

Original Article

Impact of land use land cover changes at meso-level on the flood response of an inland city-A case of two watershed areas of Bengaluru, India

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Received: 22 November 2022; Revised: 7 March 2023; Accepted: 9 April 2023

Abstract

Floods in urban areas have become a common problem globally. Extensive research has been done to understand the changes in urban areas that are resulting in floods, such as Land Use Land Cover changes and insufficient subsurface sewer systems. However, many of these studies have concentrated on the city-level changes causing increased flood events. Hence, this paper explores the impact of temporal changes in Land Use Land Cover (LULC) at the geographic unit (meso) level on the flood response for inland cities. LULC changes for two watersheds, Ulsoor and Bellandur in Bengaluru, are assessed using Remote Sensing data and GIS, and flood metrics are calculated using the Hydrologic Engineering Center Hydrologic Modeling System (HEC HMS) between the years 2003 and 2021. Changes in LULC classes are correlated with the changes in flood metrics. Results indicate that the LULC changes were similar in the two watersheds but with varying rates of change. While changes in built-up areas impacted flood metrics in the Ulsoor watershed, vegetation and open land changes impacted the Bellandur watershed.

Keywords: LULC changes, urban floods, Meso-level, flood metrics

1. Introduction

Floods and waterlogging have become a significant global concern in most urban areas (Griffiths & Singh, 2019; Lin *et al.*, 2022; Locatelli, 2016; Nasrin, 2018). Expanding urban areas impact the urban ecology, resulting in various ecological disasters like increased frequency and intensity of precipitation, flooding, and waterlogging on streets (Mah, Bustami, Putuhena, & Dianty, 2022; Sjöman & Gill, 2014; Zimmermann, Bracalenti, Piacentini, & Inostroza, 2016).

Urban floods and waterlogging conditions are mainly caused by an increase in impervious cover, insufficient stormwater infrastructure, garbage dumping, stream

disconnects, and landscape fragmentation (Dai, Wu, & Du, 2018; Miller *et al.*, 2014; Zhao *et al.*, 2019). Much research has gone into understanding simulations, methods, and stormwater management models (SWM) (Boonrawd & Jothityangkoon, 2015; Bruwier *et al.*, 2020; Kayembe & Mitchell, 2018). SWM and flood mapping address the post-flood scenario to handle the excess stormwater generated in urban areas (Boonrawd & Jothityangkoon, 2015). However, focusing on the problems causing excess surface runoff reduces the load on SWM systems and can help improve urban ecology (Vietz & Hawley, 2018).

Spatio-temporal changes in LULC, increase in impervious cover and its location, Green Infrastructure (GI), and sustainable urban drainage systems (SUDS) have been vividly explored (Sharma, Rashednia, Gardner, & Begbie, 2019; Zimmermann *et al.*, 2016; Zope, Eldho, & Jothiprakash, 2016). Future urban sprawl and flood

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simulations also emphasize the changes in impervious cover at the urban level (Lin *et al.*, 2022; Nithila Devi, Sridharan, & Kuiry, 2019). Research indicates that LULC changes at the urban (macro) level confirm the increase in impervious cover and loss of green cover (Zope *et al.*, 2016). While this is true at an urban level, a meso-level understanding of LULC changes and the composition of urban landscapes is less explored (Miller & Brewer, 2018). Inland cities that depend heavily on underground water and lake bodies for day-to-day activities are undermined. To revive the health of streams and lakes, it is not just sufficient to secure the boundaries of streams and lakes, but we need to look beyond the borders and into the watershed (Vietz, Geoff J. Rutherford, Ian D. Fletcher, Tim D. Walsh, & Christopher J., 2016). Hence assessing the LULC changes at the watershed level, while the watersheds serve as integral parts of different administrative boundaries, needs to be pursued for a clear understanding of the hydrologic processes in the natural terrain.

This study aimed to use a combination of DEM model, to delineate a watershed, and LULC maps of the watershed to study the impacts of LULC change trends on flood response. Four objectives were set for the same: (a) to identify different watersheds in an urban area, (b) to explore the LULC changes in the watershed over a period, (c) to simulate the flood metrics, and (d) to assess the impact of LULC changes on the flood metrics.

2. Study Area

Bengaluru (Figure 1), known as the “Silicon City of India,” is the capital of the Indian state of Karnataka. The city is spread across 741 Sq. Kms and registered the highest population growth of 44% from 2001-to 2011, much higher than the state's (31.5%) or the country's (31.8%) (Ramachandra, Shivamurthy, Vinay Aithal, Bharath, 2017). Located between 12°49' 55" N to 13°8' 32" N and 77°27' 29" E to 77°47' 2" E, and at an elevation ranging between 740M and 960M above the Mean Sea Level (MSL), Bengaluru has a

pleasant climate throughout the year. Summer temperatures range between 21°C and 34°C, and winter temperatures are between 15°C and 25°C. Bengaluru receives an average annual precipitation of 800 mm.

