Modeling Hydrological Response of Indus Basin as a Function of Geomorphology and Land Cover Change

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Key words: - SWAT model, DEM, Morphometry, Drainage density, runoff, Taudem.

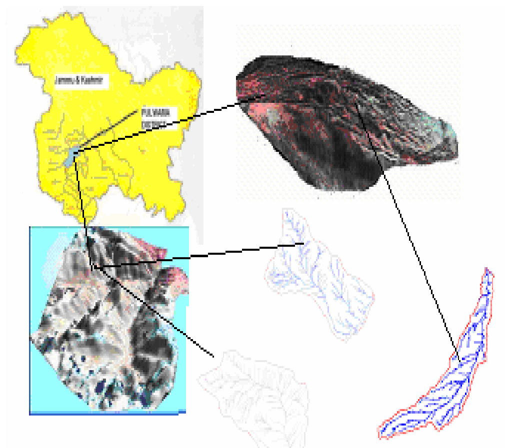
ABSTRACT:

Geomorphological characteristics of a basin represent physical and morphological attributes that are employed in synthesizing its hydrological response. These attributes have direct bearing on the hydrologic regime, annual water production, flood volumes and soil erosion. The Indus basin is experiencing recurrent floods during the last few decades and therefore it is important to study the influences of Morphometry and other hydro-Geomorphological processes on the flood characteristics of the basin. The current study was conducted in the upstream portion of the Indus River that drains three countries, India, Pakistan and China. Three micro-watershed in upstream of the basin (J&K, India) between (long 74°32, 74°36) E, (Lat.33°40, 33°43) N and (long. 74°32, 74°33) E, (Lat.33°39, 33°40) N and (long. 74°43, 74°46) E, (Lat.33°41, 33°44) N respectively, were selected for detailed Morphometric analysis. For the purpose of discussion, they are henceforth referred as Ind A, Ind B and Ind C in this paper. Their areal extent spreads over 11.57 Km^2, 11.07 Km^2 and 10.00 Km^2 respectively. In this study, a variety of data including satellite images, digital elevation model, soil map, standard 1:50000 scale SOI topographic maps, hydro-meteorological data and various thematic maps obtained from various sources have been used as data sources. LANDSAT ETM (2001) and LANDSAT MSS geometrically corrected satellite images were used to identify the land information of the area. Digital elevation at 20 m resolution, from 1: 50000 scale SOI topographic maps were generated using contour information at 20m intervals. SWAT Model was used to obtain the surface runoff of these micro-watersheds. Results shows that there is very much increase in runoff from 1976 to 2001, the runoff of IndA during 1976 was 82.467 mm/ 5yeas and in the year 2001 it was 116.649 mm/5years, Ind B shows 79.905 mm/5years runoff during the year 1976 and in 200, 91.042 mm/5years and IndC show 0.012 mm/5years and 2.096 mm/ 5years during the years 1976 and 2001 respectively. These results reveal that hydrological process has very much disturbed during last 25 years both in high and low altitude watersheds. Detailed Morphometric analyses have been carried out at 20-meter resolution Digital Elevation Model using Taudem software and self developed programme. The drainage network of IndA & Ind B watersheds shows that terrain exhibits Dendritic to Sub-dendritic drainage pattern, while as Ind C exhibits parallel to sub parallel drainage pattern. Stream Length, Mean stream length, Stream length Ratio and Bifurcation Ratio shows order-to-order variation. The Drainage density of Ind-A, Ind-B and Ind-C are 8.48 km/km^2, 7.7 km/km^2 and 5.48 km/km^2 respectively. The Stream frequency of Ind-A, Ind-B and Ind-C are 32.15 km/km^2, 30.89 km/km^2 and 30.06 km/km^2 respectively. The Stream frequency shows positive relationship with drainage density. Form factor (Ind-A =0.40, Ind-B = 0.33 and Ind-C = 0.18), Elongation Ratio (Ind-A =0.73, Ind-B = 0.65 and Ind-C = 0.47) and Circulatory Ratio (Ind-A =0.53, Ind-B = 0.36 and Ind-C = 0.20) reveals Ind-C is more or less elongated than Ind-A and Ind-B. The watershed characteristics using DEM and various Hydrological models could provide valuable insight into the hydrological response of the ungauged watershed

