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Research Paper

Urban Flooding Assessment using SWMM Model

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ABSTRACT

To avoid the Urban Flooding scenario during rainy season, accessing the ground reality of the study area and running a SWAT analysis would help us to access and study the sub catchment parameters. The present case study of IIT Delhi campus will help us to deal to provide a solution to storm water management problem in an urbanized area. A two-dimensional (2D) SWMM model will be used to access the natural stream flow in the study area and 24 hours rainfall data is used as input parameters. This model will assess how to design an efficient drainage system and how we can overcome the flooding phenomenon. This study provides the insights that how importance it is channelized storm water flow according to natural stream flows.

Keywords: SWMM, SWAT Analysis, Urban Flood Modelling, Drainage Design, Storm water.

INTRODUCTION :

Urban flooding has become a phenomenon caused greatly due to human activities as globalization is exponentially increasing, resulting in the land use/ land cover over the years. In Mumbai, Chennai, Bangalore, Delhi, and specifically the big metropolitans, we can witness that the population growth directly increases industrialization and urbanization, whereas it drastically affects the hydrological methods like an infiltration, evapotranspiration, interception, and erosion which influences the rainfall-runoff process in urban catchments (Agarwal, 2019). Most of the urban flood occurs due to ill-designed or insufficient drainage system as the runoff volume increase in the extreme rain events and the existing storm management infrastructure is not able to overcome the destruction which may create casualties and huge economic loss. The city development planning plays a huge role in the urban flooding if it has not been done concerning the growth of the city (El Alfy, 2016). Floods occur due to meteorological and hydrologic events caused due to anthropogenic activities i.e., human actions, but it is very important to know that suburbanization makes the infiltration process slow and runoff intensity higher which cannot be controlled even in the low terrain areas (Gupta, 2007). It has been observed that irregular maintenance and improper calibration of drains exacerbate the flooding problems in urban setup.

To prevent urban floods, it is highly required to work upon the hydrological processes occurring within the urban environment, as it should cover all the engineering objectives to deal with peak flow control, drainage design, and location management. Geospatial modeling has become an integral part of hydrologic driven research as it covers the boundary conditions to the core and helps in building an optimal framework. Simulation and modeling of urban floods are essential to design an optimal drainage design and to estimate the flood-prone areas. Improvement of the drainage framework for floods will account for much lesser than that of after flood works will cost. To prevent hydrologic problems like prediction of runoff intensity, hydrograph based on different scenarios, design of surface drainage system, and application of flow routing techniques more appropriately we will be making a GIS-Based auto-calibrated Strom Water Management Model (SWMM) for the flood-prone urban settlements. Storm Water Management Model (SWMM) will help in the simulation of storm water for large and small catchments, whereas

GIS will help to study the drainage patterns in the campus area. The Indian Institute of Technology Delhi, 320 acres campus can play as a pilot region, as this model can be traced to a bigger region. This will allow water resource or public works administrative in the efficient planning of the drainage system to prevent urban floods.

Major urban flooding in recent years

There has been an escalating trend of urban flood calamities in India, Although the Indian Meteorological Department forecasted 2020 a normal monsoon season. But regional rainfall variation has already developed the tension in many areas in Assam and Bihar, Including India's' many top metropolitans like Delhi, Mumbai, Bangalore, Hyderabad, Surat, and many cities in the south. A study shows that for every 1% increase in the watertight surface area there is a 3.3% increase in urban flood magnitude that depicts how infrastructure can deviate storm water runoff from roads to streets and increase its intensity level. In August 2020, Mumbai witnessed 294 millimeters rainfall in just 12 hours and 331.8 mm rainfall in 24 hours – which was categorized as 'extremely heavy' by IMD, this was the highest recorded rainfall since 1974 which made the entire drainage system collapsed. The National Capital Delhi Witnessed highest rainfall in past 5 years, around 70 mm rainfall which made many parts in the territory facing water logging because of silted, choked, and insufficient capacity drains.

