Automated Calibration of the EPA-SWMM Model for an Impact of Land Use and Land Cover Changes on Peak Discharge for a Sub-Urban Catchment of Delhi

Ved Prakash
Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati, Assam, India
ved174104112@iitg.ac.in

Dhruba Jyoti Sarmah
Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati, Assam, India
dhrubajyotisarmah3@gmail.com

Rajib Kumar Bhattacharjya
Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati, Assam, India
rkbc@iitg.ac.in

Abstract

The Environmental Protection Agency's (EPA) Storm Water Management Model (SWMM), USA is a dynamic hydrologic-hydraulic model that simulates the amount and quality of runoff from urban areas. It is broadly used for planning, analysing, and designing storm water runoff, combined and sanitary sewers, and other urban drainage systems. SWMM can solely be used to do the modelling of urban drainage systems. However, SWMM can be automated and convert model files to and from GIS data using R programming, allowing for more in-depth analysis and visualization. Automatic calibration is also a promising alternative, ideally supporting a user-independent and time-efficient method for estimating model parameters. This study investigates the impact of Land Use and Land Cover (LULC) variation on peak discharge at the outfall of the Najafgarh-Mahipalpur drain during rapid urbanization from 2005 to 2022. The findings show that the historical LULC fluctuation for seventeen years resulted in a nearly 28% rise in the peak flow rate at the outfall, according to SWMM simulation. The findings of this study could serve as a guide for planning and managing urban flooding in cities that are rapidly expanding, particularly in developing countries.

Keywords: Urban drainage modelling; SWMM; R; Automated calibration; LULC

1 Introduction

Natural disasters, such as flash floods caused by severe storms, can have devastating effects on human life and society, especially in densely populated urban areas (Gülbaz et al.). Numerous scholars have investigated flash floods, their driving mechanism, their simulation, and their local and regional prediction (Jiang et al.). Concerned City officials have been working on a new system to better handle flooding from heavy rainfall. An abundance of lumped and distributed software packages was applied to construct stormwater drainage systems, propagate flood throughout the landscape, and model the rainfall-runoff process. One of these models that are frequently utilized is the Storm Water Management Model (SWMM). It allows for modelling surface water processes, sewage system flows, and stormwater quality. The variety of modelling approaches now accessible is expanding their use in the actual design of drainage networks and assessing urban runoff and loads (Mehr et al.).

Creating and applying automatic calibration processes for estimating model parameters could be a viable option, resulting in timesavings and a more user-independent approach. (Perin et al.). To evaluate the performance achievable by automated calibration tools, in this paper, we automated EPA-SWMM. A SWMM model calibration for a runoff time series can be carried out using the current R code SWMMR (Leutnant, 2019). However, RSWMM is primarily concerned with calibration and output generation; it does not account for the curved drainage line geometry and the irregular cross-section of the drain.

We converted model files to and from GIS (Geographic Information System) data using R programming, allowing for more in-depth analysis and visualization. It is demonstrated that integration of GIS using R programming in SWMM models, in addition to the automated analysis of output, significantly improves the efficiency of modelling tasks. A workable option that could result in timesavings and a more user-independent method is the creation and usage of automatic calibration procedures for estimating model parameters. The goal of automatic calibration techniques is to automate the input data curve number based on the LULC change and get the discharge variation at the outfall as a runoff. This is accomplished through a self-driven search in the parameter space of the model.

Changes in Land Use and Land Cover (LULC) as well as climate alteration, have far-reaching impacts on the hydrological cycle, influencing variables like precipitation, infiltration, and evapotranspiration in significant ways, thus affecting the rainfall-runoff processes and the quantity of accessible water resources. Therefore, a study on runoff response to LULC modification and climate change is crucial for planning and managing water resources. Therefore, research on runoff response to LULC modification and climate change is crucial for planning and managing water resources (Umukiza et al.).

This study uses the Automated calibration of the EPA-SWMM model to assess hydrological changes in an urbanizing catchment. The study assessed the impact of Land Use and Land Cover (LULC) change on peak discharge at the outfall of the Najafgarh-Mahipalpur drain. Analyze the peak discharge and flow volume under various LULC projections based on a diachronic analysis of satellite images from 2005, 2010, 2015, and 2022.

