Rainfall-Runoff Modeling of Upper Mountainous Riverine Watershed Area in Uttarakhand

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Abstract*: *Floods are one of the most prevalent natural catastrophes that occur every year all around the planet. Due to severe precipitation, cloud bursts landside, or glacial lake outbursts, flash floods are a typical occurrence in alpine rivers and places. Hydrological modeling is the outcome of a precise calculation for various mountainous aggregations. Flash flood prediction owing to heavy perception is being replicated in this research study utilizing rainfall data from a different occurrence for hydrological modeling. The parametric hydrologic modeling for the Mandakini River system upstream to Rudraprayag is covered in this research. Hydrographs are generated using the HEC-HMS semi-distributed hydrological model. In HEC-HMS, both stations, Agastmuni and Thaytur, are employed as point locations for precipitation time - series. Precipitation parameterized numerous climatic factors such as land use/land cover, topography information, rains, and soil texture, and ASTER DEM data were utilized as input to the model. The data was processed and analyzed using ArcGIS and the HEC-HMS model. These settings were used to simulate three historical flash floods: July 31, 2010, September 13, 2012, and June 13, 2013. Utilizing IMD rainfall distribution and TRMM 3B42 v7 3-hourly products, these parameters are confirmed for accuracy and likelihood of detecting flash flood ratio. For the study, the obtained results might be valuable to the hydrology and water reserves departments and research institutes.

***Keywords*: Hydrological Modeling, Rainfall-Runoff Modeling, HEC-HMS.**

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I. INTRODUCTION

Flooding is a natural calamity that has an impact on a wide range of environmental elements and activities, including agriculture, vegetation, human health, and the local economy. Floods are one of the world's most dangerous natural dangers, taking many lives or causing so much damage to property than any other natural occurrence. Various consumers are interested in trustworthy and reliable flood data for proper management, including top-level politicians at the state, provincial, and municipal levels, consultants, aid organizations, and water managers. There are three primary phases of disaster risk management efforts. A novel flood frequency distribution based on physical principles has been devised. This approach employs a bivariate exponentially distributed for rainfall duration and intensity, as well as the CN method to calculate effective rainfall probability distribution functions.

Kinematic evanescent waves underpin the effective rainfall-runoff system. As a consequence of the model's outcomes for three Indian basins, it appears to be a viable option for calculating flooding quintiles at gauging locations [1]. The preparation phase includes actions including such risk zone identifier and prognostication long before the event; the preventative measures phase includes activities including such advance detection, monitoring, as well as contingency preparedness only before and during the occasion; and the response/mitigation phase includes activities such as damage assessment and reprieve maintenance just after the event.

Flood prevention has shown to be beneficial and must be maintained. To mitigate the adverse consequences of flood danger, various preventative techniques such as good land use planning, the construction of a computerized GIS database for flood-prone regions, and a complete flooding risk evaluation and maps are necessary. Hydrological modeling is a numerical depiction of natural phenomena that have an impact on a watershed's energy output. There are two sorts of hydrological models: concept and practice [12]. The modified soil and water conservation service curve number approach and a soil moisture accountancy process were used to construct a model to forecast runoff volume from minimal interference. The model was evaluated using data from seven different watersheds at the ICRISAT facility, and it properly predicted daily, monthly, and yearly runoff volume. The main objective of this research is to the generation of hydrological modeling for peak floods and use integrated flood modeling hydrologic and hydrodynamic models.

Conceptual-Lumped Models are built up of a limited number of interconnected concept pieces and can be thought of as a system that averaged inputs/outputs across a large region and combines many hydrologic cycles with their variability [6][7][10]. These are catchment-oriented, employ relatively simple inputs since they lump spatial/temporal heterogeneity, have fewer data requirements, are easy to use, and integrate with GIS. Those methods may be too generic or just too specific to be useful. The flood inundation models for the partly gauging stations upper Ganga basin are being developed. The 100-year duration of 1 h period rainfall was used in the design flood calculations. This is determined using an (IDF) connection based on the research area's Self-Recording Rainfall Gauge (SRRG) data. The SCS-CN technique is used to calculate rainfall surplus. Since no observable hydrograph was available, the Nakagami-m distributions were utilized to generate Geomorphic Simultaneous Unit Hydrograph (GIUH) of several watersheds in the upstream Ganga Water system [3].

