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Evaluation of flood impacts vis-à-vis urban sprawl and changing climate in Srinagar city and its environs

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ABSTRACT
In the present study, the urban growth of Srinagar city was monitored using multi-temporal satellite data during 1972-2015. Also the flood inundation of 2014 was estimated using high resolution satellite images and correlated with the built-up land and its growth over the years. The study exhibits that the built-up area was increased from 5.12 km^2 to 109.67 km^2 with 21 time increase during 1972-2015. The flood inundation study revealed that a significant part of built-up area although lesser in proportion has been developed over the flood prone regions during 1972-2015 as 44% (48.5 km^2) of built-up area was possibly affected by the flood in 2015 as compared to 72% (3.70 km^2) in 1972. The settlement along the river is more vulnerable to flood and southern part of the river gets more risk as the river water spills towards the southern area by breaking its banks. As the urban growth is 21.4 times in last 5 decade within Srinagar municipal boundary and flood vulnerability increased by 13 times within the urban areas, the Srinagar city needs planning on aspect of urban flood management in order to safeguard valley inhabitants under erratic and extreme rainfall event in future.

Keywords: *Urban Growth, Flood hazards, Geoinformatics.*

INTRODUCTION

The urban growth is recognized by the physical and functional changes due to the transition of rural landscape to urban forms (Xiao *et al*., 2006). Rapid urbanization is one the most significant anthropogenic influence apparent on the earth surface (Dewan and Yamaguchi, 2008), which is induced by the high population increase in the era of globalization, privatization and liberalization (Van, 2008). This altered the natural land cover to irreversible impervious surfaces and affecting urban living conditions to a greater extent (Shaw, 1999). The considerable impacts evident in terms of decrease in infiltration and an increase in runoff (Arnold & Gibbons, 1996), degradation of drainage systems, ground water depletion and excessive erosion (Goudie 1990), groundwater depletion and contamination (Kumar and Pandey, 2016), deterioration of urban environment (Kumar et al., 2013). Also, the disaster vulnerability is substantially increased in the urban area due to rapid urbanization, population concentrations and their movement in changing climatic conditions, primarily affecting the low-income urban dwellers (Hardoy *et al.*, 1992).

Flood in the urban areas is one of the major natural disaster affecting worldwide a large population. Urban flooding is relatively short time phenomena, which is increasingly rising in the recent decade due to changing climatic conditions (Sebastian *et.al*, 2017). The complex impervious surface growth in urban area exacerbate the high intensity rainfall events to devastating flood situation to a greater extent. The increasing urbanization induce higher flood risk due to vast population residing within the urban area (Brush et al. 1968). This increasing flood intensity and reoccurrences influence the patterns of urbanization in the form of significant decrease (Hollis 1975). The integrated remote sensing and geographic information systems approach is being widely applied and recognized as a powerful operational instrument in urban growth mapping and monitoring (Yeh and Li 1996; Lal *et al.*, 2017) as well as in urban flood mapping, assessment and hazard zonation modeling. Flood hazard maps are also recognized as useful instruments for flood risk management in many other countries (Merz et al., 2007)

China and India together contain 37 percent of the world's total population, thus, their approaches to urban growth are particularly critical to the future of humankind (UNFPA 2007) that impose higher risk.

The occurrence of exceptionally heavy rainfall events and associated flash floods in many areas during recent years is attempted through study of long-term changes in extreme rainfall over India (Guhathakurta*et al.*, 2011). Flash floods are common in the Himalaya, but the kind of destruction witnessed in recent years was unparalleled in recent history (Rana et al., 2013). Srinagar City in J&K carried a unique ecological setup with extensive area under wetlands, lakes and water channels. The subsequent encroachment, earth filling, construction had alter the natural landscape and make it prone to urban flood situation (Rashid and Naseem, 2008). The flood of 2014 significantly affected the population of Srinagar (Mishra, 2015). Therefore, in the present study an attempt has been made to understand the urban growth patterns in Srinagar city during 1972-2015 and possible flood inundation patterns due to urban growth.

