Impact of Land use/Land cover change on Runoff Regime of the Upper Jhelum Catchment

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Abstract. The factors which govern the response of hydrological processes to a rainfall storm are interrelated across a river basin. There is a close relation between water resource management, river management and land use management. This paper aims at assessing the impact of land use/land cover change on the hydrological regime of the Upper Jhelum Catchment. Land use/land cover has drastically changed in the study area and as a result the annual peak discharges from 1991 to 2010 with different recurrence intervals have been more intensive in magnitude than the peak discharges from 1971 to 1990. During 1991 to 2010 the rainfall, recorded from the various meteorological stations located within the study area, has shown a decreasing trend. This increase in various hydrological events from 1991 to 2010 clearly reflects the role of the land use/land cover as a determinant of hydrological response of a watershed to a given amount of rainfall.

Keywords: land use/land cover, runoff, peak discharge, recurrence interval

1. Introduction

Hydrology of a watershed shows an intimate relationship with the prevalent land use. Land cover plays a key role in controlling the hydrologic response of watersheds in a number of important ways (Schilling et al., 2008; Mao & Cherkauer 2009; Elfert & Bormann, 2010 and Ghaffari et al., 2010). As the watershed becomes more developed, it also becomes hydrologically more active, changing the flood volume, runoff components as well as the origin of stream flow. In turn, floods that once occurred infrequently during predevelopment periods have now become more frequent and more severe due to the transformation of watershed from one land use to another. Changes in land cover can lead to significant changes in leaf area index, evapotranspiration (Mao & Cherkauer 2009), soil moisture content and infiltration capacity (Fu et al., 2000; Costa et al., 2003). Furthermore, land use modifications can also affect flood frequency and magnitude (Ward et al., 2008; Remo et al., 2009; Benito et al., 2010; Qiu et al., 2010).

In the upper Jhelum Catchment, floods are causing enormous damage to life and property very often. The flood problem in the study area arises primarily from the inadequate carrying capacity of the Jhelum in its length from Sangam to Wular Lake. The safe carrying capacity of the Jhelum from Sangam to Wular Lake ranges from 40 000 to 50 000 cusecs (cusec = cubic feet per second = = 0.028316847 m^3s^{-1}) and through the Srinagar city only about 35 000 cusecs. Compared to this, the flood discharge at Sangam rose to as much as 90 000 cusecs in 1957 and over 100 000 in 1959. The inadequate discharge carrying capacity of the Jhelum results in different type of flood problems in various reaches of the study area.

2. Study area

The study area spatially lies between 33° 21′ 54″ N and 34° 27′ 52″ N latitude and between 74° 24′ 08″ E and 75° 35′ 36″ E longitude with a total area of 8600.78 sq.km^2 (Fig. 1).

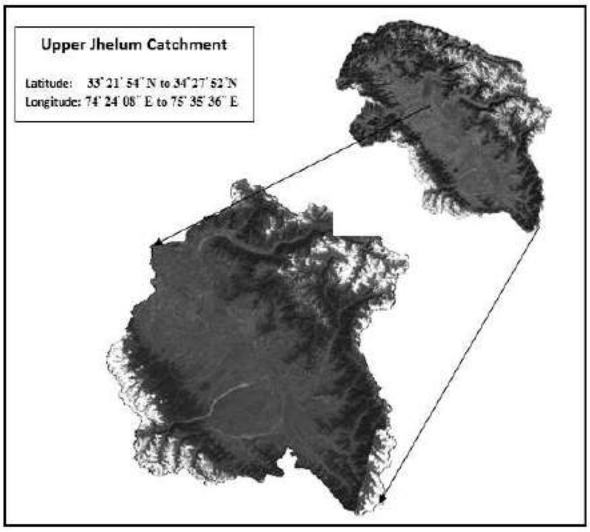


Fig. 1. **Study area map**

It covers almost all the physiographic divisions of the Kashmir Valley and is drained by the most important tributaries of the river Jhelum. The Jhelum and its associated streams that drain the bordering mountain slopes together constitute the drainage network of the study area. They include the fairly developed systems of the Sind, Rembiara, Vishaw and Lidder rivers as well as tiny rivulets such as the Sandran, Bringi and Arapat Kol. Adjusted to the varying nature of the geomorphic and geological setting, the fluvial systems in the study area have peculiar characteristics of their own. Four meteorological stations are situated within the study area namely Pahalgam, Srinagar, Qazigund and Kokarnag. Kokarnag is a high altitude meteorological station like Pahalgam, situated in the south bordering mountain chain of Pir Panjal. The monthly mean minimum rainfall recorded at this station from 1971 to 2010 is 25.8 mm while as the monthly mean maximum is 208.2 mm. Qazigund meteorological station is no exception to this variability. The monthly mean minimum and the monthly mean maximum rainfall figures recorded at this station during the above mentioned period are 73.3 mm and 234 mm respectively.

