Rainfall-Runoff Modelling Using HEC-HMS Model: An Application of Regression Analysis.

[1]Kishanlal Darji, [2]Vidhi Khokhani, [3]Dr.Indra Prakash, [4]Khalid Mehmood, [5]Binh Thai Pham
[1]M.E. Final, [2]Assistant Professor, [3]Faculty, [4]Manager, [5]Lecturer
[1,2]Civil Engineering Department, [3,4]Department of Science and Technology, [5]Department of Geotechnical Engineering
[1,2]Lukhdhirji Engineering College, Morbi, Gujarat, [3,4]Bhaskaracharya Institute for Space Applications & Geo-informatics Gandhinagar Gujarat, [5]University of Transport Technology, Hanoi 100000, Vietnam

Abstract: The runoff estimation process is extremely complicated, nonlinear, and dynamic in nature, which depends on the meteorological and various physical features of the catchment area. Rainfall-Runoff modeling of the Machhu River basin was done using HEC-HMS method. Data of 12 Rain gauge stations pertaining to 40 years period (1978-2017) was used in the analysis. Total runoff estimated for each year was correlated with the rainfall data by carrying out regression analysis. Results of the analysis indicate that coefficient of determination (R^2) was 0.85, which suggest good correlation between observed rainfall and estimated runoff value. Performance of the model was also evaluated by regression analysis which gave R^2 value 0.89 which indicate very good correlation between observed and simulated value of runoff. Results of HEC-HMS study were also used for the flood frequency analysis for the better watershed management.

Index Terms - Rainfall-Runoff Modelling, Geographic information system, HEC-HMS Model, Initial and Constant rate Method, Regression Analysis.

I. INTRODUCTION

Runoff is one of the important hydrologic parameter used in the watershed management. Assessment of the surface runoff which mainly depends on the meteorology, topography, geology, soil and landuse pattern is required for proper planning of the hydraulic structures as well as mitigation of Natural hazards in the area. There are many methods available for the determination of runoff based on the above factors (Subramanya, 2014). Nowadays Geographic Information System (GIS) in conjunction with hydrological models is being used for the estimation of runoff (Jayakrishnan *et al*., 2005; Martin*et al*., 2005; Reinelt *et al*., 1991). Some of these models which determine runoff are: HEC-HMS (Hydrologic Engineering Center – Hydrologic Modeling Sysrem) , SWAT (Soil & Water Assessment Tool) , TOPMODEL, and WEPP (Water Erosion Prediction Project) . This integration allows assessment and prediction of the impact of watershed management practices (Arnold*et al*. 1998; Verma*et al*. 2010; Wheater*et al*. 1999; Zhang*et al*. 2008]. In the present study HEC-HMS model has been used for the prediction of annual runoff based on the yearly rainfall data of the Macchu River catchment for the period 1978-2017. In this study Initial and Constant method was used for estimation of Runoff which depends on the Topography, Land use Land Cover and soil Type of the Study area. Regression analysis method was applied for the prediction of the runoff, which also helped in the estimation of flood frequency in the catchment area. This study would help in the proper management of watershed.

There are three main dams namely Machhu dam I, II, and III are located across Machhu River mainly for the irrigation purpose in the Rajkot district. The Machhu dam-I is located in the upstream part of the catchment near village Jalsika, 15 Kms south of Wankaner Town, .the Machhu dam-II is located near village Jodhpur of Morbi Talukain the middle part of the catchment, whereas the Machhu dam-III is located near Village Vanaliya of Morbi Talukas in the downstream part of the catchment. A number of check dams were constructed across tributaries of the Machhu River on both the banks.

II. STUDY AREA

Machhu River originates in the hills of Chotila taluka of Surendranagar district at an elevation of 220 m (m.s.l). The Machhu basin is located between 22^0 10' to 23^0 10'North latitude and 70^0 40'to 71^0 15'East longitude. It flows in north westerly direction and debouches near Malia in the little Rann of Kachchh. This river with its tributaries flows 52% in the hilly area and 48% in plain region. Machhu drains an area of 2515 sq/km. Total length of this river from its origin to its outfall is 141.75 km (https://swhydrology.gujarat.gov.in).

This region is characterized by a semi-arid climate, with warm and dry summers and mild winter conditions. The monsoon season is from mid-June to early October. The average rainfall in the Machhu River catchment area is 533.5 mm, Average Maximum temperature is 41^0 C and Average Minimum Temperature is 14^0 C (http://cwc.gov.in).