Study area

IIT Delhi campus area measures around 129.504 hectare (320 acre) with a population of about 23000 Residents. IITD coordinates are 28.545,77.192222, it is situated at Hauz Khas which is an upscale suburb in South Delhi, with an average temperature of 38 °C in summers and 7 °C in winters and little monsoon influence in June to August which houses the reminiscences of the long-gone years and opens a platform for the modern trends to swap in. The Institute campus is fringed by Qutub Minar and the Hauz Khas monuments and well connected to the major city centres by open and wide roads, the Institute campus is about 30 minutes away from the Delhi Main Railway Station, New Delhi Railway Station, and the Inter-State Bus Terminal and 10 minutes away from Delhi Airport (Fig. 1).

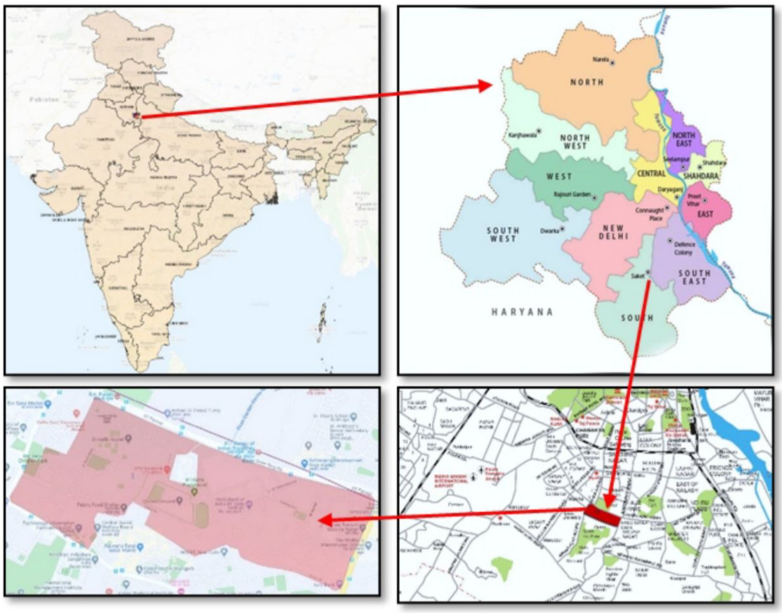

Fig. 1 Location of Study Area

METHODOLOGY

EPA's Storm Water Management Model (SWMM) model will be deployed to conduct a scientific analysis of the stormwater drainage system of the IIT Delhi, India campus. This general-purpose urban hydrology cum conveyance system hydraulics software is a dynamic rainfall-runoff simulation model and may be used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of sub-catchments that contributes runoff. GIS-Based SWMM model will help us to generate Depth Area curves, catchment delineation, and calibration using other parameters obtained through field surveys and existing data. (Kumar, 2020). The flow chart of the methodology is presented in Fig. 2.

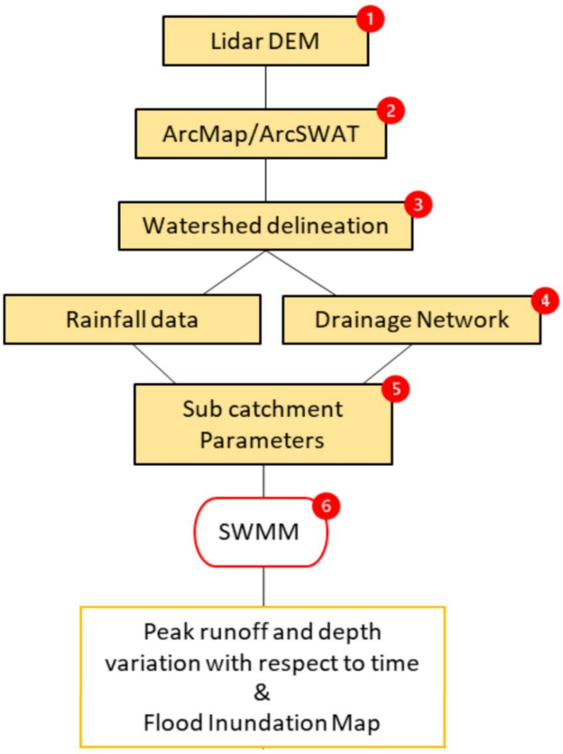

Fig. 2 Methodology Flowchart

RESULTS AND DISCUSSIONS

Digital Elevation Model (DEM)