The city has an undulating topography and an interconnected lake system falling into three valleys, with the Koramanagala Challaghatta valley (KC Valley) being the biggest of the city. These lake systems are interconnected receiving the overflowing water from the preceding lake and serve as freshwater sources for domestic and irrigation purposes. Varthur Lake series from the KC valley is the largest of all the existing lake series within the city, and has the largest lake in the city- Bellandur. The KC Valley Lake series begins with Ulsoor lake, located in the city centre. Ulsoor lake has a catchment area of 11.13 sq. km, and the catchment of Bellandur lake extends over 28.81 Sq. Km.

3. Materials and Methods

3.1 Subbasin delineation

Advanced Space Borne Thermal and Reflection Radiometer Digital Elevation Model (ASTER DEM) provides accurate data (Khasanov, 2020) in plains and is used to delineate the watershed area of the Bellandur lake series. The DEM model of Bengaluru is given in Figure 2. Hydrology tools from the Spatial Analyst toolbar of ArcGIS were used to delineate the watersheds. Lake boundaries of Ulsoor and Bellandur were vectorized using the Google Earth Raster Image and Survey of India (SOI) Toposheet. Ulsoor and Bellandur Lake boundaries were used to select the outlet points for delineating the lake watersheds. The delineated watersheds were exported to HEC HMS to identify the subbasins within each watershed using the GIS processing. Smaller subbasins were merged to achieve an average area of 1.2 sq. km for Ulsoor and 1.8 sq. km for Bellandur (Figure 4) (U.S. Army Corps of Engineers, 2017). The subbasins of the Ulsoor and Bellandur watersheds are given in Figure 3.

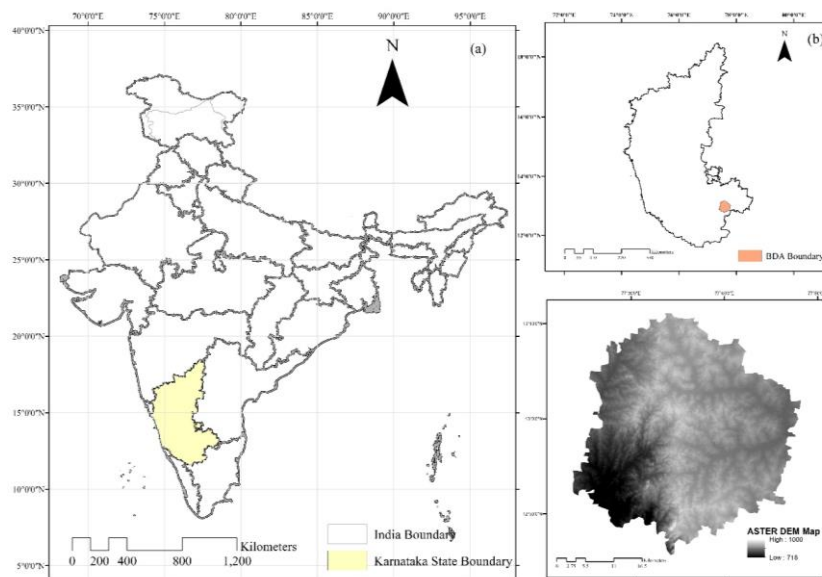


Figure 1. (a) Map of India with state boundaries, (b) Karnataka state map with the Bengaluru Development Authority (BDA) limits, and (c) DEM map of Bengaluru

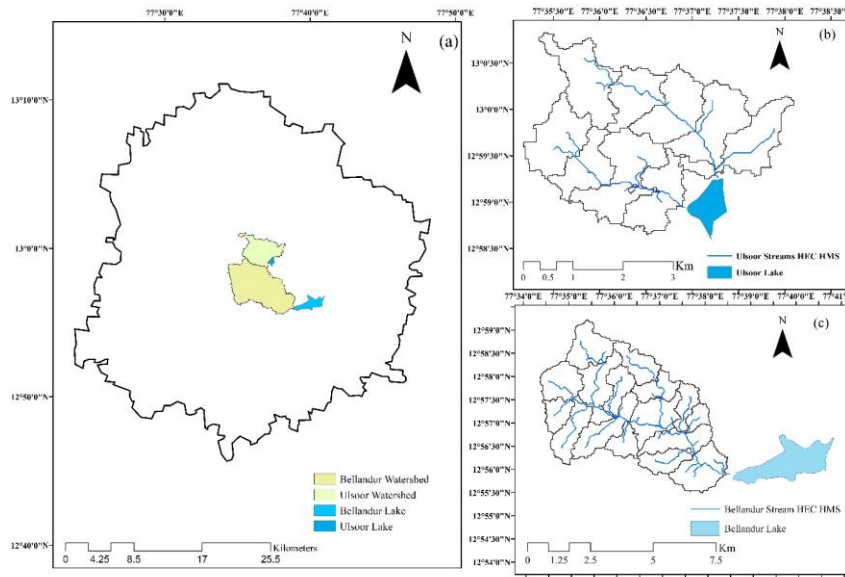


Figure 2. (a) Bengaluru map with the study watersheds and lakes, (b) Ulsoor watershed and lake with the natural streams, and (c) Bellandur watershed and lake with the natural streams