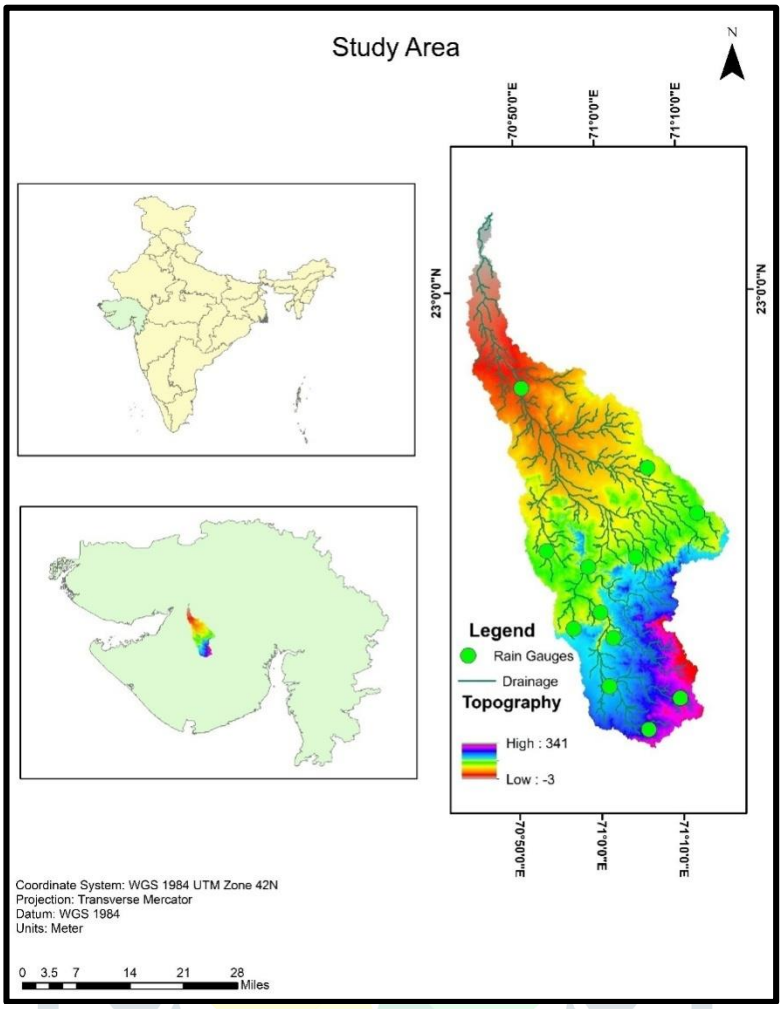

Figure 1 Location Map of the Machhu River Catchment

III. DATA USED

Meteorological data of the study area was collected from the State Water Data Center (SWDC) (https://swhydrology.gujarat.gov.in), Government of Gujarat and Indian Meteorological Department (IMD) (http://www.imd.gov.in/). Thematic maps such as landuse, geology, topography and soil were prepared from the published literature (https://www.gsi.gov.in/, http://cgwb.gov.in/) of the different agencies in conjunction with the interpretation of the Landsat images, Google earth images and Aster DEM using remote sensing and GIS technology