Light Detection and Ranging (LIDAR) is a remote sensing method in which light in the form of a pulsed laser is used to measure ranges or possibly the variable distances to the Earth. The LIDAR DEM used is of manageable accuracy of 25 meters with 210.301 and 240.358 as minimum and maximum elevation, respectively (Fig. 3).

The ArcSWAT ArcGIS hydrological model is a graphical UI for the soil and water assessment tool model. SWAT is a watershed scale model created to foresee and evaluate the effect of land use pattern and management practices on water in huge complex watersheds with varying conditions and properties over significant stretches of time. After producing physical setting on ArcGIS, ArcSWAT was used to delineate watersheds (Luaces, 2004). The working principle is an 8-grid system by which flow directions are generated. The detailed image of sub catchments, stream network, basin, and the monitoring points (outlets) are shown in Fig. 4:

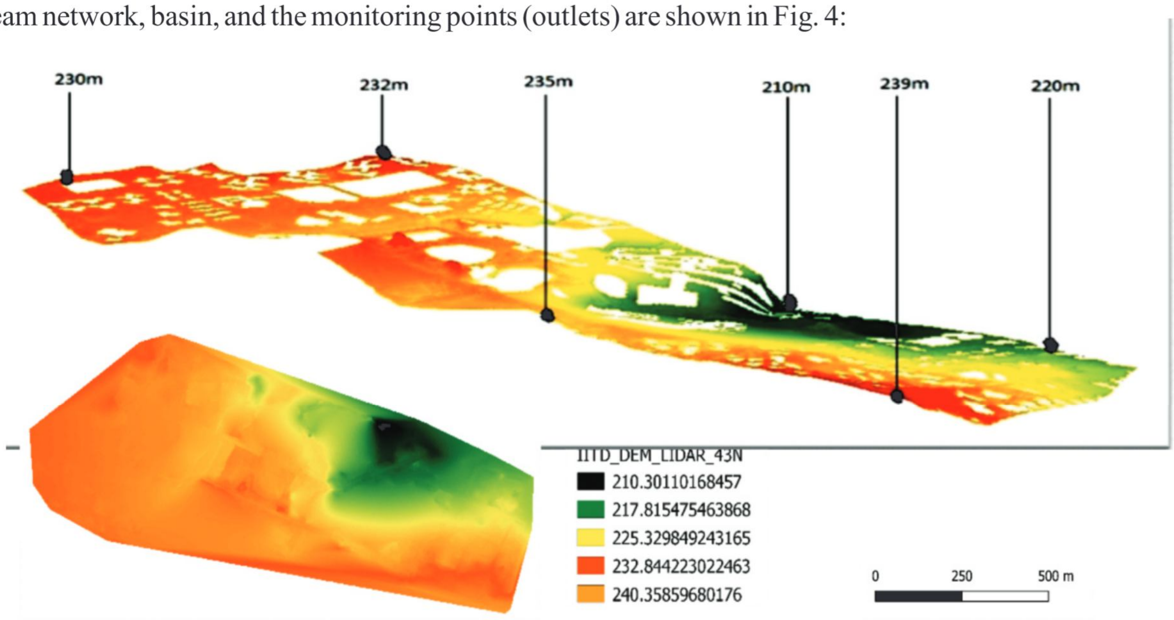

Fig. 3 LIDAR DEM of study area

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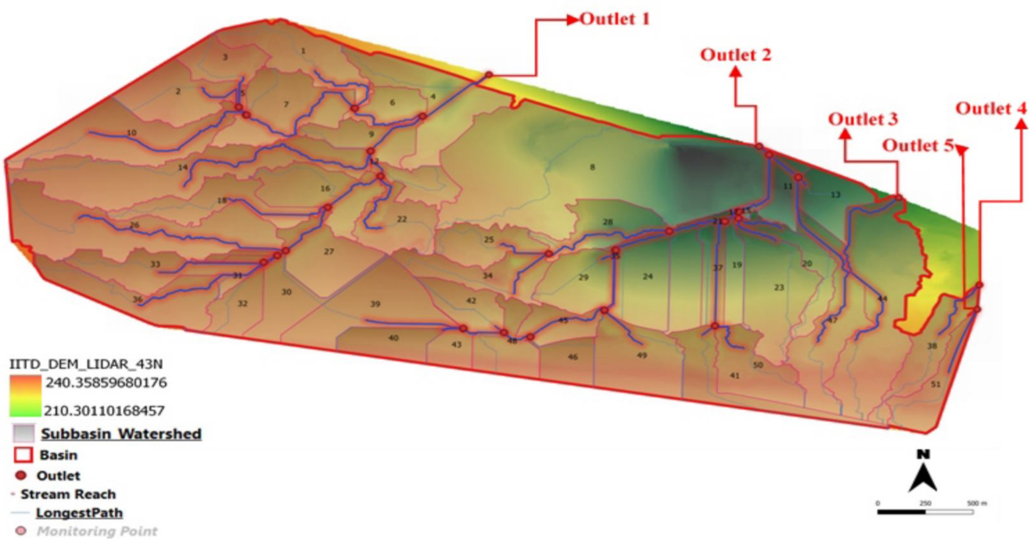

Fig. 4 Stream network of study area

Thiessen Polygons

The principle of the thiessen polygon is quite simple: for a limited number of distinctive sites in a plane (e.g., rain gauges), we wish to divide the plane into disjoint regions called cells, each of which contains exactly one site, so that all other points within a cell are closer to those cells (Rai, 2017). The watershed delineated from the ArcSWAT was converted into theissen polygons for better coverage of the study area and more precise simulation for better results (Fig. 5). These Theissen polygons are the most preferable approach to use in terms of precipitation data and is conveniently converted using ArcGIS (Deshpande et al., 2012).

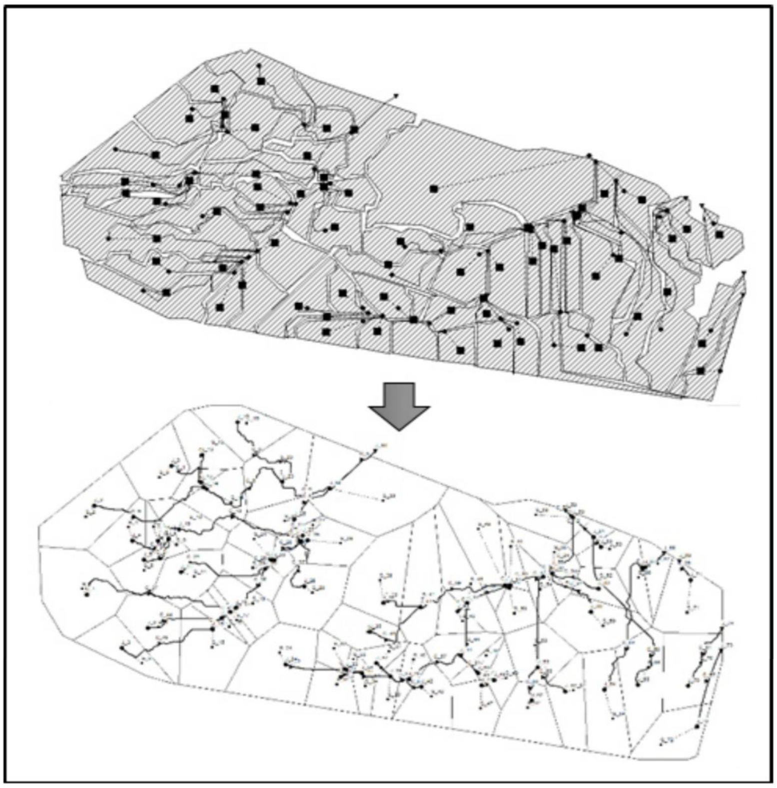

Fig. 5 Thiessen Polygon generated from the delineated watershed using ArcGIS.