The mathematics that defines the physiological interactions between different elements of the energy and water balances is included in Physically Modeling Techniques. These abstraction physical rules (or scale-dependent approximations of these laws) are linked to the particular basin via model parameters. These account for the geographic variation of processes, input, initial conditions, and systems (watershed) features including terrain, land use, soil characteristics, vegetation, rainfall, and evaporate, among others. These models may mimic the whole runoff regime and provide numerous outcomes based on their physical foundation. The St. Venant calculations for flowing water, the Richards formula for unsaturated zone stream, and the Boussinesq calculation for groundwater potential are all examples of modeling techniques for which mass, momentum, and power are calculated directly from the governmental differential equations that are fixed utilizing mathematical solutions. For a tiny wetland near Pant agar, I created a computational formula of the simultaneous hydrographs based on the time area histogram [4].Because the information and computing needs are so large, the application of the methods for real-time forecast has yet to reach the "production stage," especially in developing nations like India where data is scarce. The primary goal of hydrological modeling is to get a better knowledge of the hydrologic cycle to offer trustworthy data for long-term water management. Its usefulness is in its capacity to capture the information and data from the given data, assisting in the decision-making processes when properly chosen and modified. In hydrological, devices are increasingly has been used to simulate the change in watershed management, expand sets of data, and assess the effects of external factors (such as climate change and land cover change). They may be utilized to evaluate river flows at unconfined aquifer locations, fill gaps in damaged records, and extend flowing records to larger rainfall data. Physical laws guiding the transport of water within such a catchment region underpin powerful geographically distributed models, however, they require comprehensive, and high-quality information to be used successfully. Many simulators are used; the trick is to pick the best one for the job and balance information needs against model implementation costs.

II. STUDY AREA

This Mandakini River basin is located within 30°15'N and 30°45'E, with latitudes of 30°15'N and 30°45'E and longitudes of 78°48' and 79°20'E. It has an area of 2250km2 (See Fig 3). The basin's height ranges from 640 to 6940 meters above sea level. Mandakini is the valley's principal river, a significant tributary of the Alaknanda River that flows from the Chorabari Glacier, just 2 kilometers upwards from Shri Kedarnath temple. The research was carried out throughout the Mandakini basin up to Rudraprayag. Laster Gad, Helium Gad, Kakra Gad, Kyunja Gad, Kyar Gad, Ghasta Gad, Markanda Ganga, Kali Ganga, and Vasuki Ganga are the river's primary tributaries, while lesser tributaries include Laster Gad, Helium Gad, Kakra Gad, and Kyunja Gad, Kyar Gad, Ghasta Gad, Markanda Ganga, Kali Ganga (See Figure 1). At Rudraprayag, the Mandakini River joins the Alaknanda River.

Fig. 1. Map of Uttarakhand
(Sources-www.mapsofwolrd.com)

The cirque glaciers Chorabari or Companions are two of the most famous in the world. There are several high lakes inside the region that are supplied directly by snow/ice melting and river water. The Shri Kedarnath town located in the Mandakini River valley has a maximum catch of -96 km2 (up to Sonprayag), of that which -17 percent is surrounded by glaciers (30o 44' 6.7" N, 79o 04' 1" E) (See Figure 2), in the western end of the cent center Himalaya (30o 44' 6.7" N, 79o 04' 1" E). Mandakini River rises from the Chorabari Glaciers (3895 MSL) at Shri Kedarnath Temple and meets Saraswati River (which rises from Companion Glacier), passing across Rambara, Gaurikund, and Sonprayag, whence Vashuki Ganges joins it, before merging with the Alaknanda River at Companions Glaciers. The Saraswati and Mandakini Rivers, one from the left and the other on the right, surround this outwash Palin and merge close Shri Kedarnath village, in which the outwash Palin terminates [9].