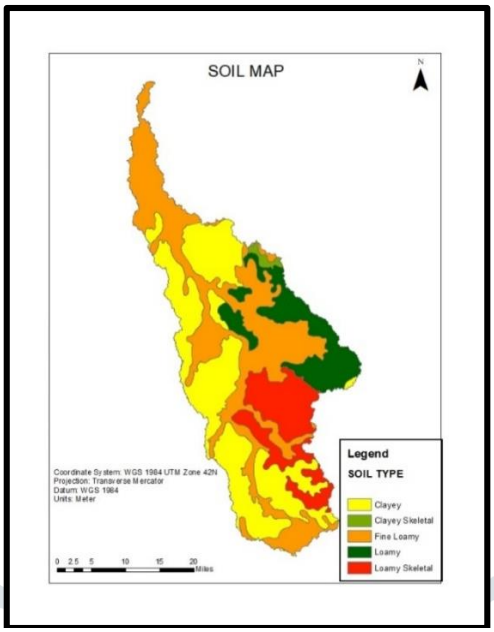

Figure 2 Soil Map of Machhu River Catchment

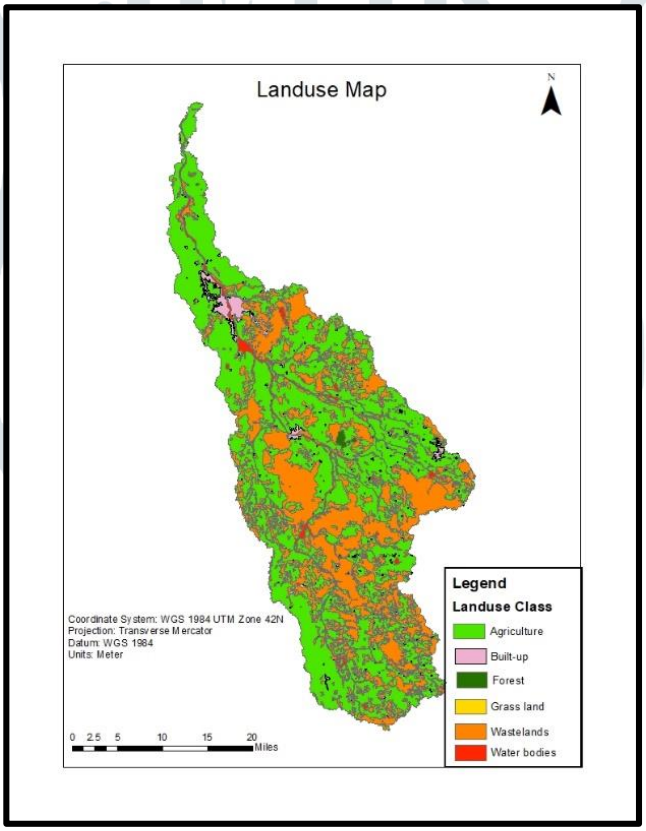

Figure 3 Landuse Map of Machhu River Catchment

IV. METHODOLOGY

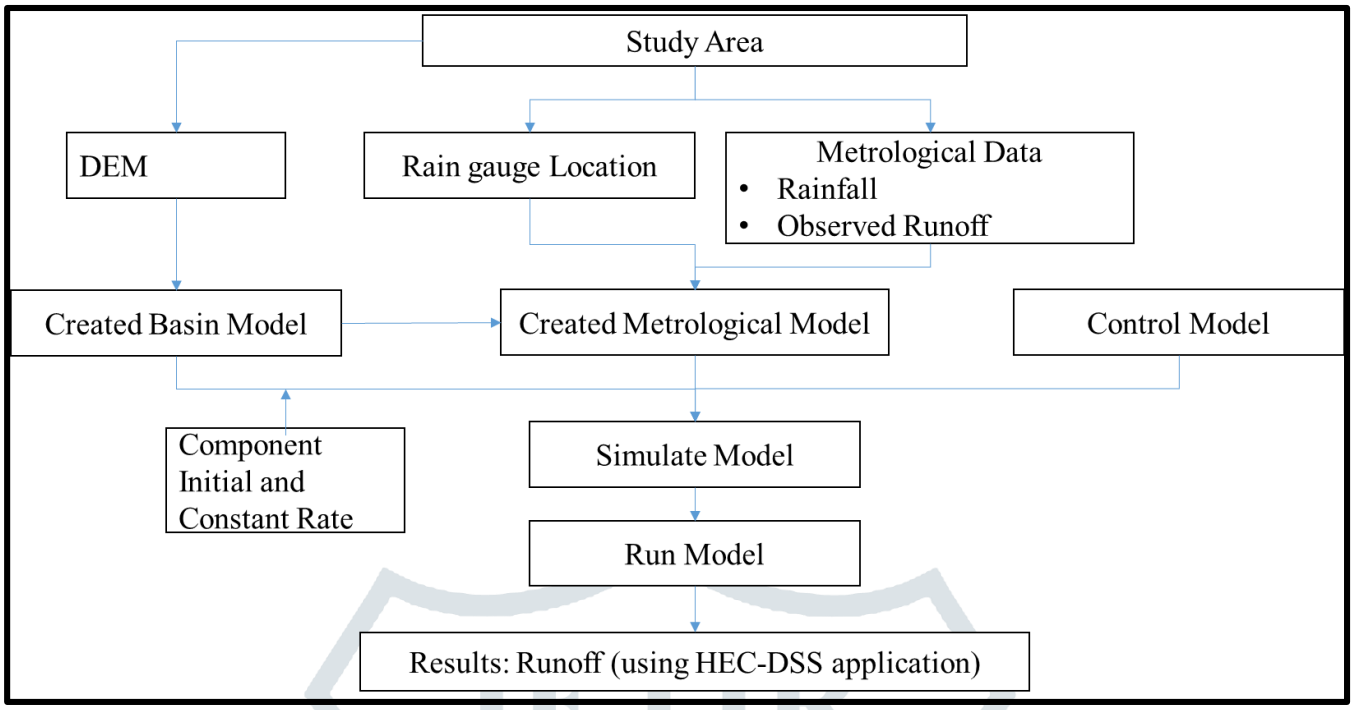

Figure 4 Flow Chart of HEC-HMS Model

Following is a summary of main steps of HEC-HMS methodology adopted in the present study:

- Created river basin from DEM using HEC-geoHMS tool in Arc GIS (This can also be done in Q-GIS). Created Metrological Model from rainfall data of rain gauges located in the basin using HEC-geoHMS. Integrated basin and metrological models prepared above in HEC-HMS.
- Inputted time-series rainfall data (Precipitation) in HEC-HMS model.
- Created Control Model to provide simulation data.
- Created Simulation Run model by integrating basin model, metrological model, and control model.
- Running of the simulation Model.
- Analysis of Result Using HEC-DSS Application to obtain Runoff.

The Hydrologic Engineering Center - Data Storage System (HEC-DSS) application was used to analyse model results for obtaining runoff of the catchment

V. MODEL STUDY

Following are the main steps of the model study:

5.1 Basin Model

In the present study, the basin model was created using the HEC-GeoHMS and then imported into the HEC-HMS with all its hydrologic elements as shown in Figure 5.

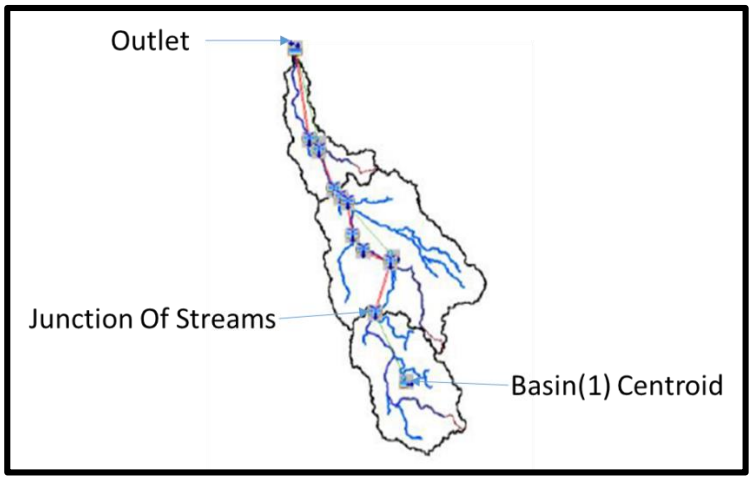

Figure 5 Basin Model of Machhu River

5.2 Initial and Constant Rate Method

For the Initial and constant loss rate method, three parameters namely topography, land use, and soil type were used in the model. The initial abstraction is related to how saturated the watershed is before the storm event. The constant rate is used to model infiltration after the soil get saturated that is when water is filled the void spaces. The constant rate parameters were estimated using the Hydrological Soil Group (HSG) Table 1 (HEC-HMS Course manual 178_2018).

Table 1 Minimum Infiltration Rate in different HSG

HSG	Characteristics	Minimum infiltration rate (inch/hr)
A	Deep well drained course soil	>0.30
B	Moderately deep and well drained	0.15 to 0.30
C	Moderately fine to fine soil	0.05 to 0.15
D	Mainly clay soils	< 0.05

5.3 Metrological Model

This model is one of the main Component of the study which create metrological boundary conditions for the basin. Before this model we have to create at least one basin model. This metrological model can be used with many different basin models. Results computed by the metrological model were matched with the sub-basin in the basin model using the name of the sub-basin. Gauge weight method was used for creating this model

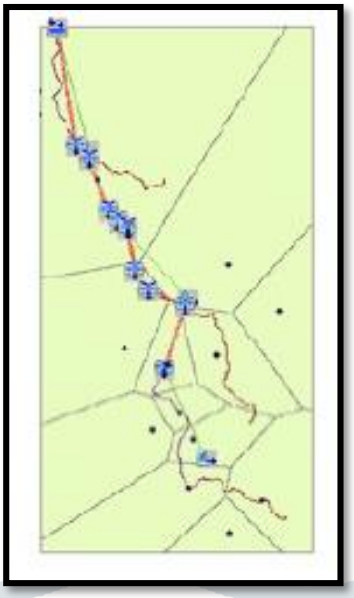

Figure 6 Location of Rain Gauges Inside Thiessen Polygons.