STUDY AREA

The area under investigation cover Srinagar city within the municipal boundary and lies between33˚59'14"N and 34˚12'37"N latitude and 74˚41'06"E and 74˚57'27"E longitude. The average relief of the study area is 1580m above mean sea level covering a total area of 285km^2 (Figure 1). Geographically, Srinagar lies in the northern part of India as it is the summer capital of Jammu and Kashmir State. It has unique topography, climate, economy, social setting and strategic location. Srinagar city is the major urban centre where Lal chowk is the main commercial location. The valley is a multi-hazard prone region with natural disasters like earthquakes, floods, landslides, avalanches, high velocity winds and snow storms. The population of Srinagar urban agglomeration is 1,236,829 persons (Census of India, 2011).

The Kashmir valley receives precipitation both in the form of rain and snow. The valley receives annual average precipitation of 650 mm, which is often higher in the outer hilly regions as compared to the central valley. The average temperature ranges from 7.5°C in winter (November to March) to 19.8°C in summer (June-August) (Husain 1998). The Kashmir valley has deciduous vegetation cover with the trees like Chinar, Poplar, Deodar, Fir, Pine, Kail, Partal, Mulbery, Walnut and other fruits, which grow throughout the year. Wular Lake and Dal Lake are the important lake of the valley. River Jhelum is the main feeder of these lakes, which originates from Verinag and flows northwards through the Wular Lake.

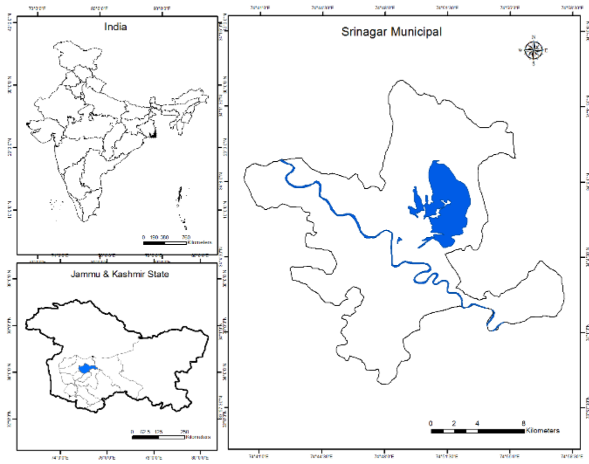


Figure 1: Location of study area

DATA AND METHODOLOGY

In the present study, various primary and secondary data were used to analyze and understand the effect of flood over the built-up in the Srinagar city within the municipal limits. The satellite images of LANDSAT 4 (30th Oct.1972) and LANDSAT 8 (13thSeptember 2015) were acquired from USGS website (http://earthexplorer.usgs.gov) for mapping the built-up lands. Google Earth images (HRS) used for mapping the flood inundation limit over the region. (Table 1; Figure 2). The built-up land were extracted from the satellite image using supervised classification by creating two class *viz.*, built-up and non-built-up. The built-up includes man-made area, which covers buildings, transport network (roadways, railways and airport) whereas all other areas are considered as non-built-up (agriculture/plantation, vacant land/ barren land/ water bodies *etc.*).

Srinagar city within the municipal limits was clipped from the satellite images of 30th Oct.1972 and 13thSept. 2015. Built-up map was prepared using supervised classification technique to delineate urban areas which leads to understand the urban expansion in the city. The quality of a supervised classification technique depends on the validity of the training sets (Palaniswami *et al.* 2006). Therefore, in the present study, 80 training sets were selected in order to perform correct classification.

Table 1: Details of satellite data used in the study

Name of Satellite	Sensor	Date of acquisition	Resolution (m)
LANDSAT-1*£	MSS	30th Oct.1972	57.5
LANDSAT-8*£	OLI	13th Sept.2015	30
Google Earth	HRS	10th Sept.2014	
TRMMβ	TRMM Precipitation Radar and TRMM Microwave Imager	June to September 2014 September 2014	

*Path and row: 92/46

£ Source: http://earthexplorer.usgs.gov

β Source: http://disc2.nascom.nasa.gov/Giovanni/tovas/

The HRS images were subjected to geometrical rectification with reference to other satellite images The georeferenced high spatial resolution satellite (HRS) data of 10 September 2014 covering Srinagar city was acquired from Google Earth with the help of El Shayal software for carrying the flood inundation mapping by visual interpretation technique. (*i.e.* LANDSAT) used in the present study. The high resolution image was classified into two flood inundations categories *viz.* flooded and non-flooded, which are based on the level of surface inundation and visibility of built-up features. The area inundated by flood water was considered as flooded. This flooded category also incorporate the urban area whose streets are inundated but buildings were visible and flood limits are visible in HRS image. Non-flooded are the area which are not affected/ inundated by flood water in any form. The area statistics of these categories was calculated from the classified images and analyzed in geospatial environment to deduce the urban sprawl and flood inundation.