1. Introduction:

The Geomorphological and climatic characteristics of a basin govern its hydrological response to a considerable extent. Geomorphological characteristics of a basin represent physical and morphological attributes that are employed in synthesizing its hydrological response. These attributes have direct effects on the hydrologic regime, annual water production, flood volumes, soil erosion and vegetation covers. Also, with the development activities, most of the basin has undergone the land use and land cover changes. The land use/ land cover changes within the basin can have significant impact on runoff characteristics. Hence, linking of the geomorphologic parameters with the hydrologic characteristics of the basin can lead to a simple and useful procedure to simulate the hydrologic behavior of various basins, particularly the ungauged ones. The current study was conducted in the upstream portion of the Indus River that drains three countries, India, Pakistan and China. The basin is experiencing recurrent floods during the last few decades and therefore it is important to study the influences of Morphometry and other hydro-Geomorphological processes on the flood characteristics of the basin. In this study, a variety of data including satellite images, digital elevation model, soil map, standard 1:50000 scale SOI topographic maps, hydro-meteorological data and various thematic maps obtained from various sources have been used as data sources. LANDSAT ETM (2001) geometrically corrected satellite images were used to identify the land use/ cover information of the area. Digital elevation models at 20 m resolution, from 1: 50000 scale SOI topographic maps were generated using contour information at 20m intervals. Digital elevation model was used to generate elevation, aspect and slope information. Mapwindow, Arcview, Taudem softwares and self developed programme have been used to generate stream network in the study areas and detailed Morphometric Analysis at 3-grid order threshold on this Digital Elevation Model has been carried out.

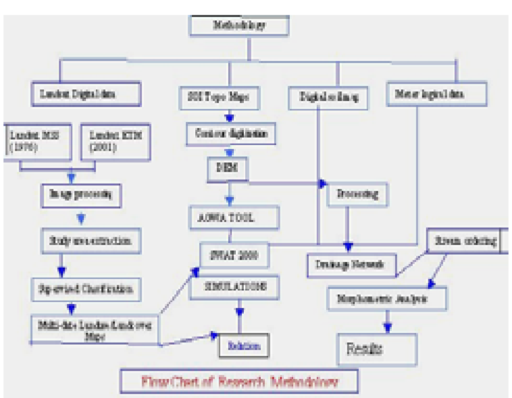
2 Study Area:
The current study was conducted in the upstream portion of the Indus River that drains three countries, India, Pakistan and China. Three micro-watershed in upstream of the basin (J&K, India) between (long 74°32, 74°36) E, (Lat.33°40, 33°43) N and (long. 74°32, 74°33) E, (Lat. 33°39, 33°40) N and (long 74°43, 74°46) E, (Lat. 33°41, 33°44) N respectively, were selected for detailed Hydro-Morphometric analysis and to see the impact of change in land cover on surface runoff using hydrological modeling. For the purpose of discussion, they are henceforth referred as IndA, IndB and IndC in this paper. Their areal extent spreads over 11.57 Km^2, 11.07 Km^2 and 10.00 Km^2 respectively.



Location Map of Study Area.

3. Data Sources
In the study, a variety of data including satellite images, digital elevation model, soil map, standard 1:50000 scale SOI topographic maps, hydro-meteorological data and various thematic maps obtained from various sources have been used as data sources together with ground truth.

4. Methodology:



4.1 Digital elevation Model

Digital elevation model has been generated from SOI sheets at 20m contour interval using Arcview and PCI software.

4.2. Land use/Land cover

The Landsat ETM (2001) and Landsat MSS (1976) images were used to obtain the land use and Land cover maps of the study area. From these maps three micro-watersheds have been selected to observe the impact of land use / land cover change on runoff.