2. General Overview of the Study Area

The total area of the catchment is about 47.14 km^2 covering the outfall of the Najafgarh-Mahipalpur drain, including a part of the Indira Gandhi International Airport (IGIA), Delhi. It is located between latitude 28°30′ N and 28°34′N and longitude 77°2′ E and 77°8″ E (Fig. *1*). About 74.91 km parts of major roads were considered for this study. The runoff from this land parcel outflows at the southern outfall and finally flows to the Najafgarh Nallah. This drain carries stormwater runoff from Mahipalpur, part of Indra Gandhi International Airport, Kapashera, Pushpanjali, Bharthal, and their adjacent areas.

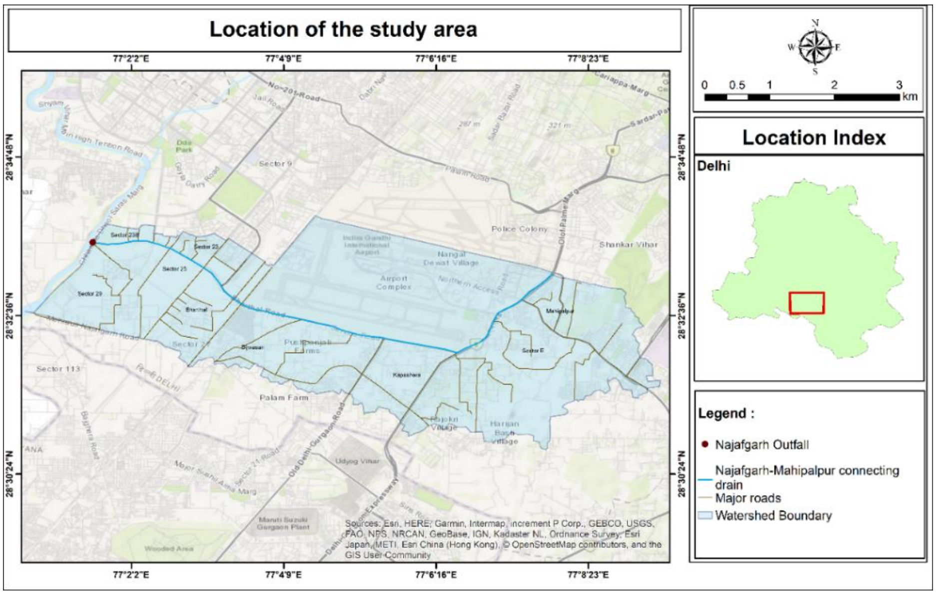

Fig. 1: Location map of the study area

3. Data and Methodology

The EPA SWMM simulates the urban catchment's hydrological response to rainfall events. SWMM is a dynamic hydrology-hydraulic water quality simulation model that can be used to simulate runoff quantity and quality from most metropolitan regions over a single event or over a long period (Continperiodan, 2010). R is compatible with most operating systems, was chosen for this study to create input files, and could execute SWMM simulations. An existing R code known as RSWMM was used for reading output generated from the SWMM for the peak flow hydrograph.