5.4 Control Specification

The principal purpose of control specification is to control the model with respect to starting and stopping simulation at specific time interval. In this method date and timing was inputted in the model

VI. RESULT OF MODEL STUDY

Analysis of meteorological data of the Machhu River catchment for the period 1978 to 2017 indicated that the average rainfall differs during this period annually between 47mm and 1058 mm. Estimation of Runoff was done using HEC-HMS Model and correlated with the rainfall data. Analysis of the runoff data indicate that that annual runoff during this period varies from 1 mm to 578 mm. Rainfall and Runoff pattern is wavy indicating increase and decrease of runoff depending on the rainfall. However, during the period 1986-1988, negligible to very less runoff has been observed corresponding to the rainfall. It is due to the fact that rainfall during this period was very less, hence most of the initial precipitation was absorbed in the ground before starting runoff. This corroborate the study of the other workers (Subramanya, 2013).

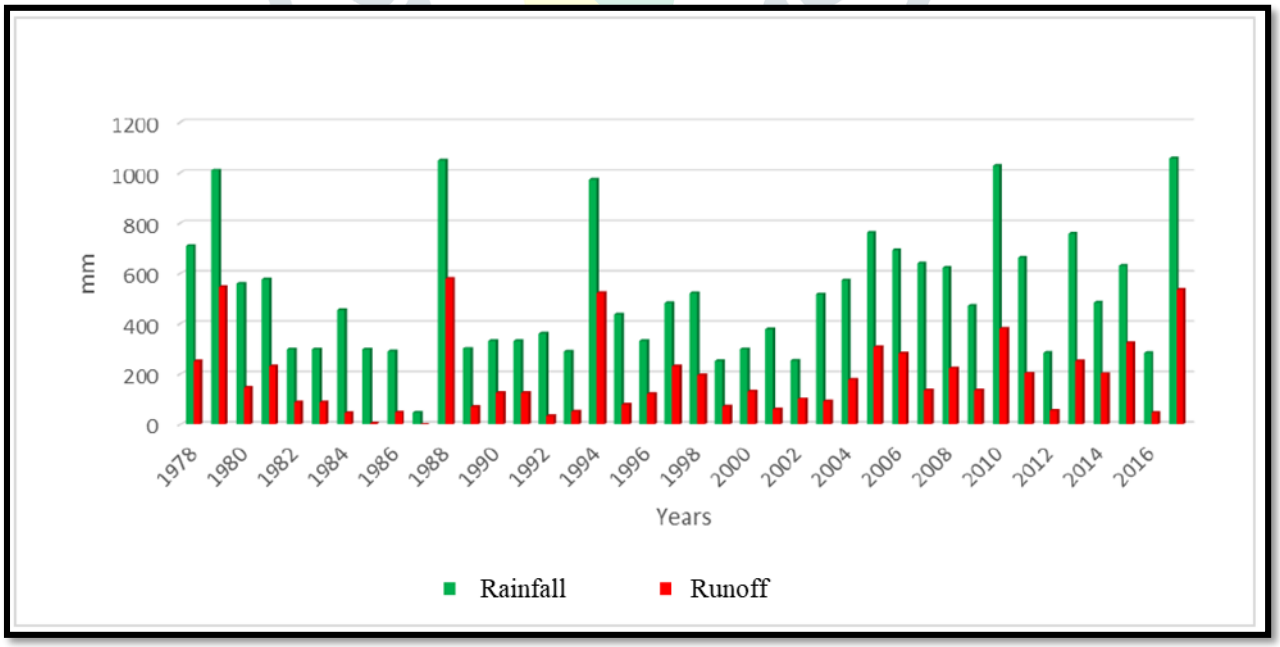

Figure 7 Result of the Rainfall and Runoff Data (1978-2017) Using HEC-HMS Model

VII. REGRESSION ANALYSIS OF THE MODEL RESULTS

7.1 Evaluation of Model Performance

Performance of the model was evaluated by the regression analysis of the observed and simulated data of the runoff. Regression analysis gave the coefficient of determination (R^2) value equal to 0.89 (Figure 8) which is a good prediction value ($0 < R^2 < 1$) (RAZI et al. 2010).The coefficient of determination is a measure of how well the regression line represents the data. It represents the percent of the data that is the closest to the line of best fit. In this study, $R^2 = 0.89$ means that 89% of the total variation in simulated data can be correlated with the observed data.