4.3. Meteorological data

Meteorological data has been collected from various Deportments of the J&K state were analyzed and used to run the hydrological model.

4.4 Soil map

Existing soil map has been digitized at the Scale of 1:250000

4.5 Hydrological model.

AGWA based SWAT model developed by USDA-ARS has been used to simulate runoff.

4.6 Morphometric Analyses.

Detailed Morphometric analyses have been carried out at 20-meter resolution Digital Elevation Model using Taudem software and self developed programme. In the present study the Morphometric analysis for the parameters namely stream order, stream length, mean stream length, stream length ratio, bifurcation ratio, mean bifurcation ratio, relief ratio, drainage density, stream frequency, drainage texture, form factor, circularity ratio, elongation ratio, length of overland flow, basin length, shape factor, compactness coefficient, texture ratio etc has been carried on 3 order threshold.

5.0 Results and discussion

5.1 Land use / land cover mapping: -

The land use/ land cover maps have been prepared using the methodology described above. The major land cover classes delineated include Exposed rock surfaces, Shrubby lands and Pastures for IndA and IndB and for watershed IndC include Barren lands, pastures, exposed rock surfaces and forest .The area of each class for Landsat ETM (year 2001) and Landsat MSS (year 1976) data have been shown in Table: I, II and III respectively.

Land cover 2001			
S. No.	Class Name	Area km^2.	Area %
1	Exposed rock surfaces	11.79	83.62
2	Shrubby lands	2.29	16.24
3	Pasture	0.02	0.14
Land cover 1976			
S. No.	Class Name	Area. Km^2.	Area %
1	Exposed rock surfaces	7.43	51.85
2	Shrubby lands	4.36	30.43
3	Pasture	2.54	17.72

Table: I Land cover statistics of Ind A Watershed

Land cover 2001			
S. No.	Class Name	Area km^2.	Area %
1	Exposed rock surfaces	8.60	63.33
2	Shrubby lands	4.77	35.12
3	Pasture	0.21	1.55

Table: II (A) Land cover statistics of Ind B watershed

Land cover 1976			
S. No.	Class Name	Area. Km^2.	Area %
1	Exposed rock surfaces	7.23	52.25
2	Shrubby lands	3.83	27.80
3	Pasture	2.72	19.74

Table: II (B) Land cover statistics of Ind B watershed

Land cover 2001			
S. No.	Class Name	Area in sq. kms.	Area %
1	Barren Lands	2.34	25.50
2	Pastures	3.24	35.29
3	Rock Exposes	0.008	0.09
4	Forests	3.59	39.11
Land cover 1976			
S. No.	Class Name	Area in sq. kms.	Area %
1	Barren Lands	0.85	8.97
2	Pastures	1.04	10.98
3	Rock Exposes	0.01	0.16
4	Forests	7..58	79.96

Table: III Land cover statistics of Ind C watershed

From the tables given, it is estimated that in the year 1976, the High altitude watersheds IndA and IndB was having 12.80 Km^2 areas under Exposed rock surfaces followed by 8.12 Km^2 under Shrubby Lands and 5.28 Km^2 under Pastures, while as in the year 2001, results show Rock Surfaces occupies 19.10Km^2, Shrubby lands covered 6.70 Km^2 and Pastures having area of 0.24 Km^2. Over all results shows there is increase in the exposed rock surfaces and decrease in other two classes, it may be due over grazing or any adverse natural phenomena. IndC, the low altitude watershed shows 0.85 Km^2 under Barren lands, 1.04 Km^2 under pastures, 0.01 Km^2 under Rock surfaces and forests occupied 7.58 Km^2 of the total land in the year 1976 .2001 land cover statistics shows Barren land has increased and forests have greatly decreased. Results depicts that there has been a large-scale deforestation in the area during last 25 years and which would cause high runoff during heavy raining and cause serious flooding in the downstream area.(table I-III)

5.2 Hydrological model results

Swat model (AGWA based developed by the USDA-ARS) was run using constant soil data and meteorological data and land cover data of two dates (1976 & 2001) were used in all the three Micro-watersheds to obtain surface runoff. It has been seen from results that incase of 2001 land cover data runoff has found high in all watersheds as compared to land cover data of 1976. It has also been observed that IndA has more runoff than other two watersheds and IndC has less among the all. (Table:-IV). The results are also shown in Figs(I- IX) for both Land cover data.