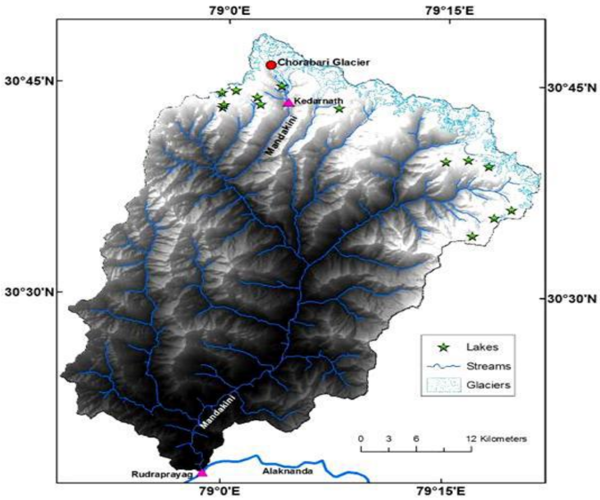

Fig. 2. Flow of Mandakini River

This Mandakini River watershed has a diverse range of soil types. These soils of the northern Himalayas are continually eroded, resulting in thousands of meters of heavy disk diffusion being deposited to form broad valleys to the plain . The erosion of the rock formations of the peninsular shields has resulted in a layer of deposition soils of different thicknesses spreading on the hillside to the south. Under various lithological, climatic, and pedo Genetic circumstances, ten groups of soil have settled inside the Basin (NGRBA, DEC, 2010). Loamy skeletal, Sandy, Loamy, and rock outcrop soils, glaciers and glacier rocky outcropping soils, and glacial and glacier rocky outcropping soil conditions are also present in the research region. The height in this location is over 1000 meters. The soils are usually rather deep. The soils map with such a level of 1:2, 50,000 is turned into several soil hydrological subgroups' maps for the 'SCS-CN' computation for the HEC-HMS hydrodynamic model based on this categorization [8].

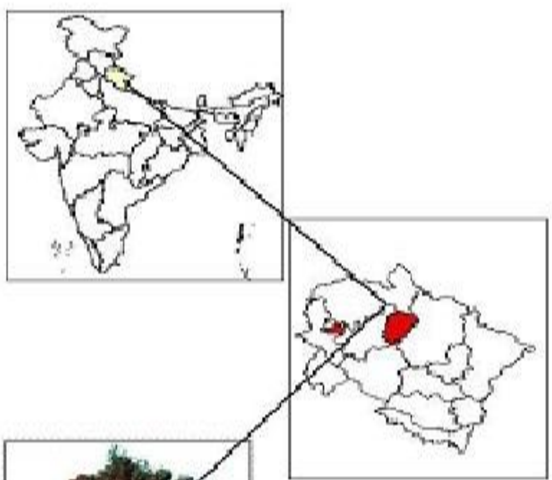
Fig. 3. Location of Study area (Mandakini river basin)

Combination forest, the body of water, agricultural, lands, grass land, snow & ice, wastes, shrubs, built up farming fields includes rainfall fed crop production, and orchards /tree plantations sectors including such mango, litchi, etc. are the most common land usage categories in this research region. Snow and ice blanket much of the high-elevation locations. The forestry types in the upper catchment region are mixture forest, which includes everlasting broadleaf trees, evergreen needles forest, and deciduous broadleaf trees. With a catchment size of over 3,250,000 square kilometers, India is drained by 14 main river systems. The Peninsular Rivers, Himalayan Rivers, Coastal Rivers, and the Indus and Brahmaputra Rivers Basins are the four main river systems around the world [11]. This Ganges basin, an enormous geographical area bordered by the Himalayan snowy peak inside the northwest and peninsular plateaus as well as the Vindhya Ranges in the south, provides runoff to the Mandakini River.

The simulation model is based on the watershed and its surface characteristics of the soil, land use land cover and altitude of the upper Teesta's river basin covering the whole Sikkim and part of the Darjeeling District and the discharge volume of water with time [5]. The Himalayan Rivers, particularly the Mandakini, have such a strong erosive capacity due to their great elevation and amazing velocity. The Himalayan Rivers travel across weakly consolidated sedimentary strata that are impacted by pleats and faults, resulting in significant erosion and silt depositing. Landslide debris contributes to the silt loads even more.