3.2 LULC mapping

Using Landsat satellite data, temporal changes in LULC were mapped for 2003 and 2021. Study area data were downloaded from Landsat 8 Operational Land Imager (OLI) for 2021 and Landsat 7 Enhanced Thematic Mapper (ETM) for 2003, from the United States Geological Survey (USGS) Earth Explorer archives. Data were collected for March and April to minimize the cloud presence and other seasonal influences. A very popular Maximum Likelihood classification tool for Image classification in ArcGIS 10.8 was used to identify four LULC classes: Built-up area, Vegetation, Open land/Agriculture, and Water (Ramachandra *et al.*, 2017). A total of 5546 and 4742 training samples for different LULC types were randomly selected across the image.

3.3 Accuracy assessment

The confusion matrix and Kappa coefficients were calculated to assess the accuracy of the classified images. Forty ground truth points per LULC class (four LULC classes were considered in the study for a total of one hundred and sixty ground truth points) were selected from the satellite image of Bengaluru City and validated against the classified pixels from the LULC image. Users Accuracy (UA), Producers Accuracy (PA), and Kappa Coefficient were calculated for the two periods, in 2003 and in 2021. Further, Kappa Coefficient was calculated to estimate the accuracy of the LULC classification (Maps & GIS Library, 2017).

3.4 Curve number generation

Curve Number (CN) is an empirical parameter that is used in hydrology for calculating direct runoff or infiltration. It is a property expressed as a combination of the soil group and LULC of the study area.

A 250-M resolution soil map from the Global Hydrologic Soil Group (GHSG) was used for CN generation (Ross *et al.*, 2018). These data were retrieved from ORNL Distributed Active Archive Centre (ORNL DAAC) repository. CN for different soil groups is given in the HEC HMS manual (U.S. Army Corps of Engineers, 2017), as shown in Table 1. The soil group, LULC, and the soil group's infiltration capacity are the major determining factors in deriving the Curve Number (CN) map and were calculated using a semi-automatic plugin in QGIS. Lag was taken as 0.6 times the T_c , given in hours, and converted to minutes. Lag in minutes was given as an input to the SCS Unit Hydrograph for the Transformation.

Time of concentration (T_c) is provided by

$$T_c = \frac{l^{0.8}(S+1)^{0.7}}{1140Y^{0.5}} \quad (1)$$

where l is given by flow length in feet, Y is the average slope of the watershed, S is the maximum retention possible, and T_c is provided by Time of Concentration.

The CN map was then exported to ArcGIS to calculate the mean CN for the subbasin using the "Zonal Statistics as Table" tool. The method presents a limitation as the soil data were given at a 250M resolution. Soil data with much more satisfactory spatial resolution can increase the accuracy of flood modelling.

3.5 Hydrologic modelling using HEC HMS

HEC HMS requires a basin model that uses the terrain data as input, a meteorologic model, and a control specifications manager to simulate a hydrologic event. The watersheds of the study lakes, Ulsoor and Bellandur, are delineated using Hydrology tools in ArcGIS and exported to HEC HMS for hydrologic modelling, as shown in Figure 3.

Table 1. Runoff Curve Numbers for various soil groups

Land-use type	Runoff curve numbers (C.N.) for various soil groups					
	A	B	C	D	C/D	D/D
Built-up area	57	72	81	86	83.5	86
Vegetation	30	59	71	78	74.5	78
Open Land	67	77	83	87	85	87
Water	100	100	100	100	100	100

