# RAINFALL-RUNOFF MODELING OF A PART-CATCHMENT AREA OF RIVER DHÜNN BASED ON PHYSIOGRAPHIC AND LAND USE CHARACTERSTICS USING MIKE BASIN

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**ABSTRACT:** *In this paper, rainfall-runoff model for a part catchment of river Dhünn has been developed using NAM module of MIKE BASIN. Integration of both MIKE BASIN and NAM allows the computation of time series data of runoff based on time series data of evaporation and precipitation. Applying graphical and numerical performance measures in calibration process, NAM parameters are estimated using data of 3 years. To get the real sense of real condition, hydrological consequences of the land use changes are predicted and implemented by using three scenarios, namely; forest, meadow and urban. Result of these scenarios indicates that water yield is enhanced from catchment area due to urbanization, while reduction is occurred due to forestation.*

**Keywords:** Rainfall-runoff modeling, NAM parameters, river Dhünn, surface runoff, precipitation.

## 1. INTRODUCTION

Hydrological model is used to simulate hydrological processes such as rainfall-runoff process. Rainfall-runoff process is the conversion of rainfall into runoff. When rainfall occurs on the land surface, it moves in various paths according to topography, soil conditions and moisture. On steep sloping sites, surface runoff is more likely to occur while infiltration lags behind. On sites more remote from streams and where the land gradient is not steep, infiltration is primary mechanism and surface runoff lags behind. Generally, infiltration is seen as controlling factor for computation of surface runoff. Estimating surface runoff from rainfall measurements is also dependent on the time scale being considered and the size of catchment.

In a deterministic lumped model, the system is spatially averaged or regarded as a single point in space without dimensions [1]. NAM (Nedbor-Afstromnings Model) is a conceptual lumped model whose characteristics have differentiated it with others such as result orientation, collocation and rationality which requires data input requirements on moderate scale. It simulates overland, interflow and base flow. Other conceptual lumped models are Sacramento model Burnash [2], Tank model Sugawara [3] and HBV model Bergström [4]. NAM was developed by Danish Hydraulic Institute in 1972 [5] and now, NAM is part of MIKE 11, MIKE BASIN and MIKE FLOOD.

Various researchers have successfully applied NAM-MIKE 11 to model the rainfall-runoff characteristics of various catchments such as, rainfall-runoff modeling of Sarisoo River [6] and Qaleh shahrokh basin,Tehran [7]. Auto calibration and verification of MIKE-NAM parameters have been done for Ben Hui river basin through shuffled complex evaluation algorithm and trial and error method [8]. NAM-MIKE has an advantage that it can be combined with MIKE 11-HD and MIKE-GIS for flood modeling and inundation mapping as it is done for Mong Duong river [9].

In present paper, modeling of water balance for a part-catchment area of River Dhünn on the basis of measurable

One of the traditional ways to show the rainfall-runoff modeling through NAM is to use the bucket diagram. It has been shown in figure 1

physiographic and land use characteristics has been done. MIKE BASIN has been used for this purpose as it has used NAM module for rainfall-runoff modeling. Also, it can be integrated with GIS.

## THEORY AND METHODOLOGY

Rainfall-runoff modeling by NAM is a pre-processing step in MIKE BASIN that creates the time series data of runoff for individual catchments and then, flow is calculated through MIKE BASIN. A mathematical hydrological model (quantitative) like NAM describes the behavior through a set of linked mathematical statements for land phase of hydrological cycle. NAM simulated rainfall-runoff processes by frequently accounting for water content in four mutually interrelated storages (snow, surface, lower or root zone and ground water) that represent different physical elements of the catchment. These storages are NAM modes in which NAM can operate. NAM parameters have to be given for each mode for a given catchment to compute outcomes. Catchment runoff and groundwater level values with land phase of hydrological cycle elements as temporal variation of soil moisture content and the groundwater recharge are computed by NAM as main results.

In figure 1, at surface level maximum water content and at zone level maximum water content are indicated with $U_{max}$ and $L_{max}$ respectively, CQOF refers to overland flow runoff coefficient, TOF refers to threshold value of overland flow and $P_N$ is normal precipitation. These buckets represent three different water storage levels. These are surface, root zone and groundwater level storage. The graph in figure 1 shows the overland flow generation which is dependent on the relative moisture content at root zone level and the runoff coefficient. CQOF is the parameter related to the land use where as TOF represents the soil parameter.

