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Identification of Dam Location and Computation of Dam Inflow using Lumped and Semi-Distributed Model

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***Abstract*—With the advancement in remote sensing technologies, many preliminary studies are carried out using space inputs. This study has been taken up to identify suitable dam location which can meet the daily demand of water to Ukhrul town in the state of Manipur, India. This study also addresses the differences in the discharge computation at the inflow of dam resulted from different approaches. With the usage of high resolution satellite imagery and Digital Elevation Model, two dam locations (Langdang Kong and Ronjal Kong) have been identified in this study. The inflow discharge to the dam from the catchment has been studied using two methods i.e. using lumped model (rational method) and most widely used semi-distributed model (i.e. HEC-HMS). From the study, it is found that a possible location for the construction of the dam can be identified and inundation on the upstream of the dam can be generated using remote sensing techniques. Also, it is found that the discharge at the inflow of dam computed using HEC-HMS is approximately three times greater than the discharge computed using the rational method for Langdang Kong and Ronjal Kong catchment.**

Keywords*—*HEC-HMS, CartoDEM, Rainfall-Runoff, remote sensing, space technology, dam, Ukhrul

I. INTRODUCTION

Usage of remote sensing and geographical information system (GIS) in the field of hydrology is one of the most effective approaches today [2]. Various studies in the past have been carried out for various hydrological applications using remote sensing technology [1], [2], [6], [9], [11]. Reference [2] used remote sensing and GIS technology for identification of suitable dam location and also to control the flood events in Tabuk city in Saudi Arabia. But limited studies found on the identification of dam location followed by generation of inundation area for specific dam height using space technology. Therefore, the present study focuses on the identification of suitable dam locations and generation of inundation area with respect to different storage levels using space inputs. The dam location needs to be identified so that it meets the daily requirement of water for the current and projected (up to the year 2041) population of the Ukhrul town.

The current practice of rainfall-runoff modeling is using lumped, semi-distributed and fully distributed models. These models have their own advantages and disadvantages. The spatial variations of the catchments are not considered in lumped models [13], [18]. The averaged value of soil, LULC and rainfall are considered in the catchment [3], [17]. This will lead to over or under parameterization [17]. In the case of semi-distributed models, the catchments are divided into sub-catchments and different parameters are assigned to these sub-catchments [17]. The semi-distributed model considers the soil and land use data without any immense model structure [10]. The advantage of the semi-distributed model is, less computation time and minimal data requirement when compared with the fully distributed model [14], [15]. Limited study found on specifically addressing the quantification of discharge computed using lumped and semi-distributed model. Hence, this study aims in the quantification of discharge obtained from the lumped model (i.e. using the rational method) and semi-distributed model (i.e. HEC-HMS) and its advantages and disadvantages. This study will be helpful in choosing the appropriate modeling approach by the research community depending upon the data availability and model building time.

II. STUDY AREA

The area chosen for the study is Ukhrul town in the state of Manipur, India. It has a population of 92,000 [5]. This town is located on the hilltop with an elevation of 1,890 m above mean sea level. Ukhrul town receives rainfall of 1,500 mm on an average annually. There are two streams flowing near to the town, those are Langdang Kong and Ronjal Kong (as shown in Figure 1).

III. IDENTIFICATION OF SUITABLE DAM LOCATION:

A. Materials and Methodology

The Survey of India (SOI) toposheets and satellite imagery are used for identification of two streams Langdang Kong and Ronjal Kong. The proposed dam locations along the streams are identified in such a way that there is sufficient availability of water throughout the year which meets the daily requirement of the population of the Ukhrul town. According to the standards, the daily requirement of water is 160 litres/person. The population of Ukhrul town is 92,000 in 2011. The growth of population in 10 years is reported as 30.7% (according to census department). Hence the projected population along with the daily requirement of water is computed as shown in Table 1

TABLE 1: ESTIMATION OF POPULATION GROWTH TILL 2041 AND DAILY WATER DEMAND PER PERSON FOR UKHRUL TOWN

Percentage increase in population	Population (nos)	Daily water demand (m^3/day)
2011	92,000	14,720
2011 – 2021 (30.7%)	1,20,244	19,239
2021 – 2031 (30.7%)	1,57,158	25,145
2031 – 2041 (30.7%)	2,05,405	32,864

A high resolution digital elevation model (DEM) CartoDEM v3 of 10 m resolution and KOMPSAT satellite imagery is used for identification of dam location and the extent of inundation. This DEM is used for generation of the cross-section at proposed dam location across two streams and also for obtaining the inundation area in the upstream of the proposed dam for a specific dam height. By taking into consideration of daily requirement of water for the projected population the dam location is chosen across two streams. The catchment area of the proposed dam location across Langdang Kong stream is 28.01 sq.km. Figure 2 shows the cross-section across Langdang Kong for a dam height of 25 m and 50 m. From the figure, it is noted that for dam height of 25 m the length of the dam is 290 m and for the height of 50 m, the length of the dam is 428m.