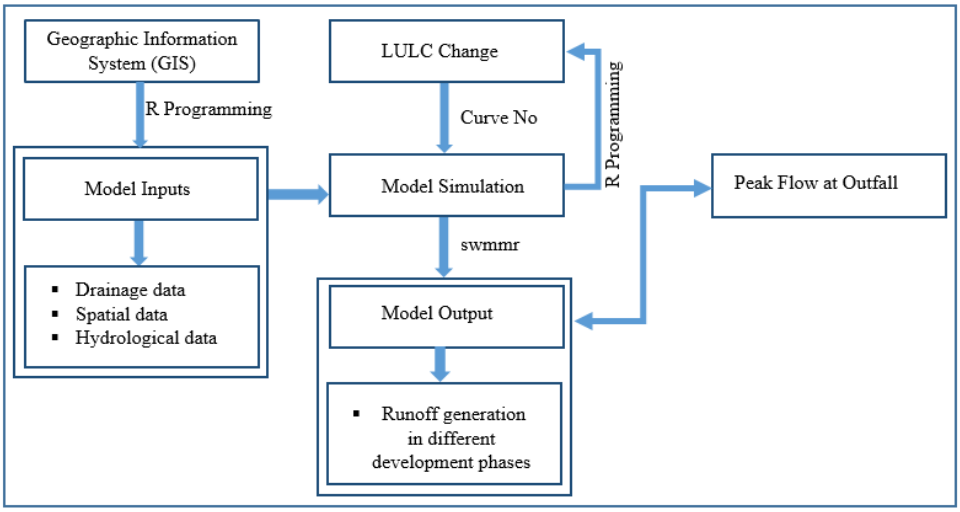

Fig. 2: Workflow for automation

One of the most challenging tasks when modeming an urban rainfall-runoff model using the SWMM GUI interface is to design a large number of drains, sub-catchments, and nodes over a sizeable urban drainage network design. GIS is the best available resource for drawing shape files such as lines, points, and polygons, corresponding to links, nodes, and sub-catchments. The shape files can be converted to input files using SWMMR, but limitation of the existing SWMMR module is that it does not consider the curvature drainage line and its irregular cross-section, which is quite reverent in the real world. In order to create the different scenario of development based on LULC change, curve number is automated for each sub catchment through R programming as shown in Fig. *2* and Fig. *3*.

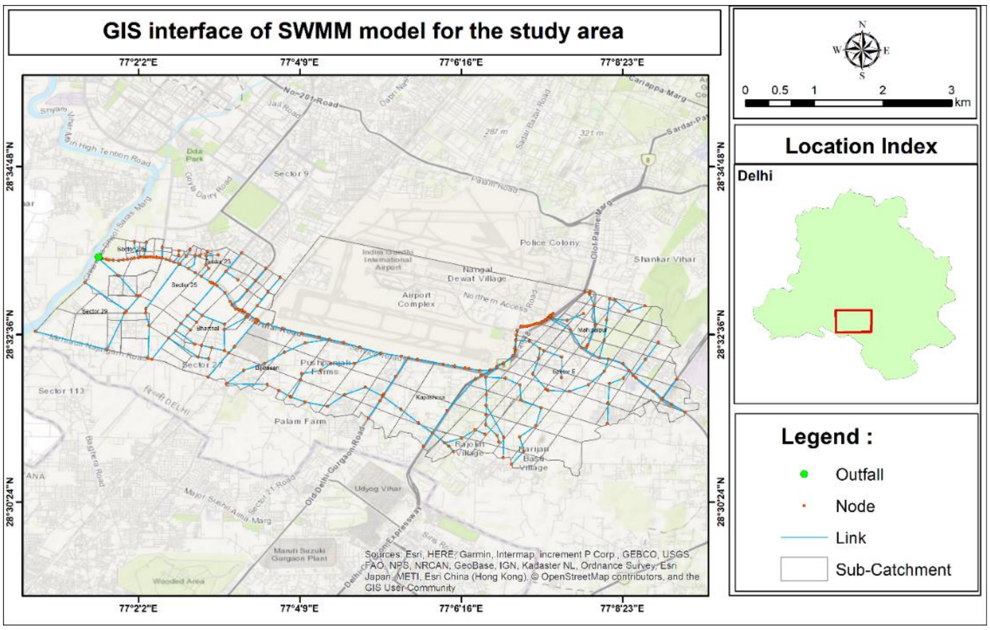

Fig. 3: Workflow for automation

The road networks of the study area were digitized from the street base map and added in Arc GIS software from the Google Earth satellite imagery. It is assumed that all the external drains are parallel to existing major roads as the actual drainage network is unavailable. The drains' size and shape are assumed so that there is no flooding in the assumed external drains. Invert levels of the drains are provided based on SRTM data.

The Curve Number (CN) is a dimensionless quantity representing the drainage basin runoff response characteristics. CN of the catchments are considered based on the past and present Land Use Land Cover (LULC) data and the tables provided in Table 2-2a (Cronshey, 1986). A synoptic view of Land Use and Land Cover changes was obtained from different multi-temporal satellite images of the last 17 years from 2005 to 2022, as shown in **Table *1***.

Table 1: Details of satellite imageries used in this study

Type of Data	Year	Source
LANDSAT_5(TM)	2005 and 2010	https://earthexplorerusgs.gov
LANDSAT_8(OLI_TIRS)	2015 and 2022	https://earthexplorerusgs.gov

Quantitative analysis of Land Use Land Cover (LULC) changes maps have been prepared over the study period by using a supervised classification technique using ESRI ArcGIS 10.8 software. The final SWMM model setup for the study area is shown in Fig. ***4***.