3. Material and methods

The methods and materials involved in the study are different for different parameters but guided to solve the main problem. In order to assess the impact of land use/land cover change on the hydrologic regime of the Jhelum basin, the methodology has been divided into various steps. The methodological set up employed during the current study can be grouped into three categories: remote sensing and GIS, field work and statistical methods.

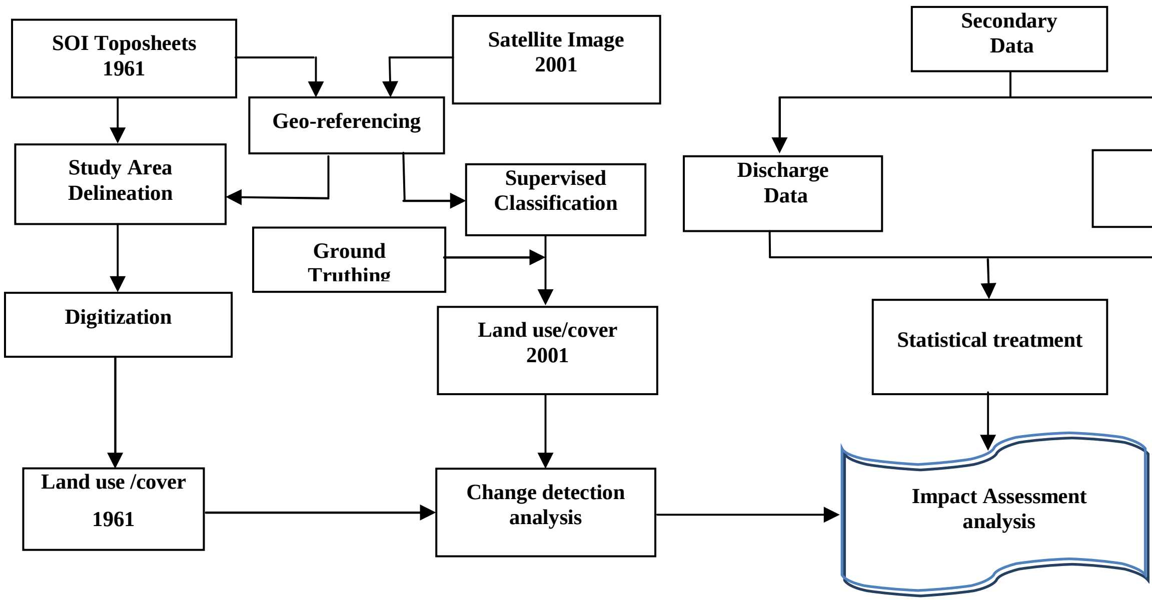


Fig. 2. **Flow chart showing methodological framework of the study**

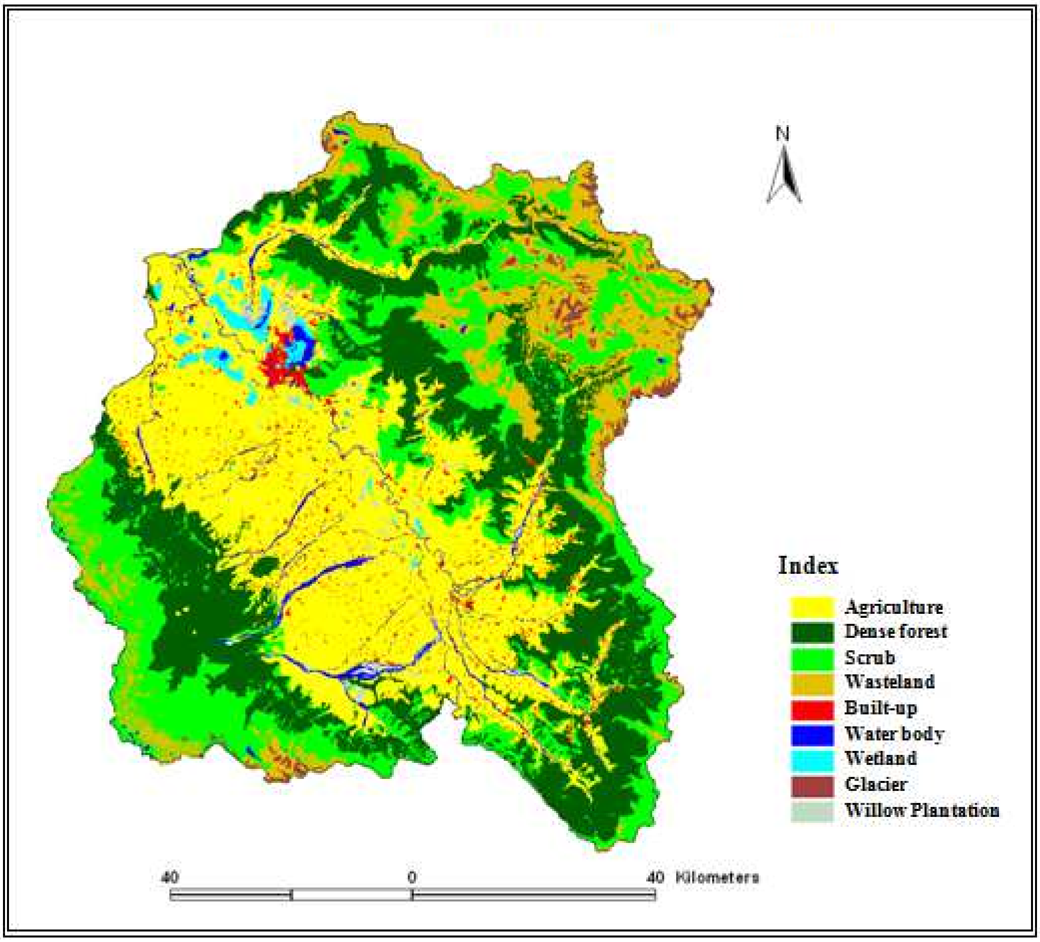
The present study has been carried out utilizing both primary as well as secondary data sets. Fig. 2 shows the general methodological scheme that has been applied in order to accomplish the present study. Primary data includes Survey of India toposheets on 1:50000 scale and satellite imagery of IRS-1C LISS III of the year 2001.

4. Results

4.1. Land use/ Land cover of the Upper Jhelum Catchment (1961)

Agriculture was the dominant land use category in the Upper Jhelum catchment in 1961 followed by the Forest cover. Agriculture being practised almost throughout the Valley floor was the dominant land use with an area of 2909.89 km^2. It comprised 33.83 % of the study area. Dense Forest and Scrub were the other major land cover classes comprising of 26.36 % with a total area of 2266.89 km^2 and 20.18 % with an area of 1735.47 km^2 of the study area respectively. Wasteland is spread throughout the study area along the periphery. It occupied 1059.83 km^2 and constituted 12.32 % of the Upper Jhelum Catchment. Willow plantation, mostly spread around the wetlands and close to the banks of the river Jhelum covered an area of 73.69 km^2 which was only 0.85 % of the study area. Water bodies occupied 174.04 km^2 which constitute 2.02 % of the study area.

Glaciers are mainly found along the higher reaches of Pir Panjal towards the south-west and Greater Himalayas but most of them are present in the lidder valley. Glaciers were extended over an area of 99.69 km^2 followed by wetlands with total area of 95.28 km^2. Glaciers and wetlands constituted 1.16 % and 1.12 % of the study area respectively.



Source: Generated from SOI toposheets on 1: 50000 scale, 1961.

Fig. 3. **Land use/Land cover** (1961) **in the Upper Jhelum Catchment**

The land use/land cover statistics of 1961 in the Upper Jhelum catchment is given in the table 1.