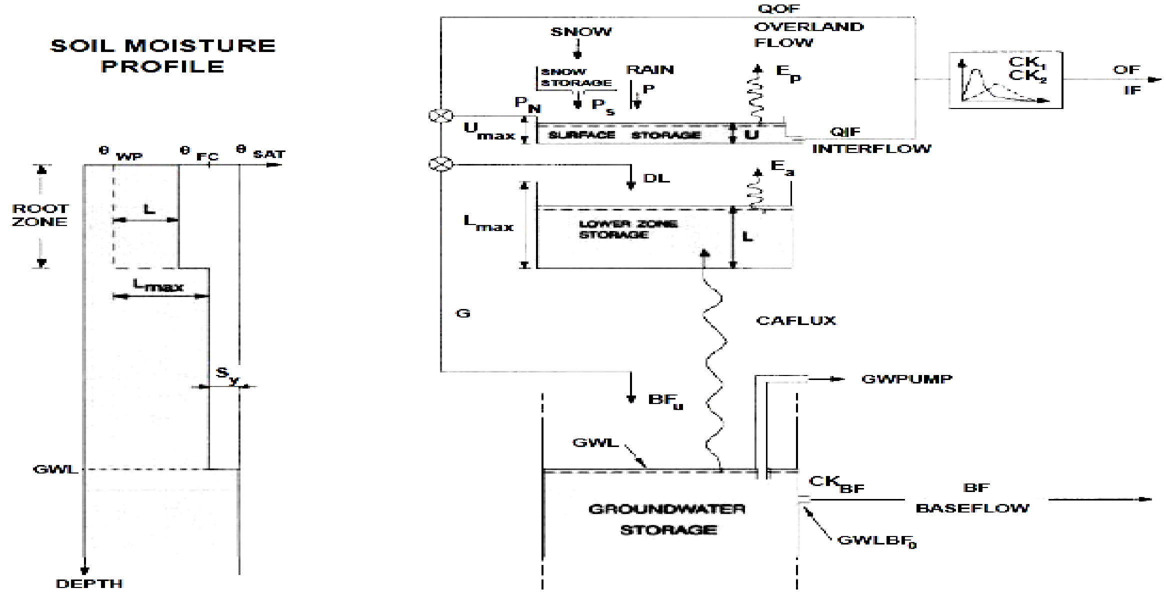


**Figure 1: NAM model structure [10].**

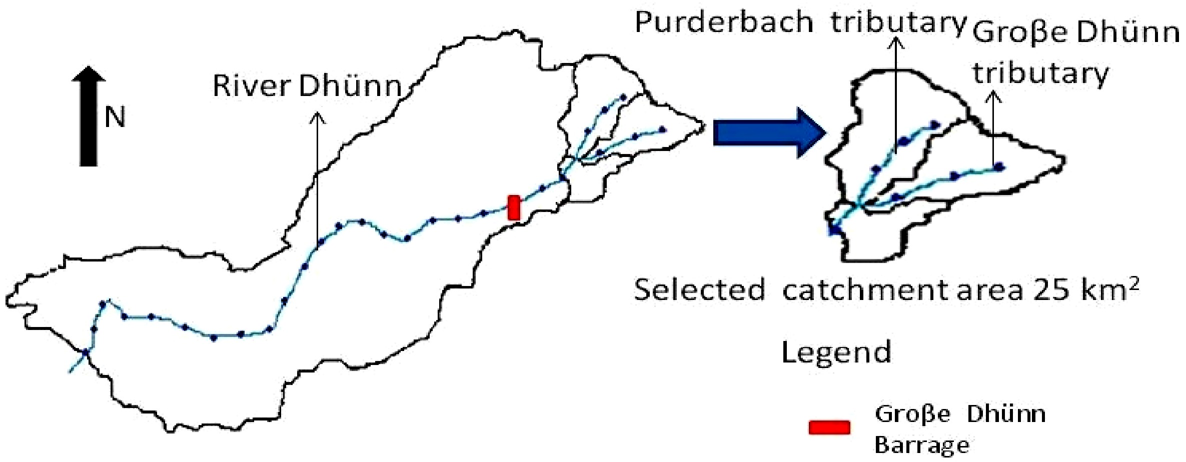


**Figure 2: Selected Catchment area**

In simple words, it can be said that TOF value can be generated at a certain value of relative moisture content at root zone level corresponding to the excess rainfall [12].

The catchment area of river Dhünn (North Rhine-Westphalia, Germany) is about 197.72 km$^2$ with alongside expansion about 30 km in one side and about 5-10 km in the other side as shown in figure 2.