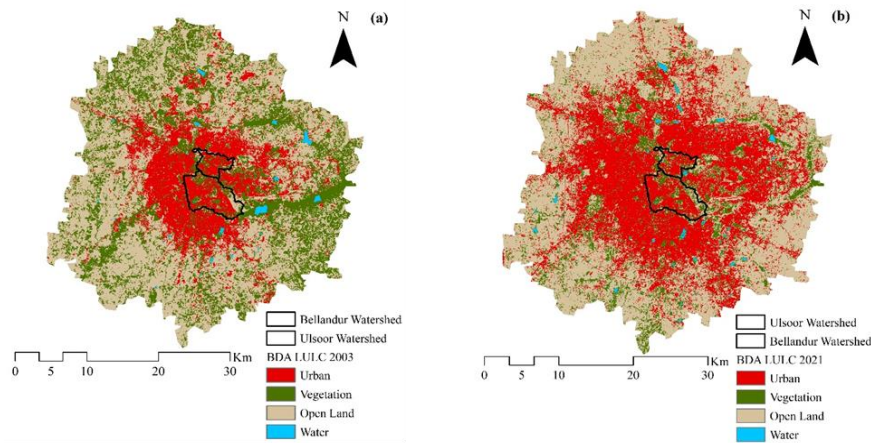


Figure 3. LULC maps of Bengaluru for (a) 2003, and (b) 2021

SCS curve number was calculated using the GHSG data as input to the loss method, and the SCS unit hydrograph was adapted for the Transformation. Lag time was calculated and used as input to the Muskingum routing method. A 48-hour storm rainfall data with an interval of one hour was given as input to the precipitation data. A frequency storm of 1-hour duration was calculated for two days. Flood metrics Peak Discharge (m³/s), Peak volume (m³), and peak time were collected for the study of watersheds between 2003 and 2021.

Rainfall runoff was calculated using the storm frequency method with 48-hour data as input. Rainfall data were derived from the weather file of Bengaluru, downloaded from the Climate.Onebuilding.org archives.

4. Results

4.1 Changes in the LULC

The temporal changes in LULC between 2003 and 2021 in Bengaluru, for Ulsoor watershed and Bellandur watershed, are given in Table 2. LULC maps generated using ArcGIS are shown in Figure 4. LULC changes in the subbasins of the Ulsoor and Bellandur watersheds are given in Table 4.

The built-up area across the two study areas depicted different change trends, as shown in Figure 5. The built-up area of Bengaluru had nearly doubled between 2003 and 2021, with an increase of 98.1% from 244.17 sq. Km to 485.20 sq. Km. However, the built-up area in the Ulsoor watershed has nearly remained the same, with an increase of 0.02 Sq. Km. Bellandur watershed experienced a slight increase in built-up area from 18.94 sq. km in 2003 to 19.31 sq. Km in 2021, with a 1.92% increase. As given in Table 2, a decrease in Vegetation is observed at macro and meso levels,

indicating the loss of Vegetation. Bengaluru lost over half of its greenery, 59.20%, from 389.17 sq. km to 158.77 sq. km. A similar decline is observed in Ulsoor and Bellandur, with decreases of 16.76% and 18.66%, respectively. While the open areas had slightly reduced in Bengaluru (macro-level) by 1.94% with a fall of 11.0 sq. km, there was an increase of open lands in Ulsoor and Bellandur by 49.96%, and 33.94%, respectively. Open areas had increased from 1.24 sq. km to 1.84 sq. km in Ulsoor and 4.3 sq. km to 5.75 sq. km in Bellandur between 2003 and 2021. With doubled built-up area and losing half of the greenery (to built-up areas and open lands), Bengaluru experienced significant LULC changes from extensive urbanization. Since the areas covered by water did not exhibit significant variations, only three LULC classes are considered for further study.

4.2 Accuracy assessment of LULC

A total of 160 ground truth points each were selected for 2003 and 2021 from the Landsat images and were compared against the same pixels from the LULC image, to assess the accuracy of the classified image. This gives a comparative assessment and reliability of the LULC classification. Producer's accuracy (PA) and User's accuracy (UA) were calculated for each year along with overall accuracy and Kappa Coefficient to indicate the dependability of the LULC classification (Table 3). The Kappa coefficient was higher than 90% for each year. Built-up area and Vegetation achieved 100% accuracy in 2003, while open land and water were classified with 100% accuracy in 2021. The presence of Vegetation in waterbodies possibly affected the PA of water in 2003. With average PA of 96.87% and 93.75% for 2003 and 2021, the LULC classification can be relied upon for the study (AnindyaBasu, 2021).

Table 2. LULC changes in Bengaluru, Ulsoor and Bellandur from 2003 to 2021

		Built-up	Vegetation	Open land	Water
Bengaluru	2003 (Area in Sq. Km)	244.17	389.17	673.40	7.41
	2021 (Area in Sq. Km)	485.20	158.77	662.38	7.80
	Change (Area in Sq. Km)	241.03	-230.40	-11.03	0.40
	% Change	98.71	-59.20	-1.64	5.38
Ulsoor	2003 (Area in Sq. Km)	7.88	3.84	1.24	0.01
	2021 (Area in Sq. Km)	7.90	3.20	1.86	0.00
	Change (Area in Sq. Km)	0.02	-0.64	0.62	0.00
	% Change	0.25	-16.76	49.96	-83.33
Bellandur	2003 (Area in Sq. Km)	18.94	9.85	4.29	0.05
	2021 (Area in Sq. Km)	19.31	8.01	5.75	0.07
	Change (Area in Sq. Km)	0.36	-1.84	1.46	0.02
	% Change	1.92	-18.66	33.94	29.31