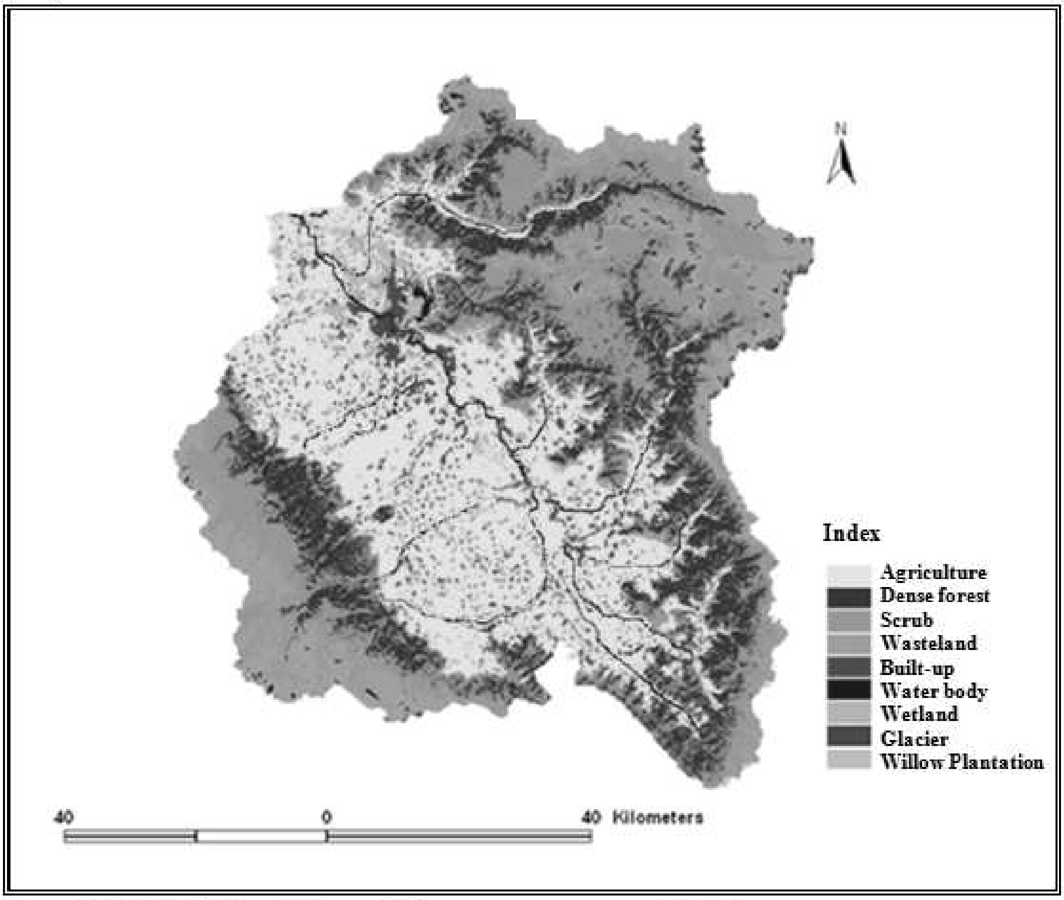
4.2. Land use/ Land cover of the Upper Jhelum Catchment (2001)

The land use/land cover map of 2001 has been generated from satellite data and is given below (Fig 1.2). Table 1.1 reveals that agriculture is the dominant land use with a total area of 3283 km^2 which constitutes 38.2 % of the study area followed by scrub that occupies 2018.5 km^2 which is 23.5 % of the total area. Forest is the next major land cover category spread over an area 1305.2 km^2 occupying 15.2 % of the study area. Wetlands have the least coverage of the area in the Upper Jhelum Catchment. Total area under this category is 46.3 km^2 which is only 0.5 % of the study area.

Wasteland is one of the dominant land cover categories in the study area. It occupies an area of 1253.2 km^2 and constitutes 14.6 % of the study area. The built-up area, which is mostly spread on the Valley floor covers 370.85 km^2 followed by plantation with an area of 146.43 km^2 constituting 4.3 and 1.7 % of the study area respectively. A total area of 122.3 km^2 is occupied by the water bodies which is only 1.4 % of the study area. Area under glaciers is 55 km^2, a little bit higher than the wetlands. They occupy on 0.6 % of the study area.

4.3. Land use/Land cover status and Change in the Upper Jhelum Catchment, 1961-2001

The land use land cover change that has occurred in the study area from 1961 to 2001 is shown in Table 1. The figures given in the table reveal that the highest change has occurred in the forest cover. It has declined from the total area of 2266.89 km^2 in 1961 to 1305.2 km^2 in 2001 thus, registering a decrease of 961.69 km^2 within a period of forty years with an average annual rate of decrease of 24 km^2.