The major portion of this area is country side. The selected portion for the current research is about 25 km$^2$ at the upstream side of river Dhünn. Two tributries named Pürderbach and Groβe Dhünn are included in this catchment area which are in the west of Wipperfurth and in south-east of Wermelskirchen. These tributaries are at the upstream of Groβe Dhünn Barrage. This area is 270-315 m high from sea level. The downstream of river Dhünn joins with river Wupper and flows into the river Rhein.

The Dhünn catchment is in the northwest-german climate area and has the influence of west wind belt with cool summer and high cold winter. The precipitations are relatively evenly distributed.

throughout the year with longer prolonged country rain in winter and shortly prolonged rain in summer. The month of July has maximum precipitation. The precipitation increases with increase in altitude. The selected catchment area is mainly divided into three main portions named as pasture, agriculture and forest. This land distribution can be seen in figure. 3.

Area covered by the forest is further subdivided into three main categories i.e. evergreen forest, deciduous forest and mixture of both. Evergreen forest is along the tributary GroBe Dhünn and most of the deciduous trees are towards the north of catchment. The rest of the catchment area includes the developed portion which is equally distributed throughout the whole area. Area covered by different land use is given in table 1.

According to Schaetzl and Anderson [11], 95% soil of the catchment area is Brown Forest soil, as shown in table 2. The Brown Forest soil is further subdivided into two categories named braunLu and braunUI4. Along the whole water body, gley soil exists. Another category of soil named as Auenboden is present only along the river side. In very small fraction, surface water gley (pseudogley) is also present there.

Estimation of NAM parameters is done through model calibration. Both graphical and numerical performance measures are applied in calibration process. Comparative study in graphical evaluation is done by comparing simulated and observed hydrograph or accumulated runoff. Overall water balance error is determined through numerical performance measures (i.e. the difference between the average simulated and observed runoff) and a measure of the overall shape of hydrograph based on coefficient of determination '$N^2$' [12].