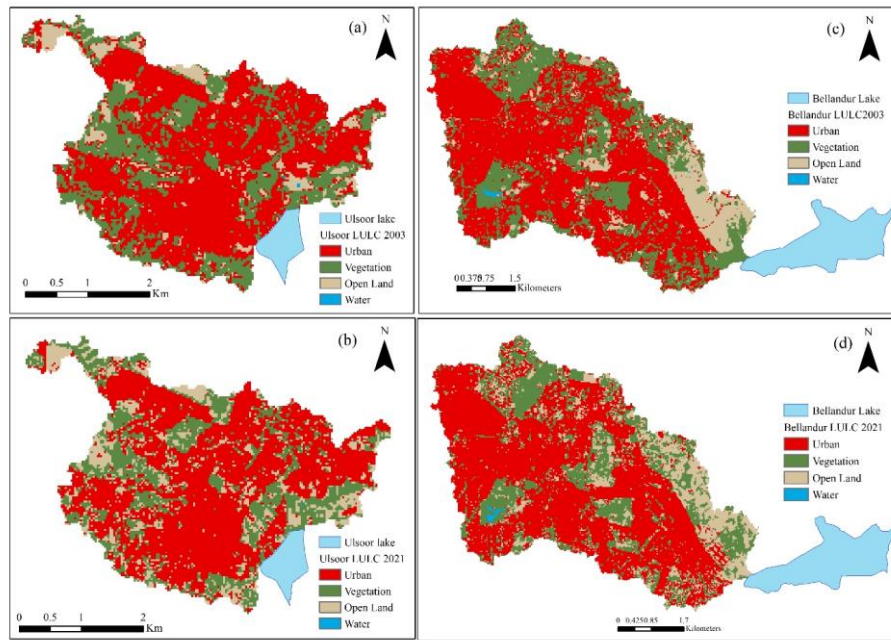


Figure 4. LULC maps of Ulsoor watershed for (a) 2003, and (b) 2021; and of Bellandur watershed for (c) 2003, and (d) 2021

Table 3. Accuracy assessment and kappa coefficient for the LULC classification

	Year	Built-up area	Vegetation	Open land	Water
Producer's accuracy	2003	100	100	90	97.5
	2021	100	100	97.5	77.5
User's accuracy	2003	88.89	100	100	100
	2021	97.6	81.6	100	100
Overall accuracy	2003	0.968			
	2021	0.937			
Kappa coefficient	2003	0.958			

4.3 Flood metrics

It is noted from Ulsoor (Table 4) that the Peak discharge had reduced while the peak volume from the subbasins was increased. Though the changes in Time of Peak are not significant, it highlights the early occurrences of flood events at the outlets. Peak volumes, however, had increased

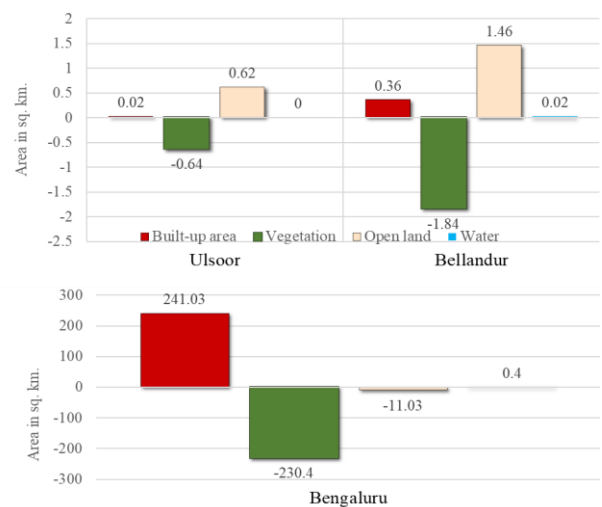


Figure 5. Graph showing LULC changes in Ulsoor and Bellandur watershed areas and in Bengaluru city

Table 4. LULC changes and flood metric changes in the subbasins of Ulsoor and Bellandur watersheds