Source: IRS-1C LISS III satellite image, 2001.

Fig. 4. **Land use/Land cover** (2001) **in the Upper Jhelum Catchment**

Table 1. **Land use/Land cover status and Change in the Upper Jhelum Catchment, 1961-2001**

Land use/land cover category	Area in km^2 (%) 1961	Area in km^2 (%) 2001	Change in area (%)
Agriculture	2909.89 (33.8)	3283 (38.2)	+373.11 (4.4)
Dense Forest	2266.89 (26.4)	1305.2 (15.2)	-961.69 (-11.2)
Scrub	1735.47 (20.2)	2018.5 (23.5)	283.03 (3.3)
wasteland	1059.83 (12.3)	1253.2 (14.6)	193.37 (2.3)
Built-up	186 (2.2)	370.85 (4.3)	184.85 (2.1)
Water body	174.04 (2)	122.3 (1.4)	-51.74 (-0.6)
Wetland	95.28 (1)	46.3 (0.5)	-48.98 (-0.5)
Glacier	99.69 (1.2)	55 (0.6)	-44.69 (-0.6)
Willow Plantation	73.69 (0.9)	146.43 (1.7)	72.74 (0.8)
Total	8600.78 (100)	8600.78 (100)	2214.2 (25.8)

Source: Computed from SOI toposheets, 1961 and satellite data, 2001

Scrub being one of the dominant land cover categories in the study area recorded a net increase of 283.03 km^2 with an average annual increase of 7.1 km^2. Total area under the scrub in 1961 was 1735.47 km^2 which has increased up to 2018.5 km^2 by 2001. Scrub has recorded a total increase of 2.3 % followed by wasteland that has registered an increase of 193.37 km^2 to its total area. Wasteland was spread over an area of 1059.83 km^2 in 1961 and this figure has gone up to 1253.2 km^2 in 2001. Net increase was of 2.3 %. On an average wasteland has increased by 4.8 km^2 per year. Built-up land in the study area has increased from 186 km^2 in 1961 to 370.85 km^2 in 2001, thus, registering a net increase of 184.85 km^2. Built-up has recorded an average annual increase of 4.6 km^2.

A net decrease of 51.74 km^2 has occurred in the water bodies located in the study area. Water bodies have decreased from 174.04 km^2 in 1961 to 122.3 km^2 in 2001 with an average annual decrease of 1.3 km^2. Wetlands have shown a reduction in their areal coverage from 95.28 km^2 in 1961 to 46.3 km^2 in 2001. The total decrease in the area under wetlands has been of 48.98 km^2 which is a decrease of 0.6 %. Glaciers all over the world are showing a fast decreasing trend and so is the case with the glaciers situated in the Upper Jhelum Catchment. The figures related to the area of glaciers in the study area have gone down from 99.69 km^2 to 55 km^2 between 1961 and 2001 respectively, which is a total decrease of 44.69 km^2. 0.6 % decrease was recorded by glaciers with an average annual decrease of 1.2 km^2. Willow plantation has increased from 73.69 km^2 in 1961 to 146.43 km^2 in 2001 with a total increase of 72.74 km^2. Plantation witnessed an increase of 0.8 % in its total area coverage with an average annual increase of 1.8 km^2.

Various hydrometeorological parameters are shown in Table 2. Average annual discharge in the river from 1971 to 1990 is showing a decreasing trend while as the total annual rainfall is depicting an increasing trend (Fig. 5a).

Table 2. **Various hydrometeorological parameters of the Upper Jhelum Catchment, 1971-1990**

Year	Avg annual discharge (Cusecs)	Total annual rainfall (mm)	Discharge to rainfall ratio
1971	3095	863	3.6
1972	14878	1252	11.9
1973	24224	1158	20.9
1974	12260	816	15.0
1975	21021	1318	15.9
1976	23826	1038	23.0
1977	5113	721	7.1
1978	8910	923	9.7
1979	7957	1170	6.8
1980	9672	1019	9.5
1981	6616	964	6.9
1982	5128	1102	4.7
1983	10675	1271	8.4
1984	6483	1034	6.3
1985	15062	823	18.3
1986	12743	1342	9.5
1987	18558	1178	15.8
1988	24348	1172	20.8
1989	10860	1084	10.0
1990	8770	1126	7.8

Source: Department of Flood Control (P & D Division) and Regional Meteorological Centre, Sgr.