Because of the great rainfall intensity in the Himalaya range, the Himalayan River, which joins the GANGA from the north, accounts for further than 60% of the water pouring into the Mandakini basins? Even though the peninsular stream's catchment spans just over 60% of the Ganga basin, the peninsular flows collectively deliver just 40% of the freshwater. The river flow in the Ganges basin's several rivers varies dramatically year to year, season to seasonally, month-to-month, or even every day. The Mandakini's whole course may be divided into the following primary five portions depending on the river's character traits:

- Mountainous
- Upper plain
- Middle plain
- Deltaic non-tidal
- Deltaic tidal plain

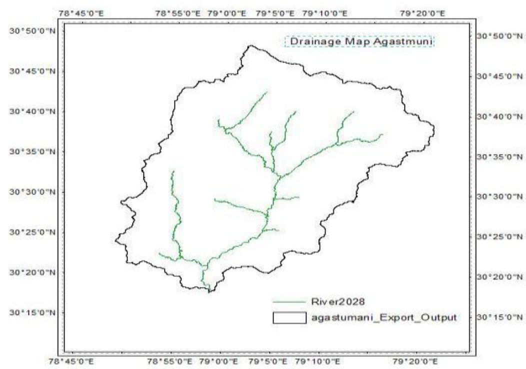

Fig. 4. Drainage Map Agastmuni

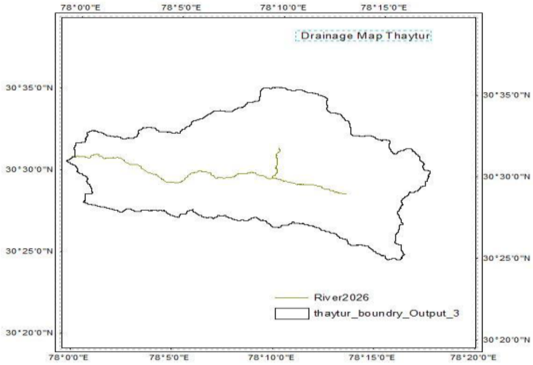

Fig. 5. Drainage Line of the Study Area

The Bhagirathi, and Alaknanda two sacred rivers that originate from the Himalayan glacier top at an altitude of roughly 7000 meters, meet near Devprayag. The Ganges flows for 2525 kilometers (1450 kilometers in Uttar Pradesh, including Uttarakhand, 110 kilometers along the UP-Bihar boundary, 445 kilometers in Bihar and Jharkhand, and 520 kilometers in West Bengal) before emptying into the Bay of Bengal. In the Genetics Plain, this soil is mostly alluvial. All of the river systems left banks streams that flow into the Ganges to originate in the Himalayas (GFCC-AR, 2010-2011). The following is a list of the flood disasters inside the Upper Mandakini's basin:

- In the watershed, there has been a lot of rain for a long time.
- During the monsoons, Mandakini blocks drainage.
- During the monsoons, the river causes bank erosion.
- Lands, property, as well as life are lost as a result of the meander or river.
- Inadequate management of flood control systems, which resulted in damages during the monsoons.
- Inundation of a community located in the river's flood zone.
- Insufficient full-capacity banks.

III. DATA SETS & MATERIALS

IRS-P6 (Internal Revenue Service) (RE-1) LISS-III DATA: Cloud-free LISS-III (Linear Imaging Self-Scanner) satellite data covers sources the whole Mandakini basin were obtained from the (NRSC) Hyderabad's public access Archives center (http://bhuvan.nrsc.gov.in) (See Table1). The IRS-P6 LISS –III information has been widely utilized to track crops, estimate agricultural acreage, and anticipate crop yields. It has strong responsiveness, radiological and spatial resolution, and a large range due to its high responsiveness. It's especially well-suited to investigating Landover processes at regional sizes. The LISS-III sensor's specifications are shown in the table, and the fake color component is shown in the picture.