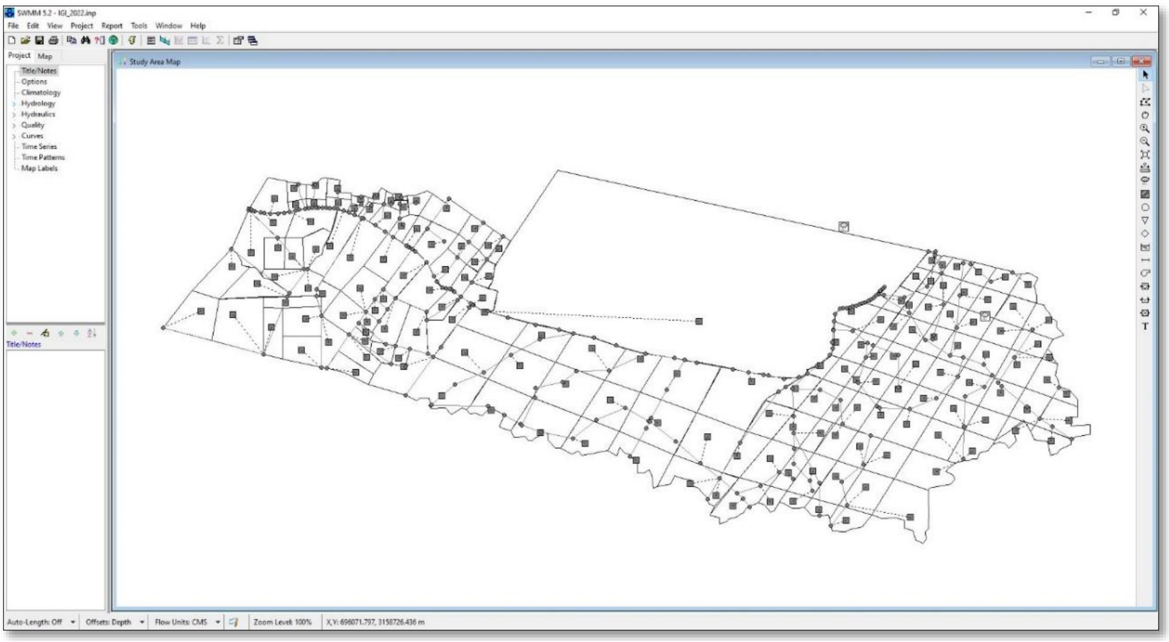

Fig. 4: SWMM model interface for the study area

4. Results and discussion

4.1. Land Use and Land Cover Change Analysis

This study demonstrates the extent of urbanization in terms of built-up areas. Rapidly development outward from the early urban establishments viz. in IGA Airport, Sector 25, Sector 23, Bharthal, Kapashera, Sector E, Mahipalpur, and their adjacent areas can be noted over the years and are still providing evidence of ongoing growth. Results of LULC changes in the study area are presented in Table 2 and Figure 5.

Table 2: Area (km^2) and percentage of Land Use and Land Cover classifications for various years (2005, 2010, 2015, and 2022) of the study area

LULC Cover Categories	CN	2005		2010		2015		2022	
		Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Built-up	90	6.22	13.04	21.39	44.85	26.56	55.71	33.89	71.07
Bare soil/Sparse vegetation	79	19.88	41.69	10.97	23.01	7.39	15.49	4.06	8.52
Shrub land	79	13.18	27.65	8.50	17.83	7.23	15.16	4.36	9.14
Trees/Grassland	61	8.03	16.84	6.54	13.73	6.26	13.13	5.13	10.76
Waterbody		0.37	0.78	0.28	0.58	0.24	0.50	0.24	0.50
Total		47.68	100.00	47.68	100.00	47.68	100.00	47.68	100.00