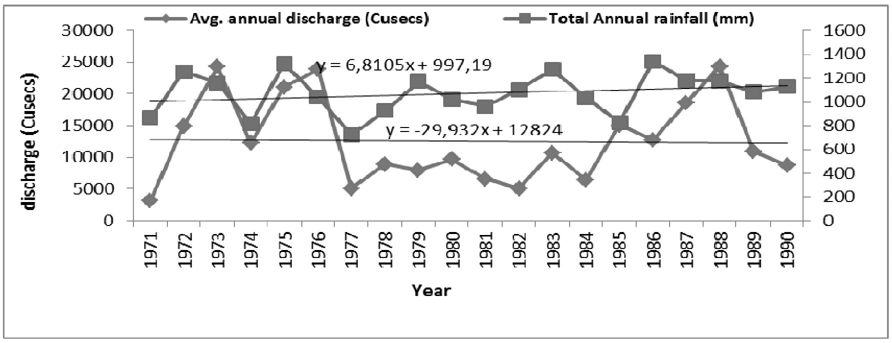


Fig. 5a. **Discharge-rainfall relation, 1971-1990**

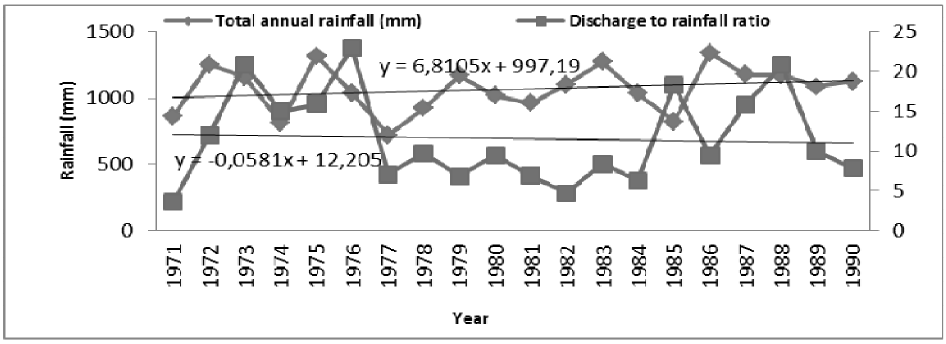


Fig. 5b. **Average annual discharge and discharge to rainfall ratio 1971-1990**

Table 3. **Various hydrometeorological parameters of the Upper Jhelum Catchment, 1991-2010**

Year	Avg. annual discharge	Total annual rainfall (mm)	Discharge to rainfall ratio
1991	10468	1039	10.1
1992	22335	1261	17.7
1993	20775	1114	18.6
1994	10401	1057	9.8
1995	27683	884	31.3
1996	26279	1090	24.1
1997	24098	967	24.9
1998	7591	982	7.7
1999	4994	828	6.0
2000	8830	905	9.8
2001	8007	897	8.9
2002	9826	802	12.3
2003	19228	1054	18.2
2004	15737	1029	15.3
2005	24098	1174	20.5
2006	27034	1194	22.6
2007	14098	754	18.7
2008	15310	845	18.1
2009	16498	766	21.5
2010	25870	1180	21.9

*Source***:** Department of Flood Control (P & D Division) and Regional Meteorological Centre, Sgr.

Discharge to rainfall ratio has also decreased during the same time period (Fig. 5b). The decreasing nature of average annual discharge and the increasing trend of total annual rainfall are evident from figures 6a and 6b.

Since 1990 onwards, the general trend of various hydrometeorological parameters of the Jhelum basin has changed significantly as shown in Table 3. Total annual rainfall in the study area from 1991 to 2010 is showing a decreasing trend where as the average annual discharge is manifesting an increasing trend along with the discharge to rainfall ratio (Fig. 6a and b).