S.No	Name of watershed	Land cover data used (1976) Runoff mm/5years	Land cover data used (2001) Runoff mm/5years
01	IndA	82.467	116.649
02	IndB	79.905	91.042
03	IndA	0.012	2.096

Table: IV. Runoff from three watershed using two date land cover data of 1976 & 2001

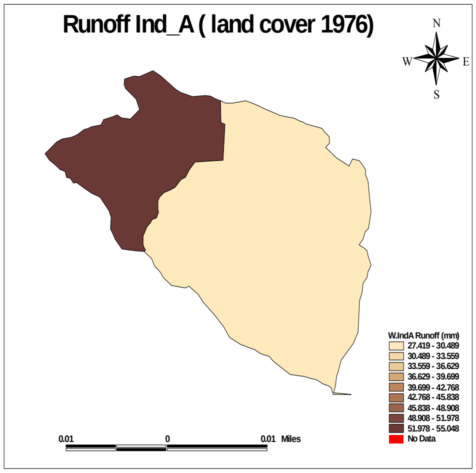


Fig: I showing Runoff using land cover data of 1976

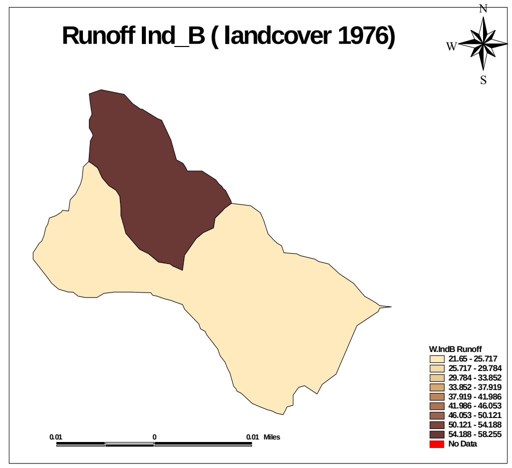


Fig: IV showing Runoff using land cover data of 1976

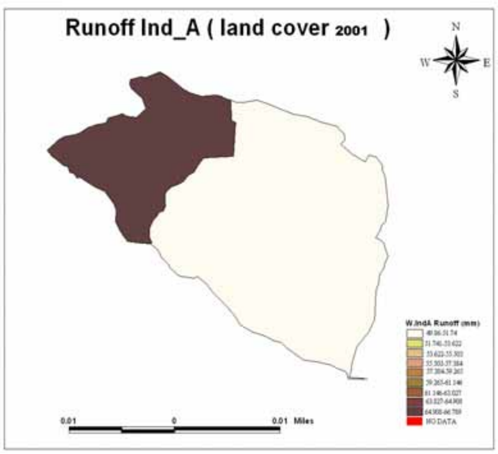


Fig: II showing Runoff using land cover data of 2001

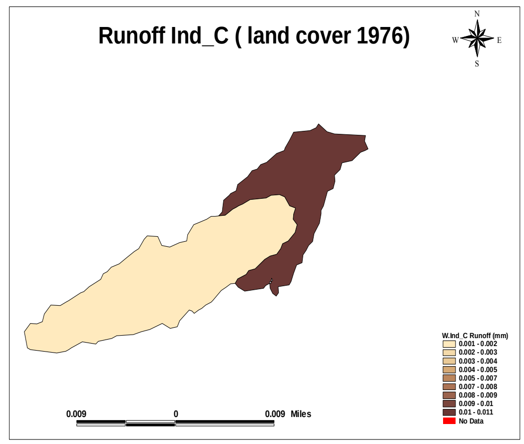


Fig: V showing Runoff using land cover data of 1976

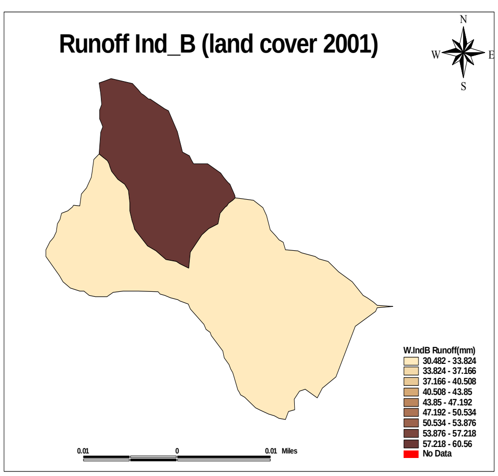


Fig: III showing Runoff using land cover data of 2001

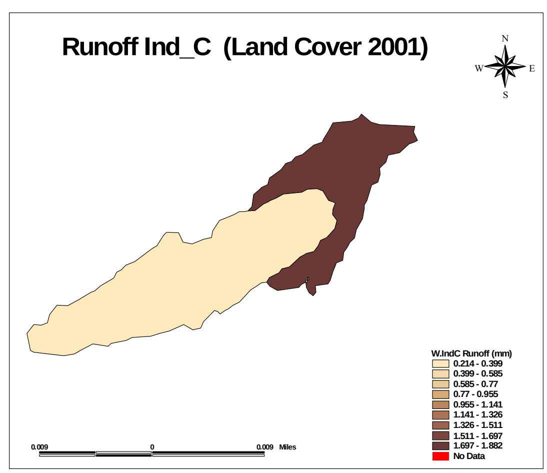


Fig: VI showing Runoff using land cover data of 2001

5.3 Morphometric Analyses

Morphometric analyses have been carried out at 20mt resolution DEM using 3 order threshold and the Strahler ordering scheme was followed to obtain the ordering scheme of the study area. A self-developed program has been used to obtain various Morphometric