TABLE I. LISS –III SENSOR SPECIFICATION

Spectral Bands	B1:0.52-0.59, B2:0.62-0.68 , B3:0.77-0.86, B4:-1.55-1.70
Swath	141 km
Average Saturation	B1:27.8(radiance)(mw/cm²/sr/micro n) B2:28.4B3:32.0B4:7.64
Integration time	3.32 msec
No. of gains	4(for visible and NIR bands)
Radiometric resolution	8 bits
Tile Size	3601×3601(1 degree by 1 degree)
Pixel Size	1 arc –second
IGFOV (Spatial resolution)	23.5

A. ASTER DEM

Japan and NASA Ministry of Economy, Commerce, and Industries collaborated just on World Digital Elevation for the Advance Space-based Thermal Load and Reflections Spectrograph (ASTER) (METI). The study will make use of ASTER GDEM V2 (published October 17, 2011), which has a precision of 30m (Posting interval) as well as a vertically DEM accurate of 7-14m. ASTER GDEM is a very accurate DEM that covers all of the lands on the planet and is extremely simple to use and it's free (http://www.gisblog.com) for all users, regardless of size or locality, based on their targeted communities.

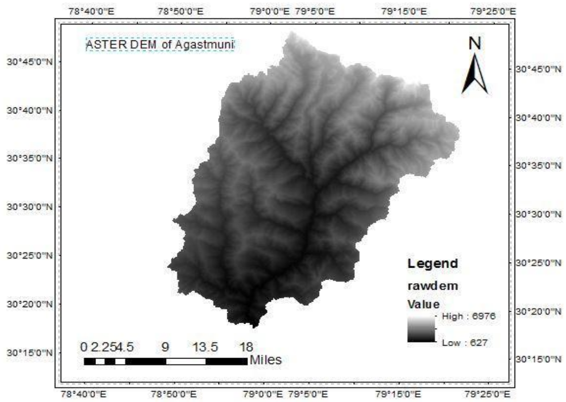

Fig. 6. ASTER Digital Elevation Model of Upper Mandakini River Basin.

B. SOIL MAP

In just this research of types of soil, the National Center of Soil Analysis and Land Usage Planning (NBSS&LUP) map at 1:2, 50, or 5000 scales was used to identify the soil characteristics . Wherever plant cover is present in the current research region, the soil is generally shallow in thickness and soil depth is rather deep. A soil map is depicted in the diagram following table:

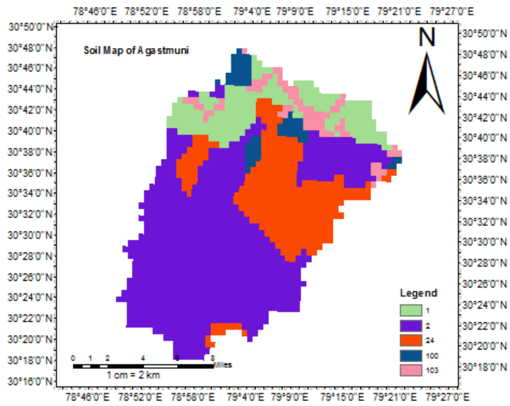

Fig. 7. Soil Map of Agastmuni

IV. METHODOLOGY

In just this flood modeling investigation, the HEC-HMS or MIKE 11 HD systems were employed, and a step-by-step explanation of these systems can be seen below. The diagram depicts the study's entire process.

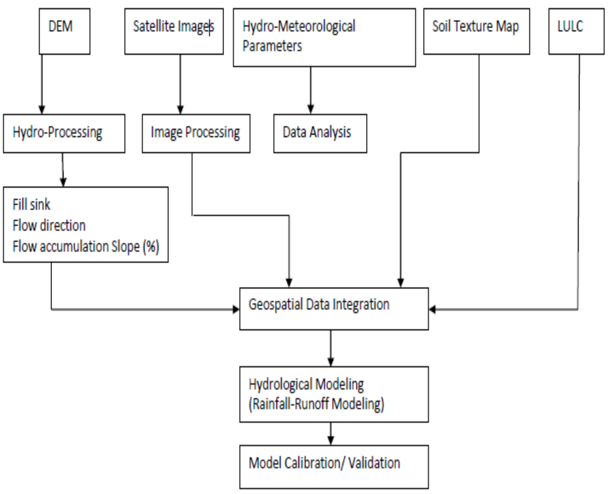

Fig. 8. Overall Methodology of the Study

V. RESULTS AND DISCUSSION

The preliminary stage in flood modeling, as stated in the technique, is to identify the corresponding watersheds from ASTER DEM (30 m). Fill DEM, Downstream Flow, or Flow Depth are among the images that depict the step-by-step procedure of basins and sub-watershed delineation, as well as the defined basin and sub-basin watersheds boundaries.