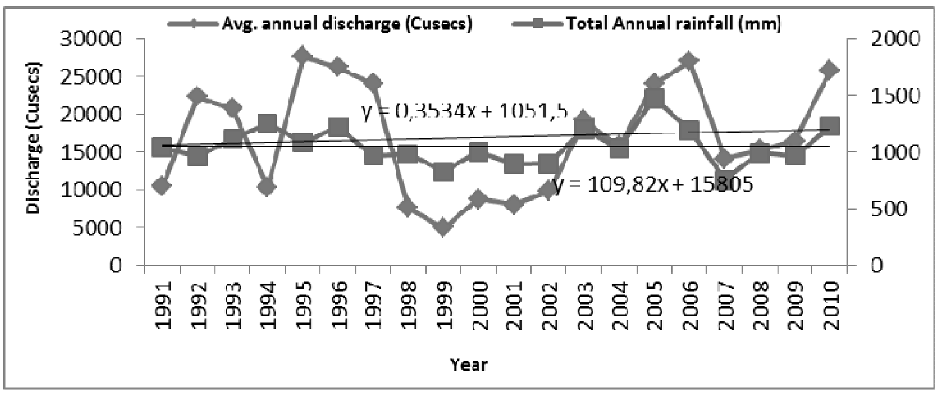


Fig. 6a. **Discharge-rainfall relation, 1991-2010**

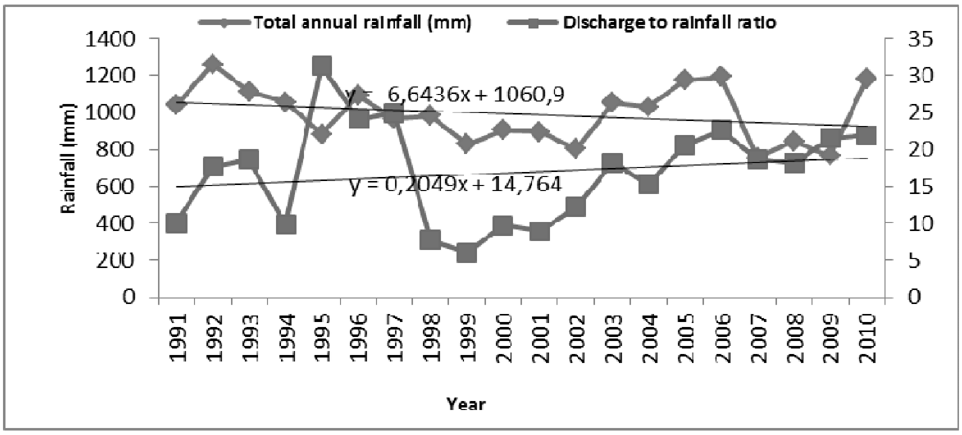


Fig. 6b. **Average annual discharge and discharge to rainfall ratio, 1991-2010**

Table 4. **Annual peak discharge with recurrence interval and exceedence probability, 1971-1990**

Peak discharge (Descending order)	Rank	Recurrence Interval	Exceedence Probability (%)
41310*	1	21.0	4.8
41100*	2	10.5	9.5
40425*	3	7.0	14.3
30665*	4	5.3	19.0
21621	5	4.2	23.8
20425	6	3.5	28.6
19801	7	3.0	33.3
18487	8	2.6	38.1
18243	9	2.3	42.9
18111	10	2.1	47.6
16410	11	1.9	52.4
15555	12	1.8	57.1
15117	13	1.6	61.9
14880	14	1.5	66.7
13501	15	1.4	71.4
11225	16	1.3	76.2
11000	17	1.2	81.0
8700	18	1.2	85.7
8674	19	1.1	90.5
4552	20	1.1	95.2

*Source***:** Department of Flood Control (P & D Division), Srinagar. *Secondary Floods

FigureS 6a and 6b clearly show that average annual discharge from 1991 to 2010 has remained above the average discharge line for most of the years. Total annual rainfall depicts a slight decreasing trend with respect to its average rainfall line.

Recurrence interval of various annual peak discharges from 1971 to 1990 has been shown in Table 4. The annual peak discharge with recurrence interval of one year is having an average magnitude of 9609 cusecs. Similarly the value of two year recurrence interval annual peak is calculated at 16386 cusecs with an exceedence probability of 54.76% which means that an annual peak discharge with magnitude of 16386 cusecs has a probability of 54.76% to be equaled or exceeded every two years on an average. The value of annual peak discharge with five year recurrence interval is 30665 cusecs. An annual peak with the calculated value of 41100 cusecs may be expected every ten years. The twenty year recurrence interval peak may come with a magnitude of 41310 cusecs, but the exceedence probability is only 4.8%.