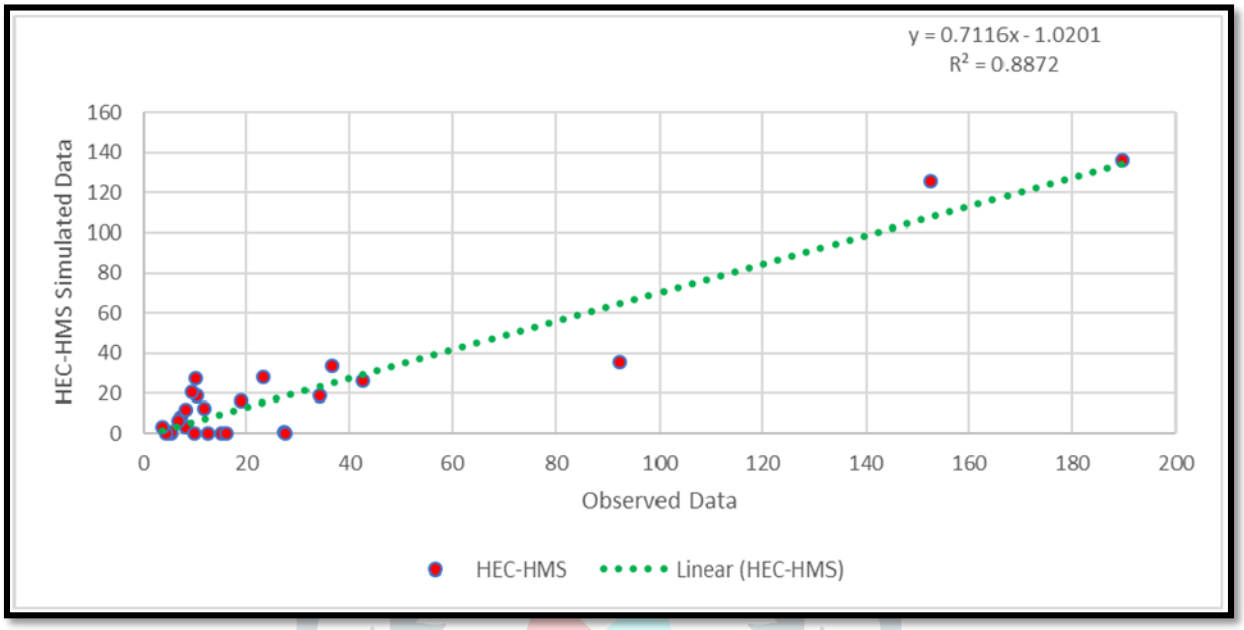

Figure 8 Observed and Simulated Runoff Graph

7.2 Evaluation of Rainfall-Runoff Relation

The relation between precipitation and surface runoff is complicated as it depends on many factors linking to the watershed and meteorology. Evaluation of the rainfall-runoff was done by the regression analysis. Following equation was obtained by regression analysis for the estimation of runoff (Y) of the Macchu catchment for given precipitation (X) (Figure 9):

Y (mm) = 0.5552* X (mm) -103.39

In this study, $R^2 = 0.85$, means that 85% of the total variation in the runoff data can be correlated with the observed rainfall data. Which can be considered as good correlation.