Thiessen polygons are produced using collective sample points; here each polygon is defining an area of influence around its point. This would help that now each point/junction have the closest region inside that polygon boundary so that parameters can be set efficiently for the catchment.

SWMM Model

The EPA Storm Water Management Model is a dynamic rainfall-runoff model for unique precipitation overflow reproduction utilized for single occasion or long-haul simulation of overland flow's quality and quantity for urban regions. The runoff component works through a collection of sub catchment areas that receive rainfall and generate water flow. The routing and directing part of SWMM transports this overflow through an arrangement of pipes, channels, and outfalls (Benaman et al., 2005).

- Modelling capabilities:
- Time varying precipitation
- Infiltration and percolation of rainfall into unsaturated soil layers.
- Interflow between natural stream and drainage system Handle network of unlimited size
- Use open conduit and closed conduits shapes as well as natural channels for the hydraulic modelling.

ArcSWAT is used for Watershed Delineation and now the SWAT parameters generated will be use accordingly in the SWMM Model. Infiltration data is taken from the CGWB database and is used as per the sub catchment based on its usage and type (Rodriguez et al., 2005). Based on rainfall data we will be running the simulation based on 15 minutes interval data of 1 Day (Fig. 6). Simulation is done with the 24 Hours Data of 15 Min Precipitation data. This data sets are specifically used to see the working of the model in the easiest and most convenient way, and any continuity error can be easily configured as the data sets is very small (Rafiq et al., 2016). Node flooding can be compared with the precipitation timing as it is just one day data (Fig. 7).

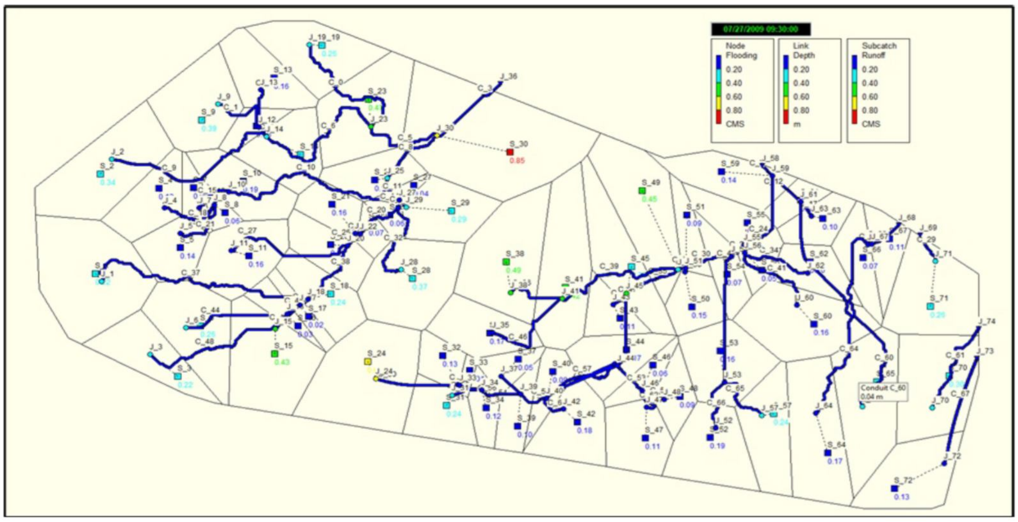

Fig. 6 SWMM Model simulation

Summary Results

Topic: Node Flooding — Click a column header to sort the column.

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr	Maximum Ponded Depth Meters
J_3	16.05	0.449	0	12:00	2.564	2.469

Summary Results

Topic: Conduit Surcharge — Click a column header to sort the column.