Buffer of 1km and 500m were created along the Jhelum River in order to calculate the built-up area in 1972 and 2015 in the vicinity of river Jhelum. The built-up and area effected by flood was calculated within the buffer to analyze vulnerability of built-up to flood inundation. Zonal analysis was also performed by considering the Lal Chowk as the center of Srinagar city and four zones viz. 1, 2, 3 and 4were created. The urban sprawl in the different zones as well as flood inundation area in these zones was calculated for built-up growth pattern with reference to flood vulnerability.

Rainfall analysis was performed to understand the variation in the rainfall. To assess the spatial rainfall variability during monsoon seasons in the region, monthly accumulative Tropical Rainfall Measuring Mission (TRMM) multi-satellite precipitation analysis product were acquired from NASA website (http://disc2.nascom.nasa.gov/Giovanni/tovas/) in ASCII format during June to September months for the period of 2014. The TRMM rainfall intensity values recorded at various points were interpolated in GIS environment using the Inverse Distance Weightage (IDW) method of spatial interpolation to examine spatial variability of rainfall over the catchment (Singh et al. 2011). The TRMM rainfall data was interpolated to map the rainfall variability in Kashmir valley using ArcGIS software *ver.* 10.1.

RESULTS AND DISCUSSIONS

Urban growth of Srinagar city

The urban built-up map using the satellite images (LANDSAT 30th Oct.1972 and 13th Sept. 2015) was prepared to demarcate the built-up development within the Srinagar municipal boundary. It exhibits that built-up of 5.12 sq. km in 1972 where the most dominant settlement lies in the middle part of the city. The built-up area in year 2015 increased to 109.67 sq. km, which was 21.4 times of built-up area in 1972 (Figure 3). The built-up increased throughout the municipal boundary with high density along the Jhelum river. The classified image of 2015 demarcated the high density built-up in the lower parts (southern) of the river. Sparse built-up are demarcated in the upper (Northern) part of river. High density of built-up were also demarcated in the western parts of Dal lake whereas sparse in its upper side. This also clarified that the people like to settle down in the plain area and along the bank of river Jhelum. Shrinking of Dal lake during 1972-2015 witnessed in satellite image possibly reflect the impact of urban sprawl in its vicinity.

Inundation during 10 September 2014 vs. Built-up

The high resolution satellite (HRS) images from Google Earth was used to map the flooded area in the

Srinagar city (Figure 4). The total area under flood was calculated to be 102.8 sq. km which is 36% of the total

