributary confluence (Shukla and Raju, 2008; Shukla et al., 2012; Singh, 2015).

3.3. Land use pattern

The Landsat data has been classified into six major classes (agriculture, river, water bodies, salt affected wasteland, wetland and urban- rural build-up area) and in view of that the land use changes in the Varuna river basin were investigated during four time spans of 1972, 1988, 2002 and 2010 (Fig. 4).

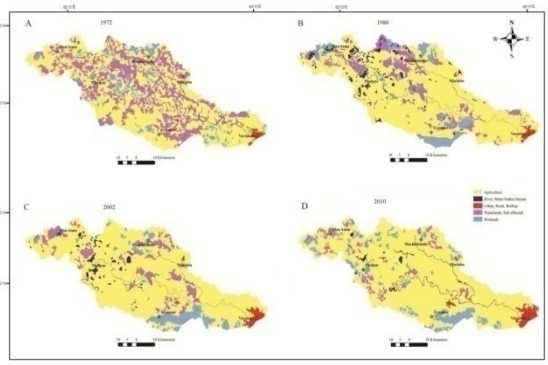

Figure 4: Land use and Land cover (LULC) map of the Varuna basin during four time spans of (A) 1972; (B) 1988; (C) 2002; and (D) 2010

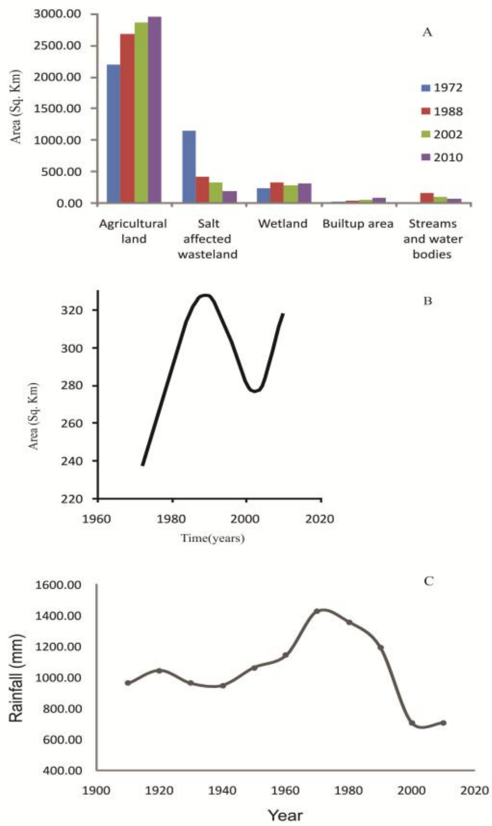

Figure 5:(A) Bar digram showing area and Landuse land cover changes in Varuna basin from 1972-2010; (B) Scatter diagram with smooth line showing change in wetland area with time; (C) Rainfall demonstrating anamolous rain fall in early 80's

In 1972, LULC of the Varuna river basin reveals that, 32% area is identified as salt affected waste land and about 60% area is used in agricultural practices (Fig.5a). The salt affected waste land area is reduced by 22% in 1988 from 1972 and the large proportion of the reclaimed land (from salt affected to useful land) is occupied by agricultural practices and some proportion is consumed in built-up areas (Fig.5a). The LULC scenario has drastically changed from 1988 to 2010 (Fig.4). In these years percentage of built up areas have increased exponentially, leaving behind the area of agricultural land and surface water bodies. The area of wetland is somehow constant with modest variation while streams and water bodies show large variation in studied time span, due to anomalous rain fall in early 80's (Fig. 5c).

Table 2: Land use land cover status in Varuna basin during 1972-2010

Area (km^2)	1972	1988	2002	2010
Agricultural land	2192.15	2688.05	2869.40	2961.74
Salt affected wasteland	1155.46	413.36	325.89	195.64
Wetland	237.15	327.44	276.62	317.90
Built-up area	28.04	32.59	57.11	78.84
Streams and water bodies	9.04	160.16	92.57	67.46
Total area	3621.83	3621.60	3621.58	3621.58

Rainfall data (Fig. 5c) from the India Meteorological Department (IMD) support the change in the surface water pattern in early 1980. The present study is confirming the important physiographic modification occurring in the Varuna River basin during the last four decades. The morphometric analysis, confluence shifting and change in land use with/ land cover pattern of the river basin highlight the necessity for sustainable development and management of ecological setup for the Varuna river basin.

4. Conclusion

The GIS techniques have been efficiently utilized for the assessment of the drainage characteristics of the Varuna river watershed and to comprehend the significance of morphometric studies and shifting of the confluence. The low bifurcation ratio and elongation ratio of the Varuna river signify the elongated shape of the basin. The elongated shapes of sub- watersheds, with the larger basin area, are due to head-ward erosion leading to expansion of channels. The study area is demonstrating very low drainage density because of permeable subsurface and dense vegetation. The low drainage density in the study area leads to very coarse drainage texture. The low values of circulatory ratio are characterized by attenuated flood- discharge periods and youth stages of watershed development. Thus the incorporation of morphometric analysis together with predictable watershed assessment methods would have a better understanding the status of land form, drainage management and evolution of groundwater potential for watershed planning and their management.

Near Varanasi, the Ganga river is flowing along a NE–SW tectonic lineament. The confluence of the Varuna river is shifted towards south from 1 to more than 1.5 km from north from its present confluence with the Ganga river. The study suggests that the morphodynamic change and confluence shift in the interfluves river (Varuna river), was controlled largely by monsoonal variability as well as directed by tectonic activity in trunk river. LULC has revealed that because of population growth build up area has drastically increased at the cost of agricultural land.

Acknowledgement

Authors are thankful to the Head of the CAS, Department of Geology, Banaras Hindu University for making available the functioning conveniences. S. Singh is grateful to the UGC, New Delhi for a fellowship in the form of BSR-SRF.

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