Conduit	Hours Both Ends Full	Hours Upstream Full	Hours Dnstream Full	Hours Above Normal Flow	Hours Capacity Limited
C_48	16.05	16.05	16.11	15.71	15.71

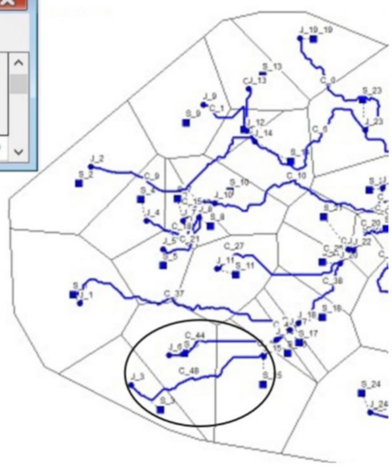

Fig. 7 Node flooding and conduits surcharge with Node J_3 and conduit C_48

For the system we just analyzed the report indicates the quality of the simulation is quite good, with negligible mass balance continuity errors for both runoff and routing (-0.44% and 0.01%, respectively). 5.34 inches of rain that fell on the study area, 1.2 infiltrated into the ground and essentially the remainder became runoff. All links are stable. Simulations are done for small time series i.e., 1 Day data; therefore, results can be different from the simulation for longer time series.

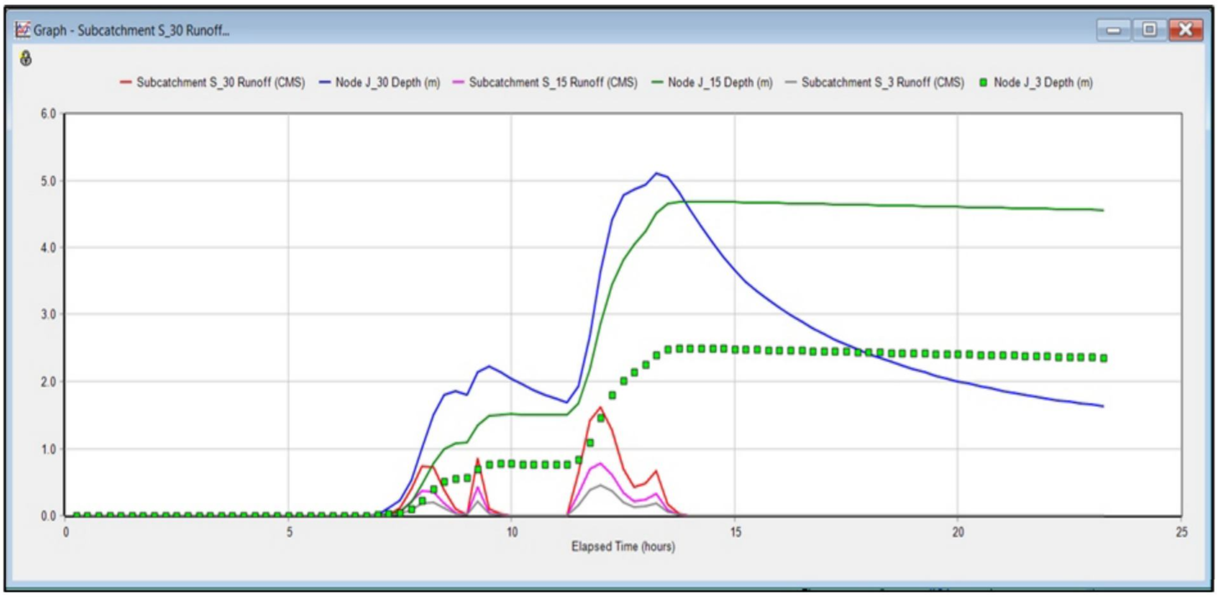

Fig. 8 Node depth and sub-catchment runoff of J_30, J_15 &J_3.