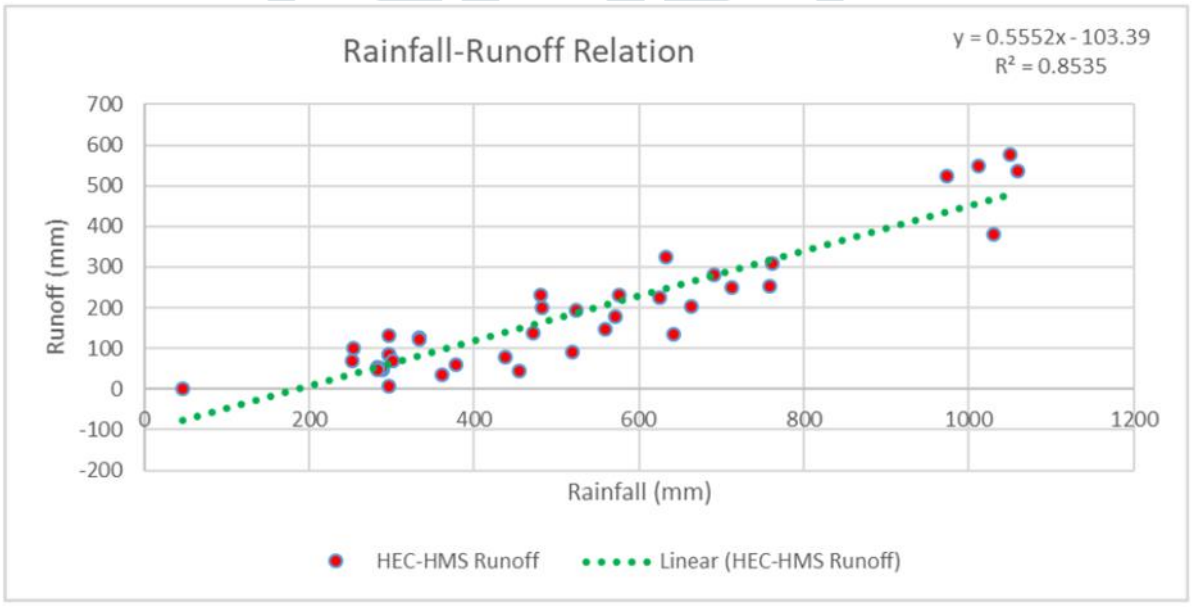

Figure 9 Rainfall-Runoff Relation Graph

7.3 Flood Frequency Analysis

Regression analysis of the HEC-HMS model data gave the following relationship between discharge (Q) and flood frequency which is represented by return period (T) in Years (Figure 10):

Q=1551.6lnT + 633.45 where R2=0.98

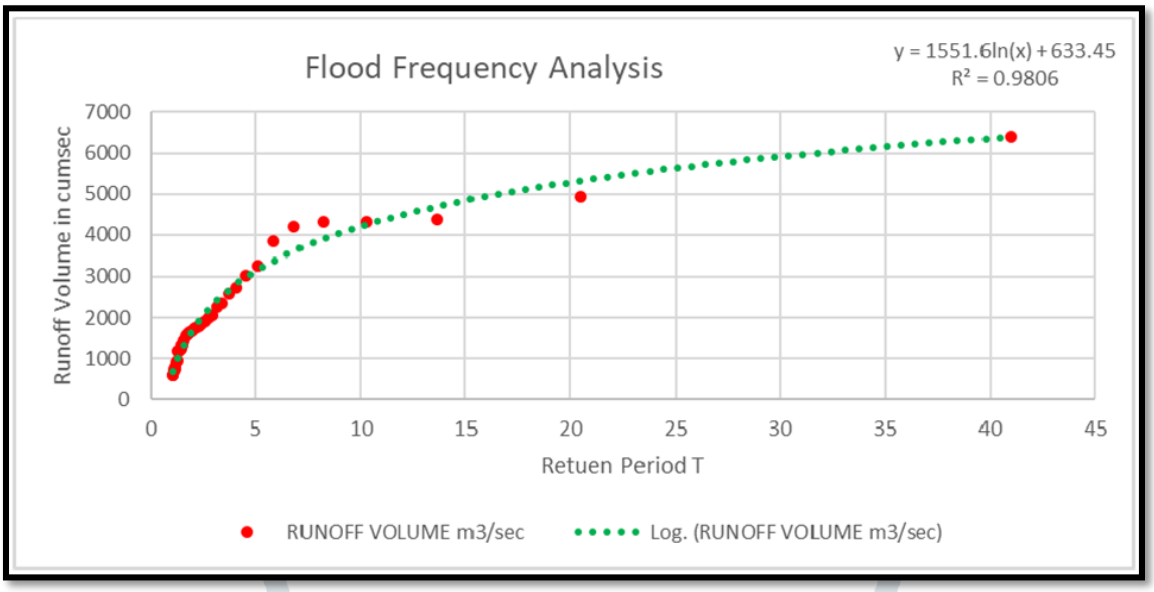

Figure 10 Flood Frequency Analysis

VIII. CONCLUDING REMARKS

In the present study HEC-HMS model has been used for the prediction of annual runoff based on the yearly rainfall data of the Macchu River catchment for the period 1978-2017. Regression analysis method was applied for the prediction of the runoff, which also helped in the estimation of flood frequency in the catchment area. Results of the analysis indicate that coefficient of determination (R^2) was 0.85, which suggest good correlation between observed rainfall and estimated runoff value. Performance of the model was also evaluated by regression analysis which gave R^2 value 0.89 which indicate very good correlation between observed and simulated value of runoff. This study would help in the proper management of Machhu River catchment. However, it is proposed to correlate this model results with other hydrological models based on the machine learning language for wider applicability in other catchment area of the world.