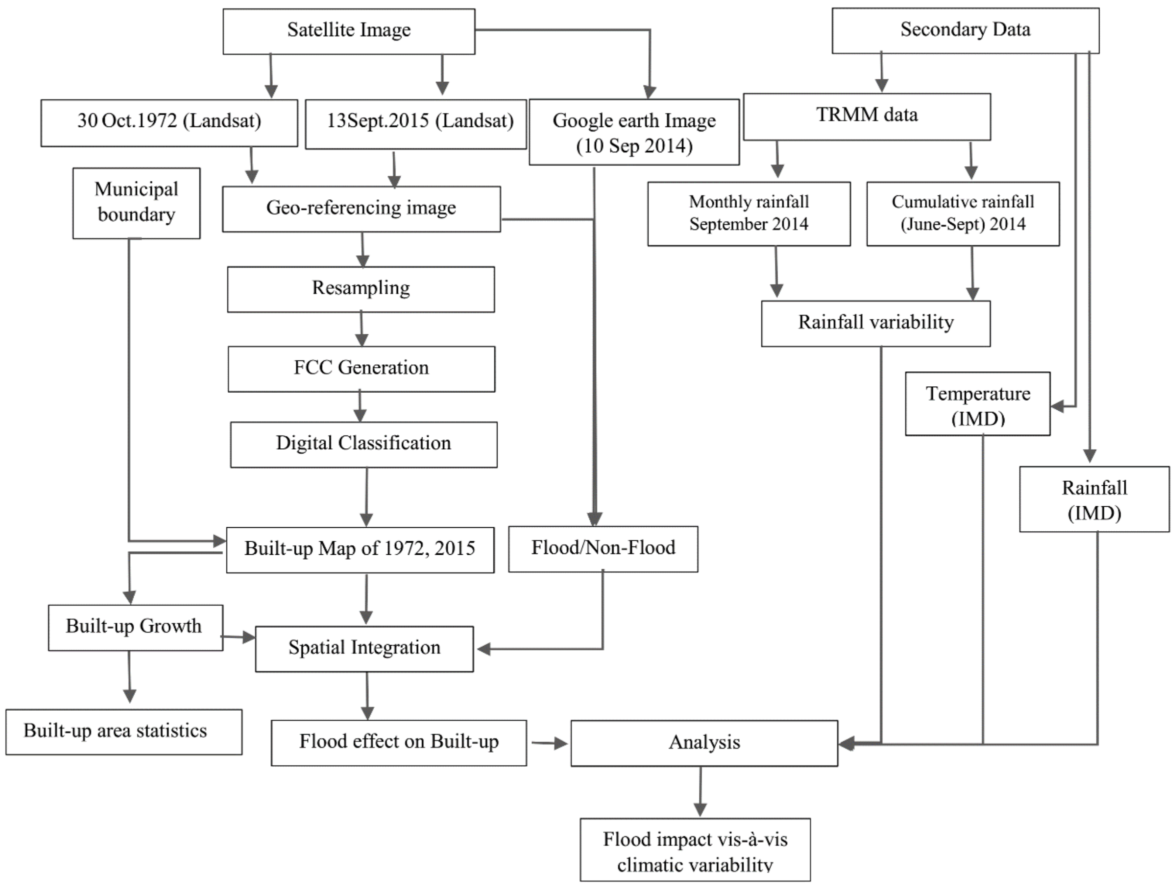


Figure 2: Flowchart of methodology

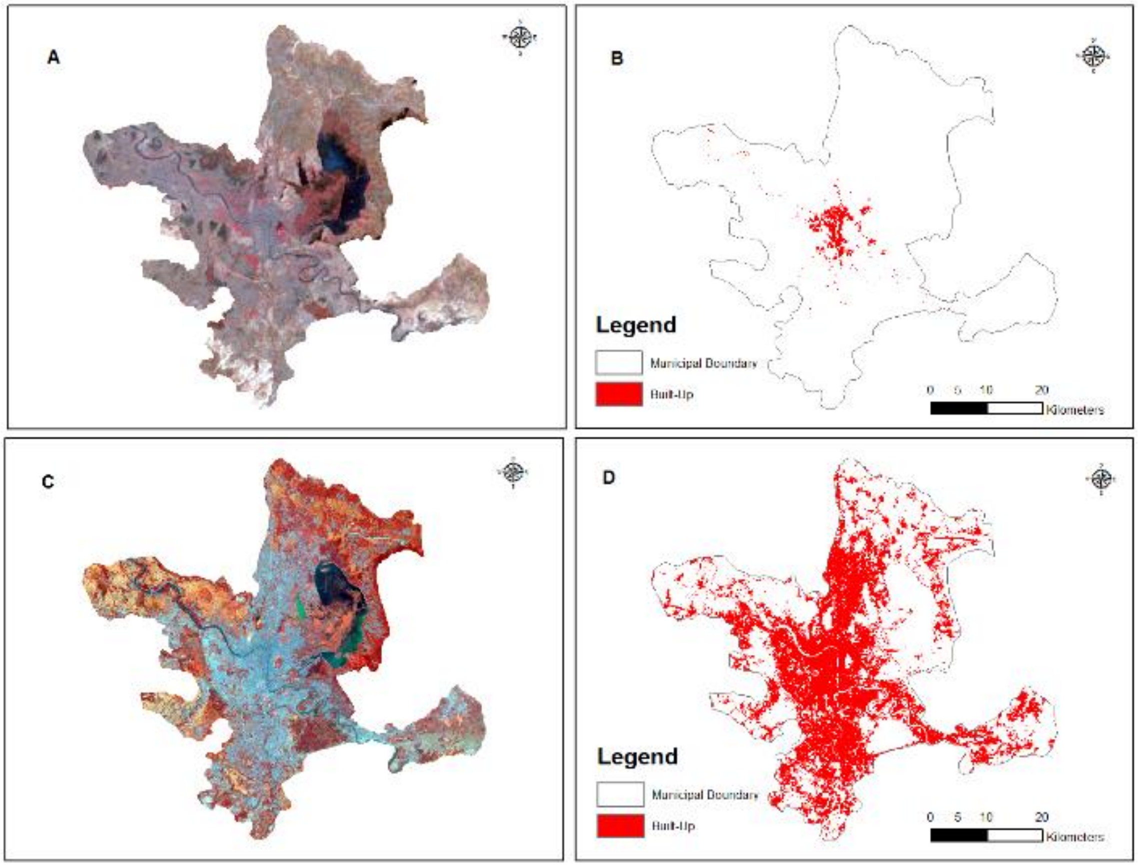
municipal area. The limits of Dal lake was exempted from the flooded category but the expansion of dal lake after breaking its limits was considered while calculating the accurate flooded area. The inundation within the dense build-up land was clearly represented in the high resolution Google Earth images, which was not visible in LANDSAT OLI satellite image. Therefore, visual interpretation technique was applied and kept the inundated streets and dense built-up land surrounded by the flood water into flooded category. Largely agriculture area was inundated outside the built-up areas.