It is inferred from Table 1.5 that the magnitude of annual peak discharge with different recurrence intervals has increased from 1991 to 2010. The magnitude of one year recurrence interval annual peak is 15397 cusecs and the two year recurrence interval annual peak has a magnitude of 19467 cusecs. The figures with asterisk sign show the secondary floods i.e. the floods that have over spilled the banks of the river due to the discharge beyond the retaining capacity of the channel or due to breaches caused in the banks.

Table 5. **Annual peak discharge with recurrence interval and Exceedence probability, 1991-2010**

Peak discharge (Descending order)	**Rank**	**Recurrence Interval**	**Exceedence Probability (% age)**
51638*	1	21.0	4.8
50361*	2	10.5	9.5
49677*	3	7.0	14.3
43731*	4	5.3	19.0
40886*	5	4.2	23.8
36867*	6	3.5	28.6
27728*	7	3.0	33.3
27534*	8	2.6	38.1
25697*	9	2.3	42.9
21913*	10	2.1	47.6
18281	11	1.9	52.4
17760	12	1.8	57.1
16721	13	1.6	61.9
16428	14	1.5	66.7
14740	15	1.4	71.4
14343	16	1.3	76.2
13404	17	1.2	81.0
12880	18	1.2	85.7
9285	19	1.1	90.5
27728	20	1.1	95.2

*Source***:** Department of Flood Control (P & D Division), Srinagar. *Secondary Floods

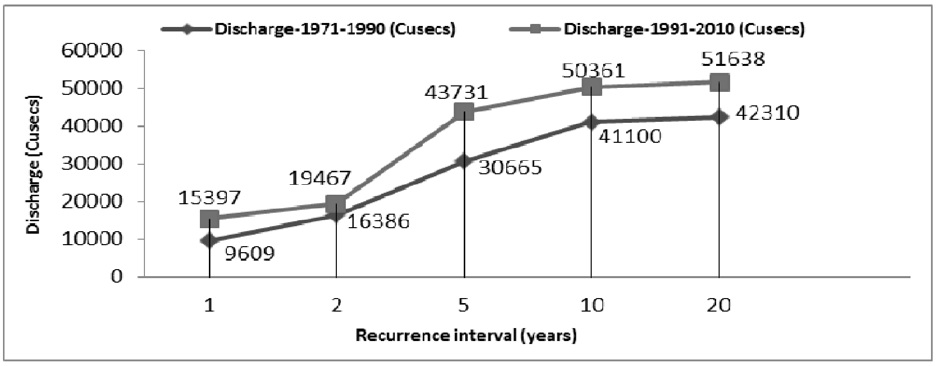


Fig. 7. **Comparative analysis of peak discharges betwwen1971-1990 and 1991-2010**

An annual peak discharge of 43731 cusecs, 50361 cusecs and 51638 cusecs may be expected every five, ten and twenty years with the exceedence probability of 19%, 9.5% and 4.8% respectively. It is clear from Figure 7 that the volume of discharge associated with the annual peak discharges has been substantial from 1991 to 2010 as compared to the period 1971-1990.

5. Conclusion

The results revealed that the detected land use changes have increased peak discharges and flood runoff volumes within the catchment. This effect was more severe within the upstream areas where higher rates of deforestation and agricultural expansion were rampant. However, the relative increases in the peak discharges were noted to diminish with increasing rainfall amounts. This portended that the detected land cover changes did not have a strong influence during large storm events. The results of the analysis have highlighted the remarkable sensitivity of the flood flow regime in response to the occurred land use changes, which implies an increase in the magnitude of peak discharges of a given frequency. Precipitation is a major factor controlling the hydrology of a region. For this purpose total annual rainfall and runoff data from 1971 to 2010 were plotted to analyze the rainfall-runoff relationship in the study area. The investigations show that changes in land use has produced significant change in the peak flow and the average discharge. From 1971 to 1990 there have been only four floods while as the river Jhelum has flooded ten times from 1991 to 2010. From 1991 onwards the study area witnessed good number of dry years. Despite this fact, five floods have been recorded from 2001 to 2010 as discharge to rainfall ratio increased due to the changing land use pattern in the upper catchments.

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