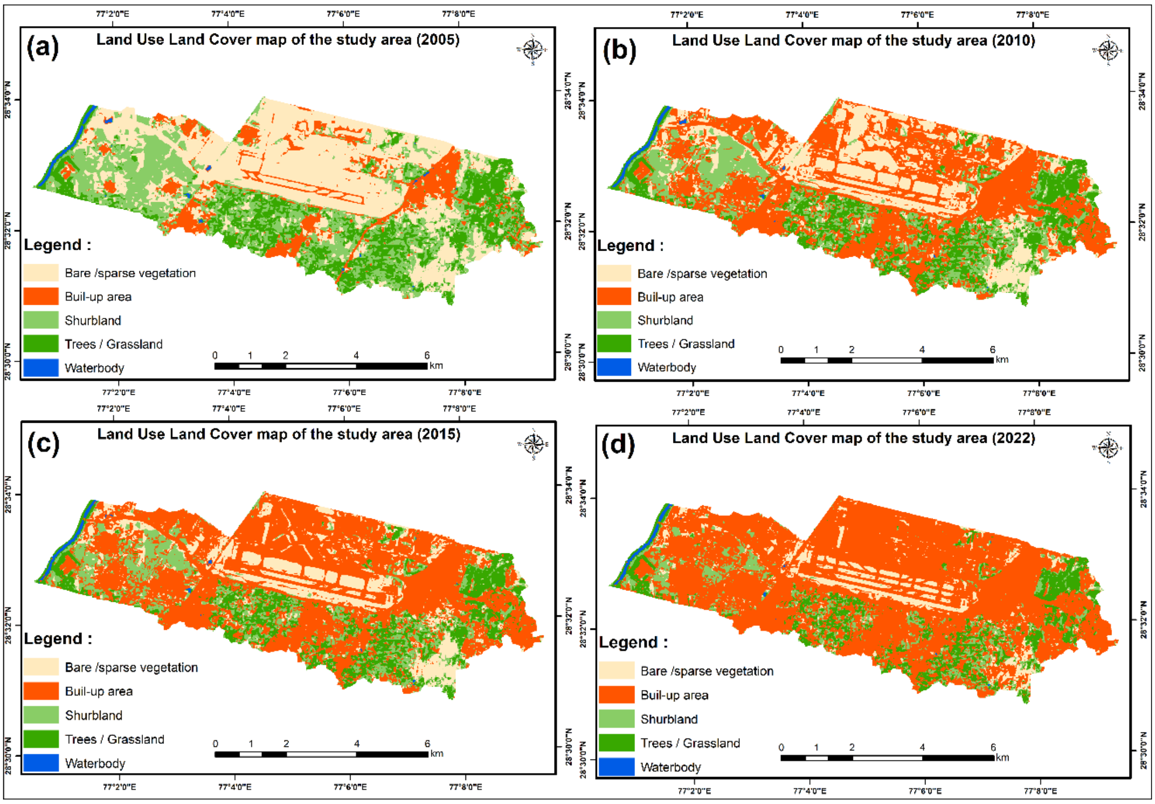

Fig. 5: Changing pattern of Land Use and Land Cover over the study area for the years (a) 2005 (b) 2010 (c) 2015 (d) 2022

It can be seen that the highest area of the built-up area has grown over time in 17 years, from 13% to 71% from the year 2005 to 2022. The area covering bare soil/sparse vegetation and trees/grassland decreased during the study period and converted to built-up areas. There is also decreasing trend of waterbodies from 0.37% to 0.24% from 2005 to 2022.

4.2 Evaluation of the Flow Contribution of the Najafgarh-Mahipalpur Drain from Different Regions Considering Different LULC Scenarios

The developed SWMM model is run for the southern outfall basin considering different LULC scenarios (2005, 2010, 2015, 2022). **Table 3** shows the change in peak discharge in percentage, considering 2005 as the base period.

Table 3: The peak flow generated for different LULC scenarios

LULC (Yrs)	2005	2010	2015	2022
% Flow change	0	3.43	22.90	27.73

According to the SWMM simulations, the historical LULC changes in seventeen years resulted in a nearly 28 % rise in the peak flow rate at the outfall. Figure 6 shows the relative change in the peak flow since 2005.