It is evident from the satellite images that the downstream regions of the Jhelum River was highly affected by the flood. The places around the Dal Lake were the most affected as the over spilled water of the lake inundated the neighboring settlements and entire road network in the central parts of the Srinagar city. The Srinagar city has a number of small water channels and dense network of street roads, which passes through the colony and wards of the city. This leads to complete/ partially submergence of the city as these channels streets as well as roads became carrier for the flood water intrusion.

Comparing on temporal ground, the impacts of present flood with reference to built-up growth during 1972-2015indicated that if this flood would occurred in 1972, the total 3.7 sq. km of built-up would have been effected by flood. The built-up affected by flood increased in 2015 with an area of 48.5 sq. km under submergence making it 13 times more vulnerable to flood risk.

Table 2: Area statistics of built-up and built-up under flood

Year	Built-up (km^2)	% of total area	Built-up under flood	% of total area



1972	5.12	1.80	3.70	1.30
2015	109.67	38.5	48.50	17.02

The settlement along the river is more vulnerable to flood and southern parts of the river render more risk as the river water spills towards the southern area by breaking its banks. The urban growth is 21.4 times in last 5 decade within Srinagar municipal boundary, but the flood vulnerability increased by 13 times within the urban areas. The built-up areas along the river and Dal Lake are more vulnerable to flood impacts.

Buffer analysis along the Jhelum River during 30th October 1972 and 13th September 2015

Buffer analysis was performed to analyze the impact of flood on built-up development along the Jhelum River by creating 500m and 1 km buffer. The total built-up area in 1972 was calculated within 500m buffer was 3.58 sq. km, which increased to 20.15 sq. km in 2015 with a growth of 1915%. The built-up under flood in 1972 calculated as 3.58 sq. km, which shows the total inundation of built-up within the buffer of 500m. The built-up increased to 15.24 sq. km with a growth of 1424%. Further analysis was performed for 1km buffer, the built-up was 4.45 sq. km in 1972 which increased with growth of 3072% and calculated to be 31.72 sq. km for 2015. The built-up under the flood in 1972 was 3.19 sq. km, which increased to 22.41 sq. km in 2015. This clearly specify that as the buffer area is increased along the river, the built-up area is also increased with the increment to vulnerability of flood deducing the risk of settlement along the river.