Watershed	Subbasin	Change in LULC areas (sq km.) between 2003 and 2021			Change in Flood metrics between 2003 and 2021		
		Built-up	Vegetation	Open land	Peak discharge (m ³ /s)	Time of peak (minutes)	Peak volume (m ³)
Ulsoor	Subbasin-1	-0.045	-0.035	0.080	-0.4	-2	21
	Subbasin-13	-0.023	-0.150	0.174	-0.2	-3	27.3
	Subbasin-2	-0.063	-0.073	0.136	-0.3	-3	18.1
	Subbasin-5	0.375	-0.293	-0.082	-0.3	-2	15.5
	Subbasin-6	-0.023	-0.068	0.090	-0.5	-3	25.3
	Subbasin-7	0.046	-0.119	0.073	-0.6	-3	31.7
	Subbasin-8	-0.077	-0.008	0.085	-0.3	-2	18
	Subbasin-9	-0.049	-0.021	0.072	-0.9	0	22.8
	Bellandur	Subbasin-1	0.054	-0.152	0.098	0	-22
Subbasin-10		0.012	-0.014	0.003	0	-3	0.6
Subbasin-12		-0.008	-0.046	0.054	0	-9	2.2
Subbasin-13		-0.019	-0.085	0.087	0.1	-20	5.4
Subbasin-14		-0.118	-0.127	0.245	0	-34	6.8
Subbasin-17		0.075	-0.257	0.183	0	-38	12.1
Subbasin-18		-0.068	-0.183	0.250	0	-58	9.1
Subbasin-2		-0.003	-0.088	0.091	0	-23	4.1
Subbasin-3		0.254	-0.398	0.144	0.1	-48	16.4
Subbasin-31		0.028	-0.052	0.024	0.1	-10	2.3
Subbasin-4		-0.048	-0.059	0.106	0.1	-9	3.3
Subbasin-40		-0.007	0.038	-0.030	0	3	-1.4
Subbasin-49		0.126	-0.100	-0.026	0	-14	3.7
Subbasin-5		0.023	0.182	-0.205	0	-32	-8.1
Subbasin-8		0.049	-0.113	0.064	0.1	-26	4.8
Subbasin-9	-0.042	-0.159	0.202	0.1	-37	8.1	

Table 5. Spearman’s rank correlation coefficient matrix between LULC changes and flood metric changes

LULC type	r- value, p-value	Built up area	Vegetation	Open land	Peak discharge	Peak volume	Time of peak
Ulsoor watershed							
Built area	Correlation	1	-0.33	0.05	-0.41	0.88	-0.48
	p (2-tailed)		0.42	0.911	0.307	0.04	0.226
Vegetation	Correlation	-0.33	1	0	-0.39	-0.14	0.5
	p (2-tailed)	0.42		1	0.339	0.736	0.212
Open land	Correlation	0.05	0	1	0.54	0.29	-0.68
	p (2-tailed)	0.911	1		0.17	0.493	0.065
Bellandur watershed							
Built up area	Correlation	1	-0.17	-0.36		0.09	-0.05
	p (2-tailed)		0.52	0.165		0.729	0.841
Vegetation	Correlation	-0.17	1	-0.82		-0.98	0.79
	p (2-tailed)	0.52		<.001		<.001	<.001
Open land	Correlation	-0.36	-0.82	1		0.85	-0.69
	p (2-tailed)	0.165	<.001			<.001	0.003

considerably. Similarly, the Bellandur watershed also experienced little to no change in peak discharge while the peak volumes have increased and range from 0.6 m³ to 16.4 m³. Two subbasins within the Bellandur watershed had experienced a fall in peak volume. Noticeable changes are the decrease in time of Peak with as low as 9 minutes to 58 minutes. Though the change trends in LULC are similar in both watersheds, the changes in flood metrics are not similar.

4.4 Analysis of changes in LULC and flood metrics

The difference in the LULC areas of the subbasins and flood metrics for the study between 2003 and 2021 were compared. Normality tests were performed for the data to assess the normality of distributions. By Shapiro- Wilk’s Test

(*p-value*<0.05) (Shapiro & Wilk, 1965) and visual inspection of the Histograms and Q-Q Plots, the variables studied were majorly not normally distributed. Spearman’s correlation coefficient was calculated for the non-normally distributed data (Spearman & Spearman, 1904). The correlations show that the LULC class majorly impacted the changes in flood metrics, as given in Table 5. Factors with correlation >0.75 and 2-tailed significance values less than 0.05 are highlighted.

A minor change in the built-up area of Ulsoor resulted in higher Peak volume, whereas no significant relation is found for the built-up area in Bellandur. Also, an increase in the open land and decline in vegetation in Bellandur resulted in increased peak volume in Bellandur. In contrast, increase in open land in Bellandur resulted in early time of peak.

5. Discussion

LULC changes mapped for Bengaluru between 2003 and 2021 in this study also emphasized the increase in the built-up area and extensive loss of Vegetation. A similar trend of increased Impervious Cover (IC) and decreased green cover is also seen in the watersheds and subbasins at the meso-level. However, the core urban area of the Ulsoor watershed experienced near saturation with little change in the built-up area, while in the Bellandur watershed, the lost vegetative cover resulted in increased built-up areas and open lands, reflecting the general urbanization process. These saturated urban pockets with dense built-up areas result in increased flood discharge.