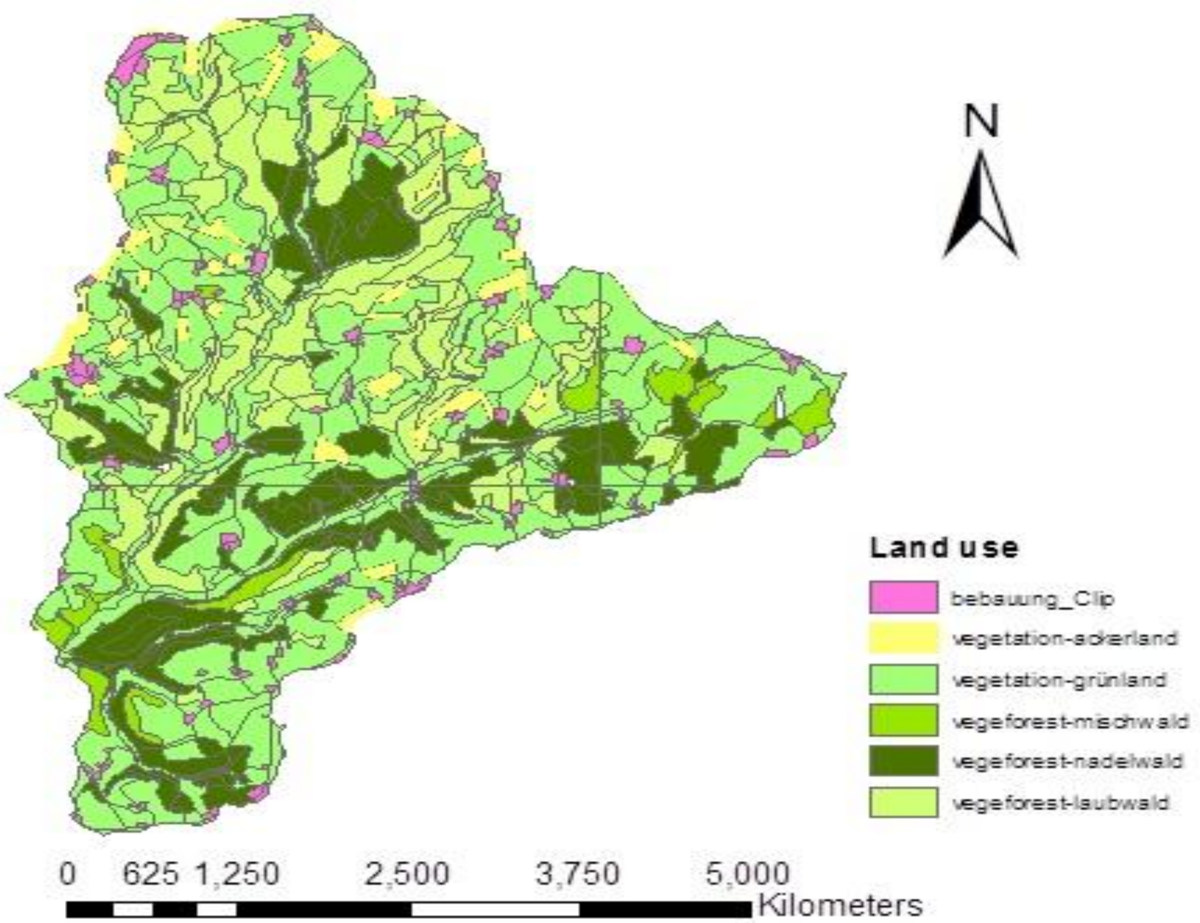


**Figure 3. Land distribution of catchment area**

**Table 1: Area covered by different land use**

| Land use type | Area $km^2$ | Percentage % |
|---|---|---|
| Developed area | 0.85 | 3 |
| Agriculture area | 1.45 | 6 |
| Pasture | 13.36 | 53 |
| Evergreen forest | 3.88 | 16 |
| Foliage forest | 4.60 | 18 |
| Mixture of foliage and evergreen forest | 0.88 | 3.5 |

**Table2: Different parameters for the five types of soils present in the catchment area.**

| Soil types | Field Capacity | Permeability |
|---|---|---|
| Braunerde (braunLu) | 68.4-288.4 | 0 |
| Braunerde (braunUI4) | 37-340 | 0-16.11 |
| Pseudogley | 197.65 | 0 |
| Gley | 104-200 | 0 |
| Auenboden | 284.52 | 17.359 |

$$N^2 = \frac{\sum_{i=1}^{N}(Q_{obs,i} - Q_{sim,i})^2}{\sum_{i=1}^{N}(Q_{obs,i} - Q_{obs})^2} \quad \text{Eq. (1)}$$

Where $Q_{sim,i}$ is simulated discharge at time $i$, $Q_{obs,i}$ is observed discharge at time $i$ and $Q_{obs}$ is mean observed discharge. The measure of interdependency of two random variables i.e. simulated and measured discharge can be shown by correlation coefficient 'R$^2$' which indicates the strength and direction of linear relationship of these variables. Negative correlation is shown by -1 and positive correlation by +1.

$$R^2 = [\frac{\sum_{i=1}^{N}(Q_{obs,i} - Q_{obs})(Q_{sim,i} - Q_{sim})}{\sqrt{\sum_{i=1}^{N}(Q_{obs,i} - Q_{obs})^2}\sqrt{\sum_{i=1}^{N}(Q_{sim,i} - Q_{sim})^2}}$$

Eq. (2)

Where $Q_{sim}$ is mean simulated discharge.

## RESULTS AND DISCUSSION

Satisfactory calibrations over a full range of flows usually require continuous observations of runoff for a period of 3-5 years. For present study, calibration is performed using data of three years from 1st January 2003 to 31st December 2005. A total of nine parameters related to NAM are estimated through manual calibration process and are given in table 3.

Manual calibration based on trial and error method has been adopted. Permissible values of NAM parameters have been used to acquire a satisfactory resemblance of simulated discharges with observed one. Furthermore, numerical performance measure is also adopted. The best values found for Nash-Sutcliffe is 0.62 and and correlation coefficient is 0.713. Figure 4 shows the comparison between simulated (measured) and observed discharges.

In winter time, maximum values of peak flows are observed in figure 4. This is because of less evaporation during that period. From the temperature values, it is clear that there is some snow during winter. This snow act as a paved base, so sudden response of rainfall is observed.