Figure 3: (a) Satellite image acquired on 30th Oct. 1972, (b) classified image representing built-up in 1972,

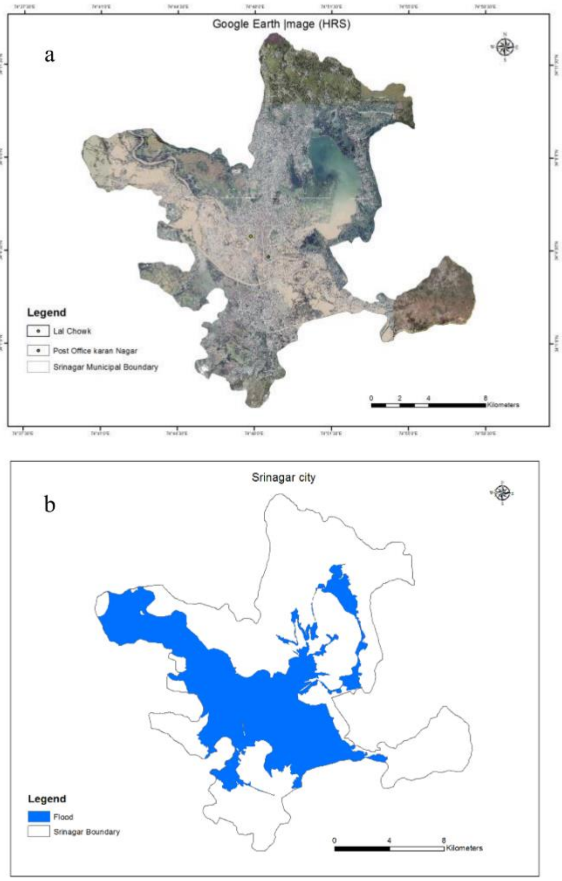


Figure 4: (a) High resolution image of Srinagar municipal boundary on 10 September 2014 (b) Flood inundation map of Srinagar city

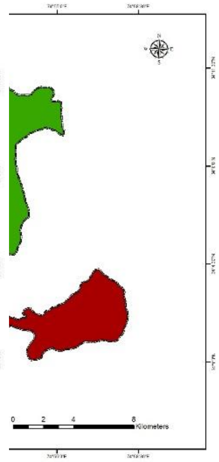


Figure 5: Zones created within Srinagar Municipal Limits for built-up growth vs. flood inundation analysis

Table 3: Area statistics of built-up area and built-up under flood within the buffer of 500m and 1 km from river bank (units area in km^2)

Year	0-500 Meters Buffer		0-1 Kilometer Buffer	
	Built-up	Built-up under Flood	Built-up	Built-up under Flood
1972	3.58	3.58	4.45	3.19
2015	20.15	15.24	31.72	22.41
Growth (%)	1915	1424	3072	2141

Zonal *Analysis*

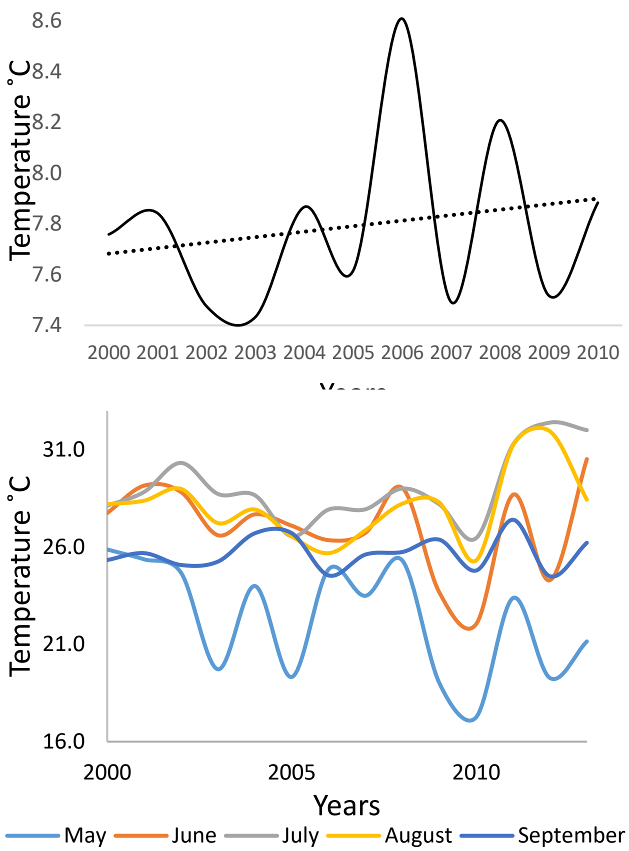
The zonal analysis indicated that built-up development was more in zone 1(69%) and zone 2(21%) during 1972 in comparison to minor development in zone 3&4. A reversal in built-up development was noticed in 2015 where zone 3 and zone 4 exhibited marked changes from 4% to 21% and 6% to 23% respectively (Figure 5). The flood impact clearly demonstrated that zone 3 and zone 4 are more vulnerable as it lies in the upper catchment area of Jhelum River as well as on southern side of Jhelum River. Therefore the built-up development during 1972-2015 in Srinagar was not done considering flood risk and vulnerability along the river banks which resulted in heavy damage and casualty during 2014 Srinagar floods