parameters (Table VI to VII). The drainage network of IndA & IndB watersheds shows that terrain exhibits Dentritic to Sub-denritic drainage pattern. Stream Length, Mean stream length, Stream length Ratio and Bifurcation Ratio shows variations order to order. The Drainage density of Ind-A, Ind-B and Ind-C are 8.48 km/km^2, 7.7 km/km^2 and 5.48 km/km^2 respectively.. The Stream frequency of Ind-A, Ind-B and Ind-C are 32.15 km/km^2, 30.89 km/km^2 and 30.06 km/km^2 respectively. The Stream frequency shows positive relation with drainage density. Form factor (Ind-A =0.40, Ind-B = 0.33 and Ind-C = 0.18), Elongation Ratio (Ind-A =0.73, Ind-B = 0.65 and Ind-C = 0.47) and Circulatory Ratio (Ind-A =0.53, Ind-B = 0.36 and Ind-C = 0.20) reveals Ind-C is more or less elongated than Ind-A and Ind-B.. The length of over overland flow of Ind-A, Ind-B and Ind-C are 0.06 km, 0.06 km and 0.09 km respectively. Dd, Fs and all shape related parameters indicates IndC shall have very low runoff during rain spells and IndA & IndB watersheds have high runoff and cause serious flooding in the down stream area during heavy rain spells