Before pursuing to quantifying the hydrologic impact of possible future land use and rainfall scenarios, response sensitivity of the catchment is subject to vary in land use needs to be investigated. Changes in the catchment response corresponding to different scenarios depicting extreme changes in land use are investigated. Three different hypothetical land use scenarios are generated

**Table3: NAM parameters**

| Parameters | Description | Permissible values | Final values |
|---|---|---|---|
| $L_{max}$ | Maximum water content in lower zone storage | 50-300 mm | 70 mm |
| $U_{max}$ | Maximum water content in surface storage | 5-35 mm | 10 mm |
| CQOF | Overland flow runoff coefficient | 0-1 | 0.74 |
| TOF | Threshold value for overland flow | 0-0.9 | 0.1 |
| TIF | Threshold value for interflow | 0-0.9 | 0.0006 |
| TG | Threshold value for recharge | 0-0.9 | 0.1 |
| CKIF | Time constant for routing interflow | 500-1000 hrs | 776 hrs |
| $CK_{12}$ | Time constant for overland flow and interflow routing | 3-80 hrs | 35 hrs |
| CKBF | Baseflow time constant | 500-6000 | 5400 |

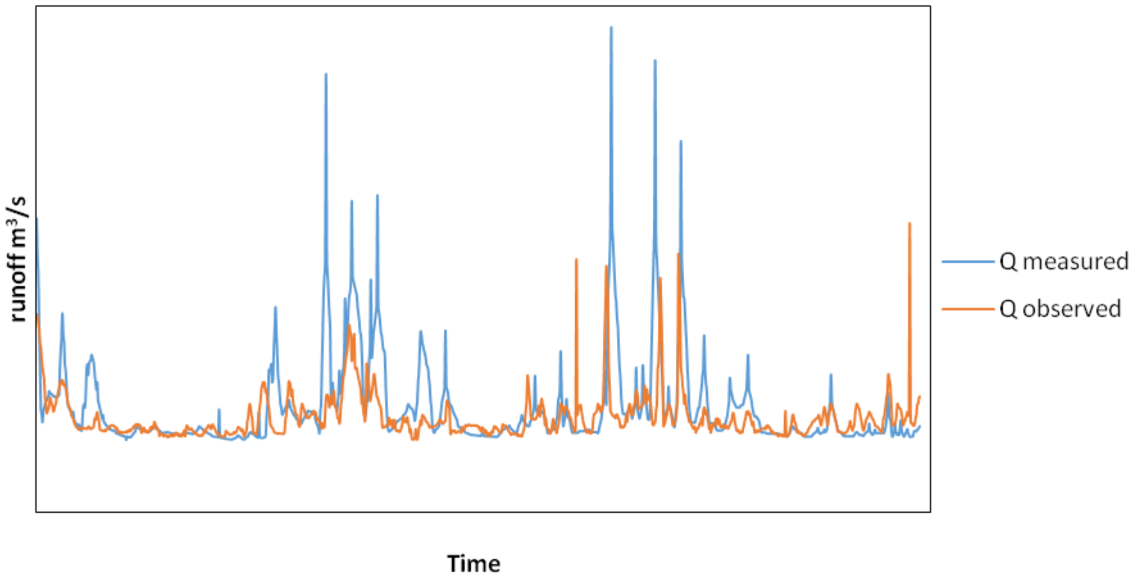


**Figure 4: comparison between observed and measured runoff time series**

**.Table 4: The scenarios for rainfall-runoff modeling adopted in NAM**

| Scenarios | Parameter Values |
|---|---|
| Forest | $U_{max}$ : 18<br>$L_{max}$ : 100<br>CQOF : 0.7<br>$CK_{12}$ : 42 |
| Meadow | $U_{max}$ : 12<br>$L_{max}$ : 80<br>CQOF : 0.78<br>$CK_{12}$ : 39 |
| Urban | $U_{max}$ : 5<br>$L_{max}$ : 50<br>CQOF : 0.84<br>$CK_{12}$ : 30 |