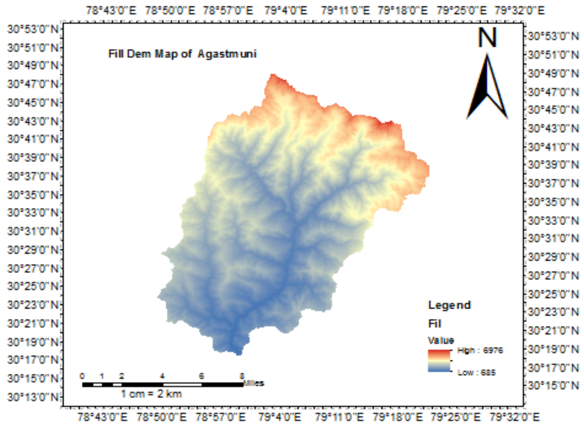

Fig. 9. Fill Map of Agastmuni

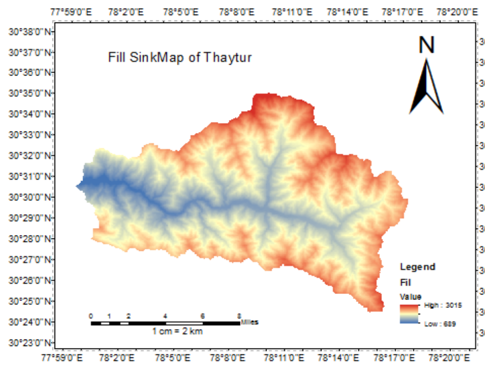

Fig. 10. Fill Sink Map of Thaytur

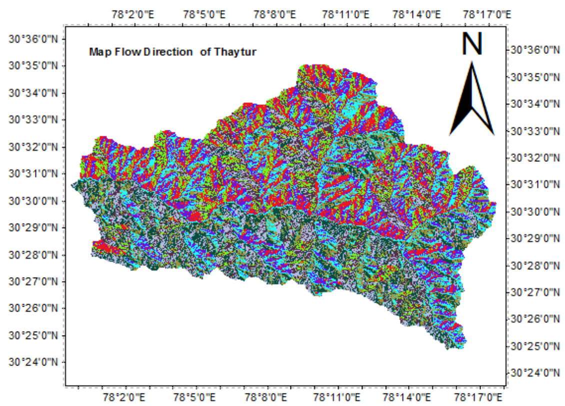

Fig. 11. Map Flow Direction of Thaytur

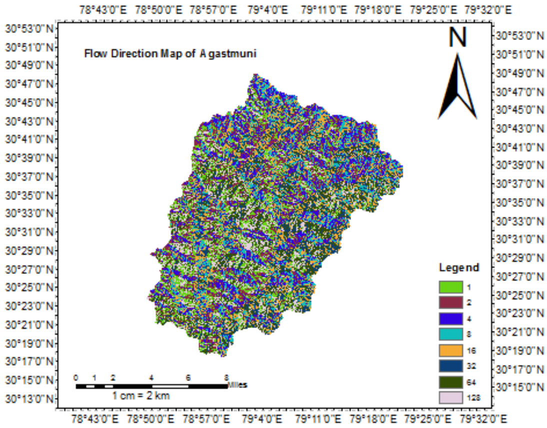

Fig. 12. Flow Direction Map of Agastmuni

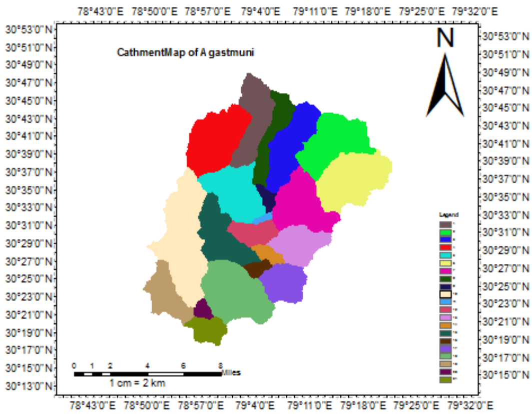

Fig. 13. Catchment Map of Agastmuni

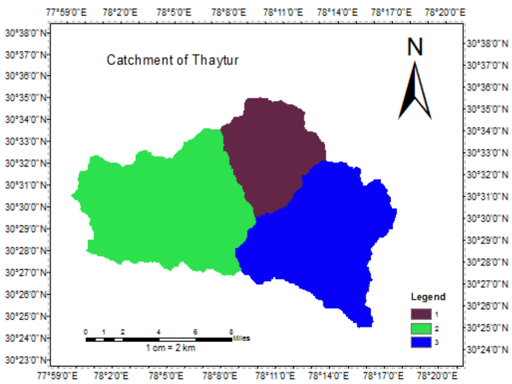

Fig. 14. Catchment of Thaytur

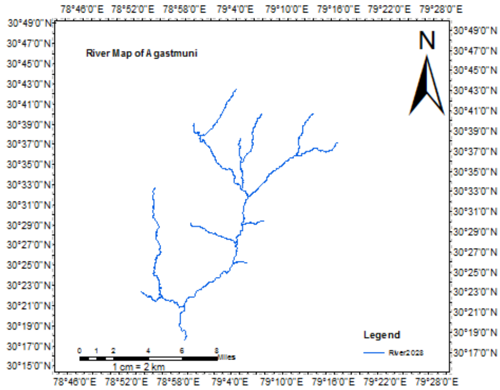

Fig. 15. River Map of Agastmuni

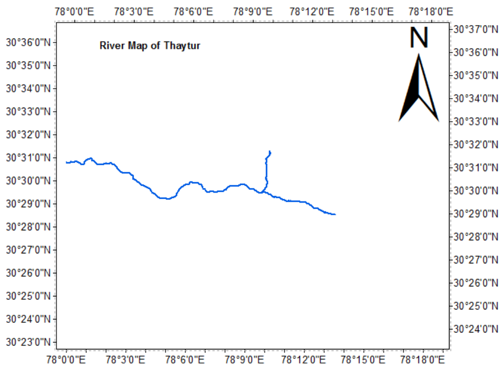

Fig. 16. River Map of Thaytur

HEC-HMS RESULT

Three years of rainfall data were utilized to simulate the discharges inside the HEC-HMS model for this study. Many flash flood events (June to September) or greater discharges occur within this time frame, according to the databases.