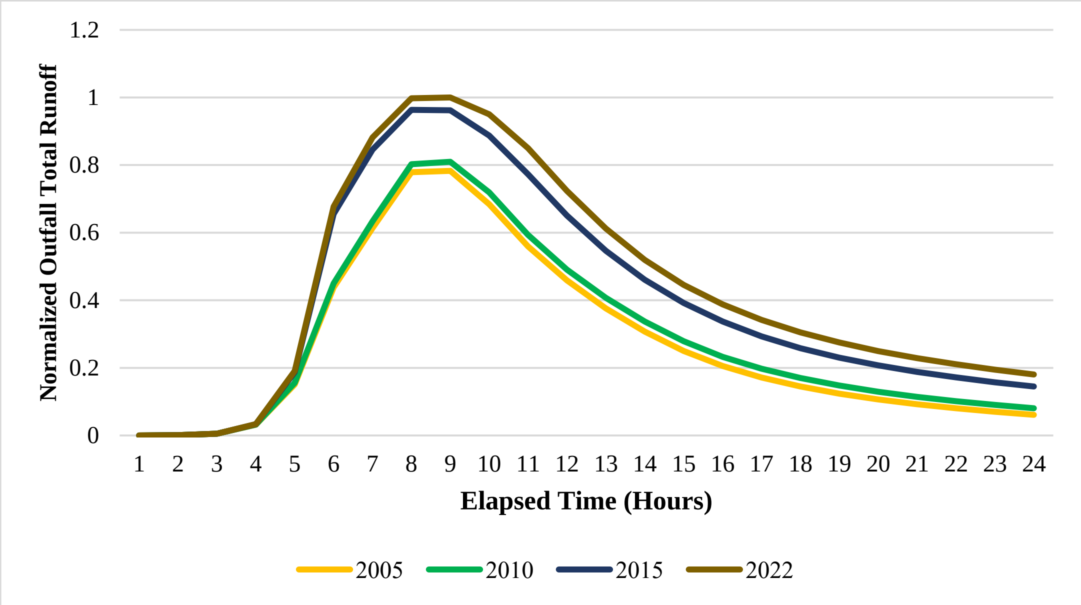

Fig. 6: The peak flow generated for different LULC scenarios

5. Conclusions

The stormwater management model (SWMM) with R, bridges the gap between modelling and advanced model analytics. Integration with Geographic Information System (GIS) and SWMM model using R, improved the automation capability and visualization the real-world problems. In this study, we examined the implementation of GIS and R programming for the automatic calibration of runoff at the outfall for the different scenarios of LULC change. The catchment covering the IGI Airport, Delhi, was examined considering the varied situations of land use/land cover (LULC), based on an assumption made after a diachronic examination of satellite imageries displaying the LULC alterations that took place during the period 2005–2022. The findings validated and demonstrated that LULC significantly affects designed systems' peak discharge and flow volumes. As a result of this analysis, the following points become clear: Sustainable land conservation techniques at a watershed scale should be paired with urban growth. Implementing strategic countermeasures that do not increase the area susceptibility is necessary if a rise in built-up areas is undertaken. The results can be used for urban runoff management plans that are appropriate for the local climate.

References

Cronshey, R. (1986). Urban hydrology for small watersheds. US Dept. of Agriculture, Soil Conservation Service, Engineering Division.

Jiang, L. E. I., Chen, Y. A. N. G. B. O., & Wang, H. U. A. N. Y. U. (2015). Urban flood simulation based on the SWMM model. Proceedings of the International Association of Hydrological Sciences, 368, 186-191.

A. D. & Akdegirmen, O. (2021). Estimation of urban imperviousness and its impacts on flashfloods in Gazipaşa, Turkey. *Knowledge-Based Engineering and Sciences*, *2*(1), 9-17.

Gülbaz, S. (2019). Water quality model for non-point source pollutants incorporating bio-retention with EPA SWMM. Desalination and Water Treatment, 164.

Perin, et al. (2020). Automated calibration of the EPA-SWMM model for a small suburban catchment using PEST: a case study. *Environmental Monitoring and Assessment*, *192*(6), 1-17.

Umukiza, et al. (2021). Impacts of land use and land cover changes on peakdischarge and flow volume in kakia and esamburmbur sub-catchments of narok town, kenya. *Hydrology*, *8*(2), 82.

Utnant, D., Döring, A. & Uhl, M. (2019). Swmmr-an R package to interface SWMM. *Urban Water Journal*, *16*(1), 68-76.

Cite as: Ved Prakash., Sarmah D.J. & Bhattacharjya R.K., "Automated Calibration of the EPA-SWMM Model for an Impact of Land Use and Land Cover Changes on Peak Discharge for a Sub-Urban Catchment of Delhi", *The 2nd International Conference on Civil Infrastructure and Construction (CIC 2023)*, Doha, Qatar, 5-8 February 2023, DOI: https://doi.org/10.29117/cic.2023.0174