Table 4: Zonal Statistics of Srinagar city

Zone	1972	%	2015	%	Flood 2015
1	3.53	68.92	32.37	29.52	17.85
2	1.07	20.89	29.15	26.58	7.77
3	0.21	4.14	23.19	21.14	11.82
4	0.31	6.04	24.96	22.76	11.06
Total	5.12		109.67		48.50

Temperature Analysis

The average annual temperature of Srinagar city exhibit minimum of 7.4^{0}C and maximum of 8.6^{0}C with increasing trend along with episodic increase – decrease pattern reflecting erratic climatic conditions especially in post 2005 periods (Figure 6a). The average monthly temperature of Srinagar city exhibit minimum of 17.3^{0}C (May 2013) and maximum of 32^{0}C (July 2010). The average monthly temperature patterns indicated low variability till 2008, whereas in subsequent years high variation with extreme temperature up to 32^{0}C clearly indicate warming conditions in the valley largely during the month of July-August (Figure 6b).



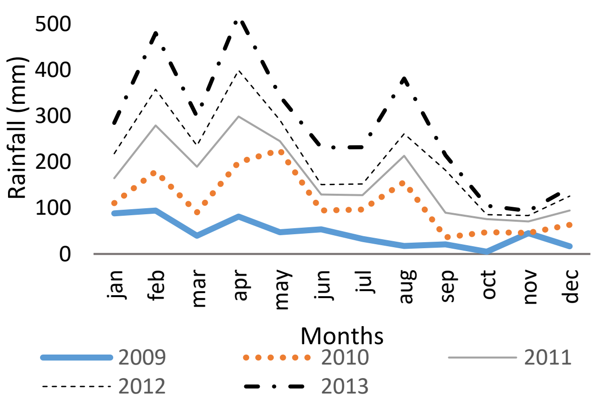


Figure 6: (a) Average annual temperature and (b) average monthly temperature of Srinagar city (source: IMD)