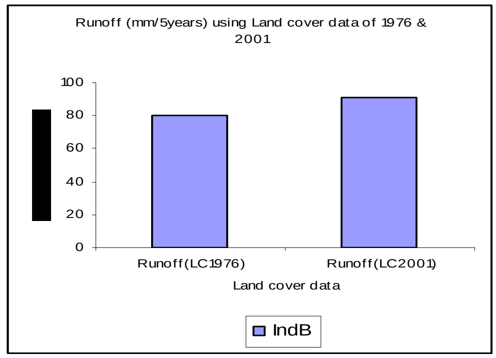


Fig:VIII

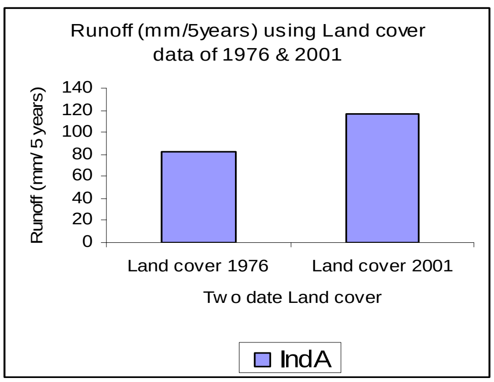


Fig: VII

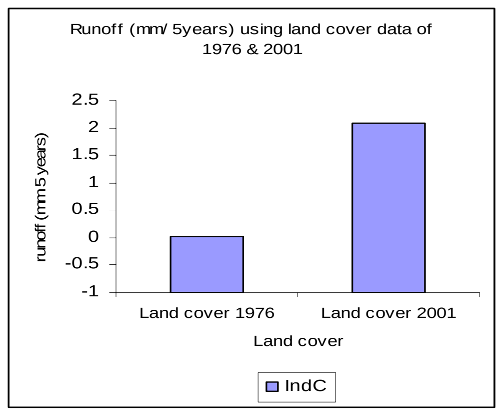


Fig:IX

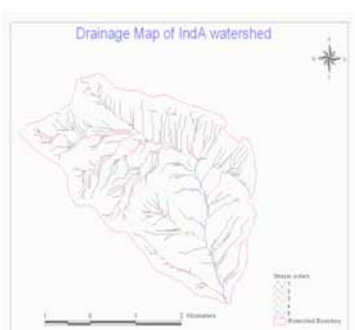


Fig: X

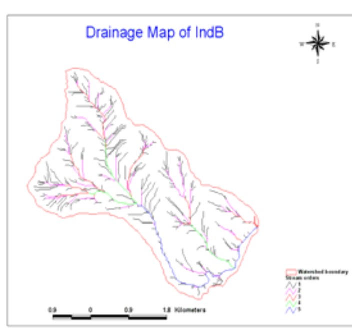


Fig: X I

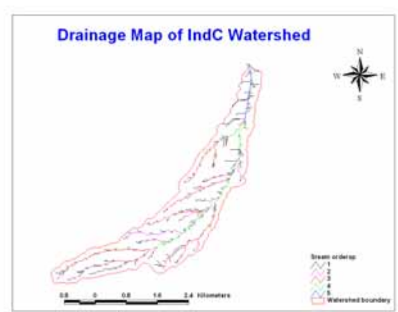


Fig: XII

S.No	Parameters	Formulae
01	Stream order	Hierarchal rank (Strahler method)
02	Stream length(Lu)	Length of streams (order wise)
03	Mean stream length(Lsm)	Lsm=Lu/Nu Where Lu= total length of order' u' Nu= total streams segments of the order 'u'
04	Stream length ratio (Rl)	Lu/Lu-1
05	Bifurcation ratio	Rb=Nu/Nu+
06	Mean Bifurcation ratio (Rbm)	Rbm=Average of Rb of all orders
07	Drainage density(Dd)	Dd=TL/A TL=total length of all orders A=area of watershed
08	Stream frequency (Fs)	Fs= Nu/A

S.No	parameters	Formulae
09	Form Factor (Rf)	Rf = A/lb Lb = Square of basin length
10	Circularity Ratio (Rc)	Rc = 4* Pi * A/P2 Pi= 3.14, p = peremeter
11	Elongation ratio (Re)	$Re=1.128A^{0.5}/Lb$
12	Length of over land flow	Lo = 1/2Dd
13	Elipticity Index(E)	$E= \Pi L^2/ A$
14	Basin Length(lb)	$Lb=1.312A^{0.568}$
15	Shape factor(Sf)	$Rf=(Lb)^2/A$
16	Compactness coefficient	$Cc= 0.2821P/A^{0.5}$