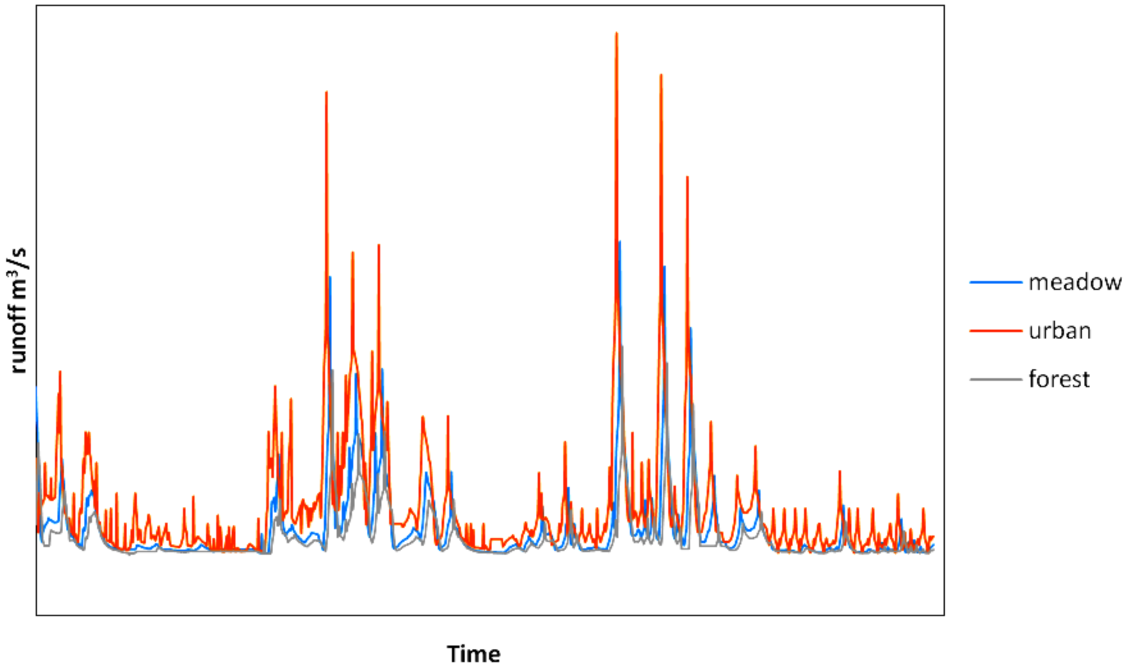


**Figure 5: Runoff time series for meadow, urban and forest scenarios.**

along with rainfall events and their associated impacts are assessed by running the model with parameters corresponding to the changed situations using the same meteorological inputs used to analyze the model. A slight change in some parameters or variables may lead to significant change in the model simulation result. The model is said to be sensitive to such parameters or variables. On the other hand, no noticeable change is felt due to change in other parameters and they constitute a group of parameters to which model is insensitive.

In this model, $U_{max}$, $L_{max}$, CQOF and $CK_{12}$ are sensitive to the land use changes. Original rainfall time series has been adopted for computation of runoff. For land use change, the considered area is hypothetically changed into forest, Meadow and urbanization. Three scenarios are being made to study the impact of strong forestation to urbanization in the study area. Table 4 shows the scenarios and figure.5 shows the simulation results.

For forest scenario in figure 5, a considerable reduction in peak runoff in all seasons has been observed. It is also evident from the value of CQOF. This is mainly due to the absence of sealed area, this generates direct runoff with high speed, peak runoff follow decreasingly. In addition, evapotranspiration rate is higher which is significant in summer season. The removal of soil water through evapotranspiration leads to an increase rate of infiltration, which consequently leads to a reduction in the portion of the rainfall that contributes to surface runoff. Higher interception capacity reduces rainfall. These all factors contribute in the reduction of final runoff. However, these factors have affect on minor storm events and their affect is minimized on major storm events. Furthermore, long perennials or deeper roots increase the transpiration rate which affects the seasonal and long term mean runoff but this affect is not very prominent.

However, peak runoff values are not changed significantly in case of meadow scenario. This is because around 60 percent of original land use area is in meadow domain. From urban scenario, results show peak runoff is increased. Degree of this increase varies from event to event. It can be concluded that the increase in urban area at the expense of forest land use or meadow conditions would lead to less possibility for infiltration because of closed surface. So, surface runoff will be elevated as the precipitation that otherwise would infiltrate also contribute to the runoff. The increase in the peak runoff due to urbanization is accompanied by a time reduction in peak arrival at the outlet of the catchment. This reduction actually depends on the catchment size, in addition to the degree of increase of the urban area.

It should be noted that runoff values are not changed dramatically in case of urban scenario. The main reason is the chosen area for this work is not quite big enough because of unavailability of the data. Therefore better results are expected for a larger area.

## CONCLUSIONS

NAM is a conceptual lumped model that requires less input data. It is efficient, easy to use and can calculate runoff for larger areas. Rainfall-runoff modeling has been done for catchment area of river Dhünn using MIKEBASIN. Manual and automatic calibrations of 9 NAM parameters have been done for three years which shows satisfactory similarity between observed and measured discharges. Forest, meadow and urban scenarios for the given catchment have been used to study the changes in surface runoff for three years time period. Peak runoff values are considerably low in forest scenario due to more infiltration. In meadow scenario, peak runoff values are approximately similar to the measured values as 60 percent of actual land is meadow. In case of urban scenario, high peak runoff values are obtained but runoff values are not dramatically changed due to small catchment area.

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