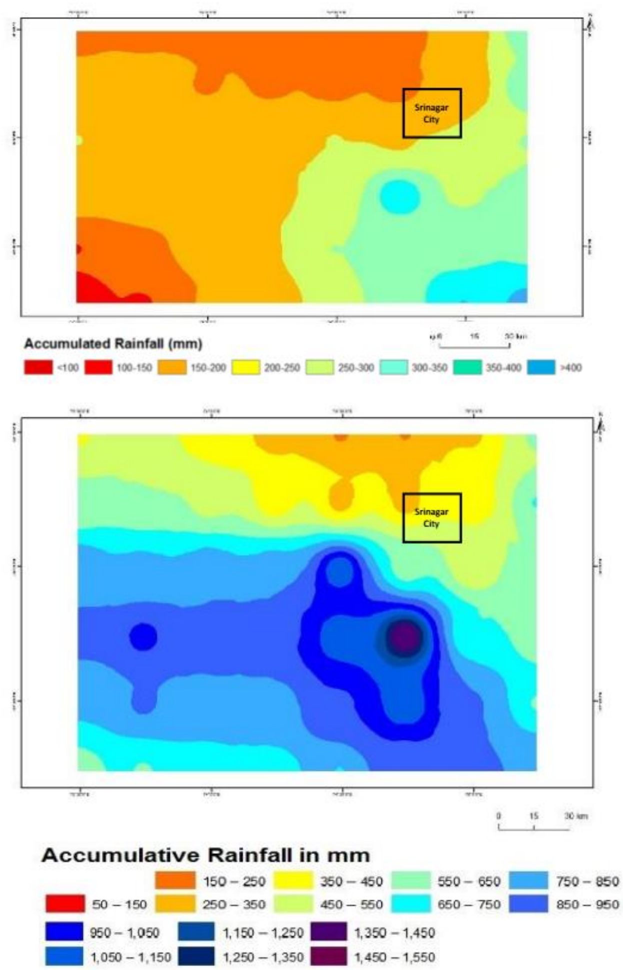


Figure 8: (a) interpolated TRMM rainfall map of September 2014 (b) interpolated TRMM accumulated rainfall map (June-September 2014)

The rainfall pattern reflects precipitation in the form of snow during Jan-Feb. and as rainfall during March-April periods. This precipitation as snow/rainfall upto maximum of 500 mm is not capable of producing river flooding in the valley (Figure 7). In contrast the monsoon rainfall during August-Sept. months is comparatively lower with maximum rainfall upto 400 mm could triggered flood situation in the valley in 2014. This could be attributed to increasing run-off due to snow melt from mountains surrounding forming the catchments of river and their tributaries which drains the Srinagar valley. This leads to increase of river water level during Aug-Sept. as well cumulative precipitation of about 1000 mm generated during June to Sept. resulted in inducing flood conditions in the valley as witnessed in June 2014 floods.

The comparative analysis of mean monthly maximum temperature during the period 1901-1950 and 1979-1996 revealed increase in mean maximum temperatures from 30.8°C to 32.4°C in the months of July (Singh., et al, 2000) which could change the snowfall and rainfall patterns during winter and summer season respectively. Increasing temperature trend especially during summer period, June to Sept. is therefore rendering the valley vulnerable to floods under conditions of high snow melt run-off and cumulative rainfall coupled with extreme rainfall continuously for a period of 2-3 days.

TRMM data acquired for the month of September 2014 represents increasing rainfall intensity from 160mm to 220mm (Figure 8a). The rainfall of September 2014 (160mm) was not anomalous to cause severe flood on its own. The variations in the accumulated rainfall (Figure 8b) was also calculated considering four months (June, July, August, and September). The rainfall intensity classes were categorized into 15 classes, where the rainfall variability ranges from 150mm to 1550mm. The accumulated rainfall patterns exhibit very high rainfall (>950mm) during 2014. Therefore it can be remarked that flooding during September 2014 was triggered due to the very high accumulated rainfall (1550mm) making the year 2014 as anomalous rainfall year. Largely the high rainfall zones during the month of September coincided with the southwestern portion of the valley. As the rivers had bank full water level received from runoff from its catchment and due to continuous rainfall, the valley soils got fully saturated creating vulnerable flood situation during September 2014.

CONCLUSION

The present study attempted urban growth in Srinagar city during 1972-2015 and flood inundation effects due to urban growth. The 21 times increase of built-up development between 1972 and 2015 reflect high influx of population to the Srinagar city which reflects increasing risk to flood hazard in the valley. The high resolution satellite (HRS) images indicated that total area under flood was 102.8 sq. km which is 36% of the total municipal area. The Srinagar city dense network of street roads, which passes through the colony and wards of the city render complete/ partially submergence of the city as these channels streets became carrier for the flood water intrusion. On temporal ground it can be remarked that if this flood would occurred in 1972, the total 3.7 sq. kms of built-up would have been effected by flood whereas the built-up affected by flood increased in 2015 by 48.5 sq. km. The settlement along the river is more vulnerable to flood and southern part of the river gets more risk as the river water spills towards the southern area by breaking its banks. As the urban growth is 21.4 times in last 5 decade within Srinagar municipal boundary and flood vulnerability increased by 13 times within the urban areas, the Srinagar city need planning on aspect of urban flood management in order to safeguard valley inhabitants under erratic and extreme rainfall event in future.

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