[2] Although realized data from India's Indian meteorological department (IMD) is available, the sample represented is only considered for Thaytur and Agastmuni. Three hours were used to train the models. And the research and 1-day intervals are depending on these input datasets. IMD For such 3 years 2010, 2012, and 2013, simulation (average) discharges are utilized to compare with generating every hour, for three hours. The figure shows a one-day average simulation and discharge.

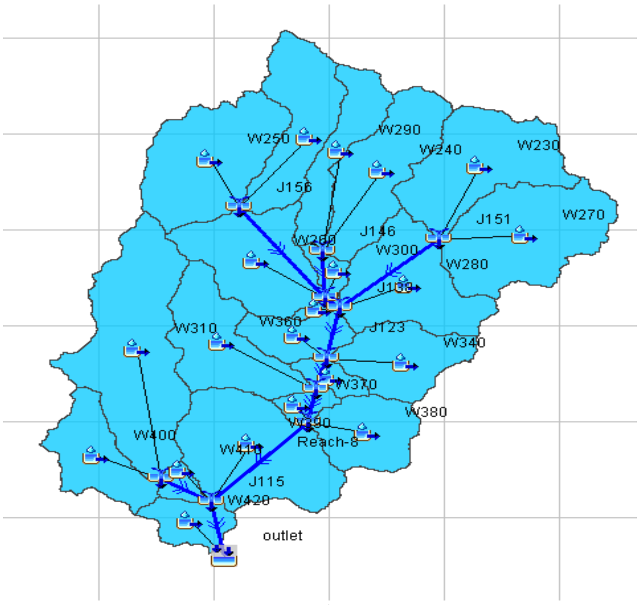

Fig. 17. HMS- Out model of Agastmuni watershed area

HMS- Out model has a flow basin that is fully joined between flow accumulations.