The same is evident through the calculated flood metrics, from the increased Peak discharge and Peak volume and reduced time to reach the Peak. The peak discharge had reduced in the Ulsoor watershed subbasins while remaining nearly unaltered in the Bellandur watershed. However, the peak volume had increased across all the subbasins of the study areas. Further, a significant reduction in the time of Peak was observed.

It was observed that the peak volume is impacted in the Ulsoor watershed with a minor change in the built-up areas, whereas loss of Vegetation in the Bellandur watershed resulted in increased peak volume. The reason for this varied impact of changes in the LULC on the flood metrics needs further understanding. In a much-concentrated Ulsoor watershed, the remaining flood metrics are not impacted from the changes in the LULC. However, Vegetation and open land exhibited complementary behaviours towards the flood metrics in the Bellandur watershed, indicating that striking an equilibrium between vegetated and open lands, built-up area is essential to containing the flood situations.

6. Conclusions

Urbanization has caused extensive damage to the ecological resources, hampering the liveability of cities and resulting in man-made disasters like Urban Heat Island (UHI), Urban floods, and waterlogging. This study examined the impact of meso-level LULC changes between 2003 and 2021 on flood metrics. While macro-level changes of LULC present a general condition of the overall situation, each geopolitical region exhibits an apparent response to the prevailing conditions. Analysis was done using various tools and methods in ArcGIS, QGIS, and HEC HMS, showing a strong picture of LULC changes in the two study watersheds, namely Ulsoor and Bellandur of KC Valley Bengaluru. Results are not uniform in the two study areas and suggest that a specific LULC class from each watershed significantly impacts the hydrologic response. The built-up area in the Ulsoor watershed considerably impacts Peak volume, whereas Vegetation noticeably affects the Bellandur watershed. Open land has less impact in the Ulsoor, contrasting with the Vegetation in the Bellandur watershed. This study can give new insights into planning and managing flood responses in different areas. Also, the findings present ideas for meso and micro-level zonal regulations for better flood response and ecological conditions. This study presents a limitation in terms of data accuracy and availability. Various other physical

features of the watersheds, like the location, terrain, and connectivity, can impact the flood metrics and be in the scope for future studies.

References

- Boonrawd, K., & Jothityangkoon, C. (2015). Mapping temporal extent of Chiang Mai floods using coupled 1-D and quasi 2-D floodplain inundation models. *Songklanakarin Journal of Science and Technology*, 37(2), 171–181. Retrieved from <https://rdo.psu.ac.th/sjst/article.php?art=1489>
- Bruwier, M., Maravat, C., Mustafa, A., Teller, J., Pirotton, M., Erpicum, S., . . . Dewals, B. (2020). Influence of urban forms on surface flow in urban pluvial flooding. *Journal of Hydrology*, 582. Retrieved from <https://doi.org/10.1016/j.jhydrol.2019.124493>
- Dai, E., Wu, Z., & Du, X. (2018). A gradient analysis on urban sprawl and urban landscape pattern between 1985 and 2000 in the Pearl River Delta, China. *Frontiers of Earth Science*, 12(4), 791–807. Retrieved from <https://doi.org/10.1007/s11707-017-0637-0>
- Griffiths, J. A., & Singh, S. K. (2019). *Urban hydrology in a changing world*. Springer Water. New York, NY: Springer International. Retrieved from https://doi.org/10.1007/978-3-030-02197-9_3
- Kayembe, A., & Mitchell, C. P. J. (2018). Determination of subcatchment and watershed boundaries in a complex and highly urbanized landscape. *Hydrological Processes*, 32(18), 2845–2855. Retrieved from <https://doi.org/10.1002/hyp.13229>
- Khasanov, K. (2020). Evaluation of ASTER DEM and SRTM DEM data for determining the area and volume of the water reservoir. *IOP Conference Series: Materials Science and Engineering*, 883(1). Retrieved from <https://doi.org/10.1088/1757-899X/883/1/012063>
- Lin, J., He, P., Yang, L., He, X., Lu, S., & Liu, D. (2022). Predicting future urban waterlogging-prone areas by coupling the maximum entropy and FLUS model. *Sustainable Cities and Society*, 80(March), 103812. Retrieved from <https://doi.org/10.1016/j.scs.2022.103812>
- Locatelli, L. (2016). *Modelling the impact of Water Sensitive Urban Design technologies on the urban water cycle*. Lyngby, Denmark: Technical University of Denmark.
- Mah, D. Y. S., Bustami, R. A., Putuhena, F. J., & Dianty, M. Al. (2022). Mitigating street flooding with permeable structures: A modelling case study. *Songklanakarin Journal of Science and Technology*, 44(4), 1091–1098.
- Maps & GIS Library. (2017). *Accuracy Assessment of an image classification in Arcmap*. Retrieved from <http://library.tamu.edu/maps-gis>
- Miller, J. D., & Brewer, T. (2018). Refining flood estimation in urbanized catchments using landscape metrics. *Landscape and Urban Planning*, 175(September 2017), 34–49. Retrieved from <https://doi.org/10.1016/j.landurbplan.2018.02.003>