Table: V(A& B) Morphometric parameter and formulae used

Sno	Name	Stream order	Area	Perimeter	Lb	Stream Order	No. of Stream segment in each order.	Total Orders	Lu(km)	T. Length	Lsm	Rl	Rb
1	IndA	5	11.57	16.5	5.25	1	303	372	60	98.09	0.2	0.33	5.72
						2	53		19.8		0.37	0.58	4.42
						3	12		11.6		0.96	0.29	4
						4	3		3.36		1.12	1	3
						5	1		3.36		3.36	-	-
2	**IndB**	5	11.07	19.6	5.8	1	282	342	51.7	85.28	0.18	0.31	6
						2	47		16		0.34	0.49	5.22
						3	9		7.9		0.88	0.58	3
						4	3		4.57		1.52	1.12	3
						5	1		5.14		5.14	-	-
3	**IndC**	5	10	19.6	7.53	1	263	306	26.9	54.82	0.1	0.41	7.97
						2	33		11.1		0.34	0.87	4.71
						3	7		9.61		1.37	0.58	3.5
						4	2		5.56		2.78	0.29	2
						5	1		1.64		1.64	-	-

Table: VI Results of Morphometric Analyses

Sno	Name	Rbm	Dd	Fs	Re	Rf	Rc	Lg	Ei	Cc	Max E	Min E
1	IndA	4.28	8.48	32.15	0.73	0.42	0.53	0.06	7.48	1.12	4700	2900
2	IndB	4.31	7.7	30.89	0.65	0.33	0.36	0.06	9.54	1.05	4700	2900
3	IndC	4.55	5.48	30.06	0.47	0.18	0.20	0.09	17.8	1.74	2700	2100

Table: VII Results of Morphometric Analyses

6.0 Conclusions: -

The present study reveals that land cover changes have disturbed the hydrological regime of the study area and caused increase in surface runoff and can be a main reason for flooding in the down stream areas. The Morphometric parameter like circularity ratio of Ind-A & Ind-B indicate that these two watersheds are more or less, circular and are characterized by high to moderate relief and the value of Ind-C indicates, it is less or more elongated. Elongated ratio values shows that Ind-A & Ind-B have Oval shape and Ind-c has elongated shape. These shape related parameters indicates that run off will take very less time to reach to outlet during precipitation period in case of Ind-A & Ind-B as compared to Ind-C and cause serious floods in the down stream portion of the catchment during heavy rain spells. The drainage density of Ind-A and Ind-B indicates resistant, impermeable subsurface material, mountainous relief and high runoff during precipitation while as drainage density of Ind-C indicates that the region has permeable subsoil and dense vegetation cover (land cover classification has also validated it) and this micro watershed may have low runoff during precipitation. This would reflect in early peak discharge in both Ind-A and Ind-B watersheds resulting in flash floods while the discharge from the Ind-C watershed would take time to peak because of low runoff rates. The drainage density for the Ind-C also indicates that the runoff would delay compared to the other two watersheds. All three watersheds depict positive relation between drainage density and stream frequency as the stream frequency increases with increase in drainage density. Length of overland flow also reveals that the runoff takes less time to reach to out let in case of Ind-A and Ind-B, while as Ind-C indicates runoff needs more time to reach the outlet. The channel maintenance values of Ind-C (1.74 km^2/km) reveal that it has relatively higher permeable underlying rocks than Ind-A. All the morphometric parameters indicates that runoff will be high and take very less time to reach to outlet during precipitation period in case of Ind-A & Ind-B as compared to Ind-C and cause serious floods in the down stream portion of the catchment during heavy rain spells The watershed characteristics using DEM and Hydrological models could provide valuable insight into the hydrological response of the ungauged watersheds.

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