ACKNOWLEDGMENT

The Authors are thankful to the Director, Bhaskaracharya Institute for Space Application and Geoinformatics (BISAG), Gandhinagar for providing facilities to complete the research work. First author is thankful to the Head and Faculty of the Civil Engineering Department, L.E. Engineering College, Morbi for the encouragement in writing the paper. The authors are also thankful to the State Water Data Centre (SWDC), Gandhinagar for providing data.

REFERENCES

1. Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. Large area hydrologic modeling and assessment part I: model development. J. American Water Resources Association 34(1):73-89.
2. D. Roy, S. Begam (2013), S. Ghosh and S. Jana, calibration and validation of HEC-HMS model for a river basin in eastern India. Journal: Asian Research Publishing Network (ARPN). VOL. 8|NO.1|2013
3. **ENGINEEERING HYDROLOGY by K. SUBRAMANYA , TATA Mcgraw Hill Education Private Limited, NEW DELHI**
4. Hawkins RH, Ward TJ, Woodward, DE and Van Mullem JA (2009) Curve Number Hydrology: State of the Practice. American Society of Civil Engineers, Reston, 106p.
5. **HEC-GeoHMS User's manual 10.1**
6. **HEC-HMS Course Manual 178_2018**
7. **HEC-HMS Quick Start Guide 4.2**
8. **HEC-HMS user's manual 4.2**
9. **http://ascelibrary.org**
10. **http://en.wikipedia.org**
11. **http://www.google.com/earth/download/gep/agree.html**
12. http://www.india- wris.nrsc.gov.in/wrpinfo/index.php?title=Dams_in_Gujarat
13. https://earthexplorer.usgs.gov/

14. https://guj-nwrws.gujarat.gov.in/
15. https://nptel.ac.in/courses/105105110/pdf/m6l01.pdf
16. **https://www.epa.gov/pollutedrunoffnonpointsourcepollution/watershedaproach**
17. Imene diabi skhakhfa (2016), lahbaci ouerdachi, Hydrological modelling of wadi Ressoul watershed, Algeria, by HEC-HMS model. Journal: Journal of water and land development. 2016| No.31(X–XII)|139–147.
18. IRRIGATION, WATER POWER AND WATER RESOURCES ENGINEERING by K.R.Arora
19. Jaimin Patel, N.P. Singh, Indra Prakash, Khalid Mehmood, Surface Runoff Estimation Using SCS-CN Method- A Case Study on Bhadar Watershed, Gujarat, India. Journal: International Journal of Interdisciplinary Research | Volume 3 | Issue 5 | 2017
20. Jaysukh C. Songara (2015), Dr. Indra Prakash, H.T. Kadivar, N.M. Joshipura, Estimation of Surface Runoff of Machhu Dam III Catchment Area, Morbi, Gujarat, India, using Curve Number Method and GIS. Journal: IJSRD - International Journal for Scientific Research & Development Vol. 3| Issue 03| 2015
21. Ketul Shah (2017), A. T. Motiani, Indra Prakash, Khalid Mehmood, Application of SCS-CN Method for Estimation of Runoff Using GIS. Journal: International Journal of Advance Engineering and Research Development. Volume 4| Issue 4| April -2017
22. Manthan K. Shah (2015), Vishvam H. Pancholi, Prof. A.T. Motiani, Dr. Indraprakash, Estimation of Runoff for Jamnagar District using SCS-CN Method and Geographic Information Systems. Journal: IJSRD - International Journal for Scientific Research & Development. Vol. 3| Issue 03| 2015
23. N. Nagarajan , S. Poongothai, Spatial Mapping of Runoff from a Watershed Using SCS-CN Method with Remote Sensing and GIS, Journal: journal of hydrologic engineering © asce (November 2012)
24. Nidhi B Chauhan (2016), Prof. M. S. Gadhavi, Dr. Indra Prakash, Khalid Mehmood, Determination of Surface Runoff in Amreli District Gujarat, India using GIS based SCS Curve Number Method. Journal: IJSRD - International Journal for Scientific Research & Development. Volume 2 | Issue 11 | May 2016.
25. Sibani Chourushi, Dr.P.P. Lodha, Dr. Indra Prakash, A Critical Review of Hydrological Modelling Practices for Flood Management. Journal: Pramana Research Journal. Volume 9 | Issue 3 | 2019.
26. Urban hydrology for small watershed (tr-55)
27. www.images.google.co.in