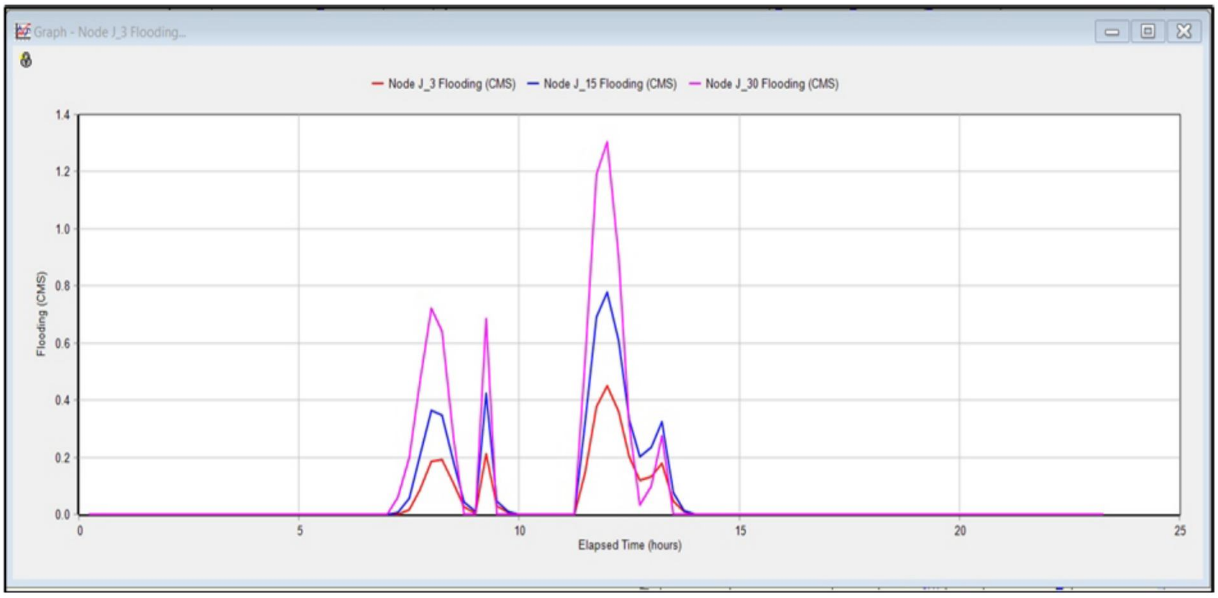

Fig. 9 Node Flooding at J_30, J_15 & J_3.

The graphs of the above simulation (Fig. 8 and 9), depicts that how much flooding is happening as per the precipitation and the Overland Water flows as a runoff over the time (Agarwal et al., 2012).

CONCLUSIONS

After running the model, it was found the natural stream flowing is itself not sufficient to tackle the problem of flooding in the current ground scenarios and with the increase in precipitation, increase in flooding is observed. The bigger problem is the solution of the problem with the existing infrastructure because designing a proper storm water network/drainage which can account all the runoff in an optimized channel network is a task. Floods are natural events that have always been an integral part of the geologic history of the earth. Floods not only happen in river basins; the risk of urban flooding is also increasing due to rapid urbanization. Unlike river floods, urban flooding happens more frequently and causes large amount of accumulated damage, though the damage per event is relatively smaller compared with the severe consequences caused by river flooding. In addition, urban flooding has brutal impacts on municipality's activities when it happens. In this context, a study was undertaken to carryout urban flood modelling and the IIT Delhi campus was chosen as the case study. Findings of the study are:

- Lidar DEM was analyzed using SWAT analysis in ArcGIS to find flow directions, flow accumulation and watershed boundaries. Higher resolution DEM & DSM can also be used for more precision of data.
- The study of the drainage pattern indicates a water divide in the campus i.e., east campus and west campus. It was also verified with the field survey. Therefore, drainage system that needs to be designed in a way that the storm water from both side of the campus channels into separate network with different configuration as per need. The maximum volume of flooding was found 6742 mm/ha for 24 hours rainfall.
- This volume of flooding was routed along the roads as compound section (having drains plus road). The maximum depth of flooding was found to be 0.95 meter above the road near the hospital, near the Guest parking 0.80 meters before swimming pool. Ponding in the area remains for about one and half hours.

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