Fig. 18. HMS- Out model of Thaytur watershed area HMS- Out model has a flow basin that is fully joined between flow accumulations.

- Simulation Run: - TRMM 3 hourly rainfall
- Start of runoff: -14 June 2013, 00:00
- End of runoff: - 21 June 2013 00:00

For the year 2013 TRMM 3-hourly and IMD every hour-2013 rainfall discharge the highest value at Agastmuni is (1559.2m³/s), (1759.6m³/s) The maximum discharge values are shown to occur during the period of (14 June to 21 June 2013) And the year 2013 2013 TRMM 3-hourly, and IMD every hour-2013 rainfall discharge the highest value at Thaytur is(509.4m³/s), (481.2 m³/s) The maximum discharge value is shown to be within the time frame of (14 June to 21 June 2013). For the Rainfall data of WRF, every hour rainfalls discharge the highest value at Agastmuni is (1344.56m³/s), and For Thaytur discharge is (923.6 m³/s.) During the period of, the maximum discharge is discovered to be (01Aug to 05 Aug 2012).

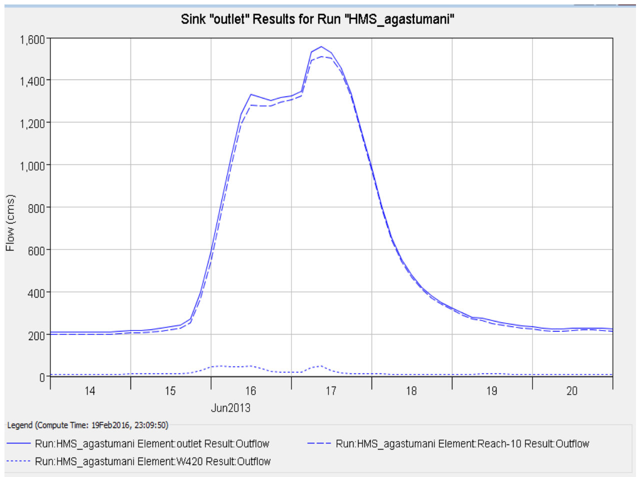

Fig. 19. Sink Outlet for Agastmuni

This graph is plotted between flow and time of Agastmuni sink outlet area in June 2013.

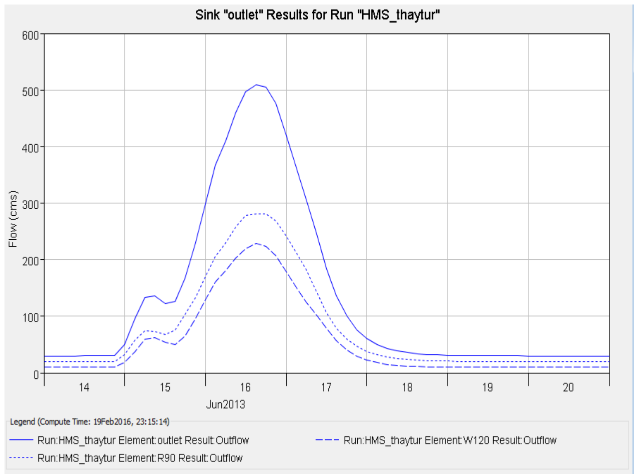

Fig. 20: Sink Outlet for Thaytur

This graph is plotted between flow and time of the Thaytur sink outlet area in June 2013.

VI. CONCLUSION

The parameter used in this study the hydrological models and the related process is discussed earlier in previous sections. LULC map, SOIL, ASTER DEM, and observed literature are used to gather and build basin parameters for hydrologic modeling utilizing HEC-HMS. The final optimized values used in this study are given in previous chapters. A sensitivities analysis is also performed to determine the study's most sensitive parameter. Curves number (CN) and initial Abstract concepts (IA) of the sub-basin are the most impacted parameters in the HEC-HMS model. The hydrographs are created using the HEC-HMS system. The (Hydrological Models) HEC-HMS are validated with the Indian Metrological Department data set at Agastmuni and Thaytur. The main objective of this study is Hydrological Modeling using Hydrologic Models. The specific objectives are Hydrological Modeling for peak flow hydrograph generation for the flood events using

Hydrological Model. This hydrological model was calibrated and validated using actual flow data.

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