- Miller, J. D., Kim, H., Kjeldsen, T. R., Packman, J., Grebby, S., & Dearden, R. (2014). Assessing the impact of urbanization on storm runoff in a peri-urban catchment using historical change in impervious cover. *Journal of Hydrology*, 515, 59–70. Retrieved from <https://doi.org/10.1016/j.jhydrol.2014.04.011>
- Nasrin, T. (2018). Water Sensitive urban design (WSUD) strategies to mitigate the impacts of intense rainfall on the sanitary sewer network performance. Victoria University, (Issue March). Melbourne, Australia: Victoria University.
- Nithila Devi, N., Sridharan, B., & Kuiry, S. N. (2019). Impact of urban sprawl on future flooding in Chennai city, India. *Journal of Hydrology*, 574(April), 486–496. Retrieved from <https://doi.org/10.1016/j.jhydrol.2019.04.041>
- Ramachandra, T. V., Shivamurthy, V., & Aithal, B. (2017). Frequent floods in Bangalore: Causes and remedial measures (Issue December).
- Ross, C. W., Prihodko, L., Anchang, J., Kumar, S., Ji, W., & Hanan, N. P. (2018). HYSOGs250m, global gridded hydrologic soil groups for curve-number-based runoff modeling. *Scientific Data*, 5. Retrieved from <https://doi.org/10.1038/sdata.2018.91>
- Sanzana, P., Gironas, J., Braud, I., Branger, F., Rodriguez, F., Vargas, X., . . . Jankowsky, S. (2017). A GIS-based urban and peri-urban landscape representation toolbox for hydrological distributed modeling. *Environmental Modelling and Software*, 91, 168–185. Retrieved from <https://doi.org/10.1016/j.envsoft.2017.01.022>
- Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (Complete samples). *Biometrika*, 52(3/4), 591. Retrieved from <https://doi.org/10.2307/2333709>
- Sharma, A. K., Rashetnia, S., Gardner, T., & Begbie, D. (2018). WSUD design guidelines and data needs. *Approaches to water sensitive urban design: potential, design, ecological health, urban greening, economics, policies, and community perceptions*. Amsterdam, The Netherlands: Elsevier. Retrieved from <https://doi.org/10.1016/B978-0-12-812843-5.00004-6>
- Sjöman, J. D., & Gill, S. E. (2014). Residential runoff - The role of spatial density and surface cover, with a case study in the Højeå river catchment, southern Sweden. *Urban Forestry and Urban Greening*, 13(2), 304–314. Retrieved from <https://doi.org/10.1016/j.ufug.2013.10.007>
- Spearman, C. (1904). The proof and measurement of association between two things. *The American Journal of Psychology*, 15(1), 72–101. Retrieved from <https://doi.org/10.2307/1412159>
- U.S. Army Corps of Engineers. (2017). Hydrologic modeling system; Application guide.
- Vietz, G. J., & Hawley, R. J. (2018). Protecting and managing stream morphology in urban catchments using WSUD. *Approaches to water sensitive urban design: Potential, design, ecological health, urban greening, economics, policies, and community perceptions* (pp. 249–267). Amsterdam, The Netherlands: Elsevier. Retrieved from <https://doi.org/10.1016/B978-0-12-812843-5.00012-5>
- Vietz, G. J., Rutherford, I. D., Fletcher, T. D., & Walsh, C. J. (2016). Thinking outside the channel: Challenges and opportunities for protection and restoration of stream morphology in urbanizing catchments. *Landscape and Urban Planning*, 145, 34–44. Retrieved from <https://doi.org/10.1016/j.landurbplan.2015.09.004>
- Zhao, G., Xu, Z., Pang, B., Tu, T., Xu, L., & Du, L. (2019). An enhanced inundation method for urban flood hazard mapping at the large catchment scale. *Journal of Hydrology*, 571(April 2018), 873–882. Retrieved from <https://doi.org/10.1016/j.jhydrol.2019.02.008>
- Zimmermann, E., Bracalenti, L., Piacentini, R., & Inostroza, L. (2016). Urban flood risk reduction by increasing green areas for adaptation to climate change. *Procedia Engineering*, 161, 2241–2246. Retrieved from <https://doi.org/10.1016/j.proeng.2016.08.822>
- Zope, P. E., Eldho, T. I., & Jothiprakash, V. (2016). Impacts of land use-land cover change and urbanization on flooding: A case study of Oshiwara River Basin in Mumbai, India. *Catena*, 145, 142–154. Retrieved from <https://doi.org/10.1016/j.catena.2016.06.009>