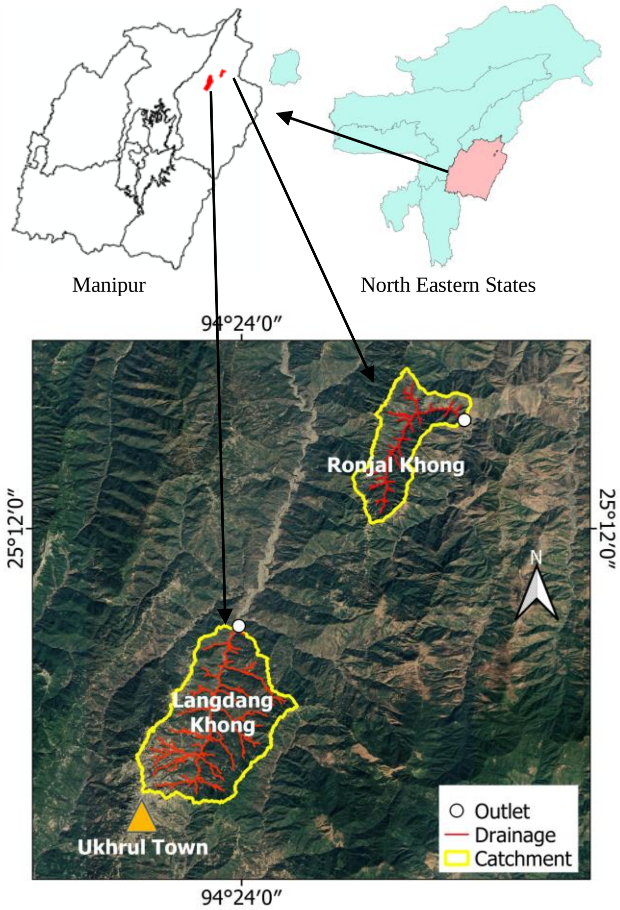

Fig-1: Ukhrul town and streams Langdang and Ronjal Kong

The inundated area for a dam of 25 m height built across the Langdang Kong stream is shown in Figure 3. Similarly, Figure 4 shows the inundation area for a dam of 50 m height across the Langdang Kong stream. This inundation area is generated using DEM. (Blue color in Figure 3 and 4 show the inundation area). From the figure, it is evident that there are no villages inside the blue polygon which implies that there are no settlements. Hence, it is safe for the construction of a dam at the proposed location.

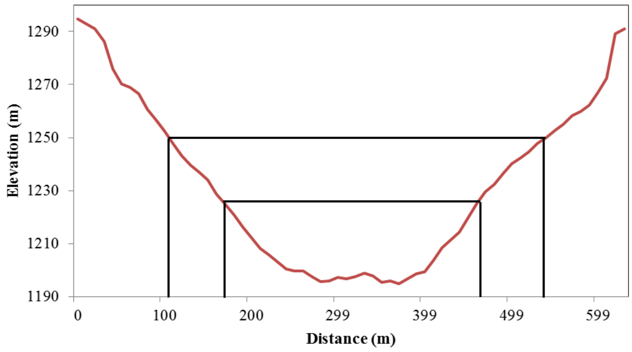

Fig-2: Cross-section across the proposed dam location for Langdang Kong

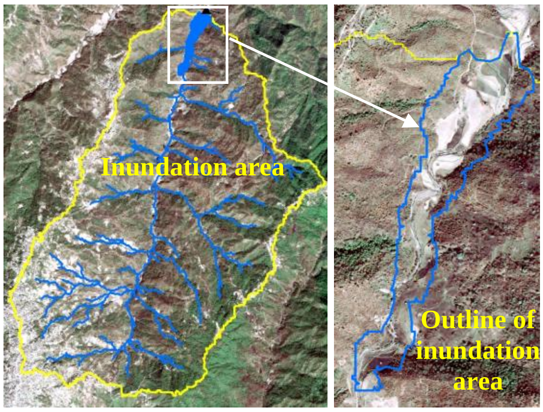

Fig-3: Proposed inundation area for the dam height of 25 m

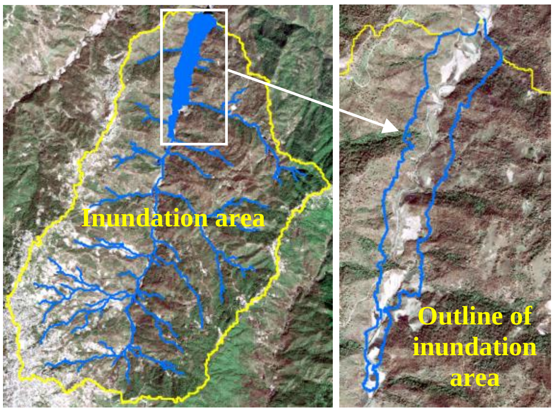

Fig-4: Proposed inundation area for the dam height of 50 m

Table 2 shows the inundation area and storage volume for a proposed dam of 25 m and 50 m across Langdang Kong stream.

TABLE 2: INUNDATION AREA AND STORAGE VOLUME FOR THE SPECIFIC DAM HEIGHT

Dam height (m)	Inundation area (m^2)	Storage volume (m^3)
25	2,14,952	28,13,126
50	6,20,119	1,31,79,620

A similar analysis is carried out for Ronjal Kong stream. The catchment area for the proposed dam location across Ronjal Kong stream is 12.03 sq.km. Figure 5 shows the cross-section across the proposed dam location for Ronjal

Kong stream. From the figure, it is noted that for a dam height of 25 m the length of the dam is 107 m and for the height of 50 m, the length of the dam is 198 m.

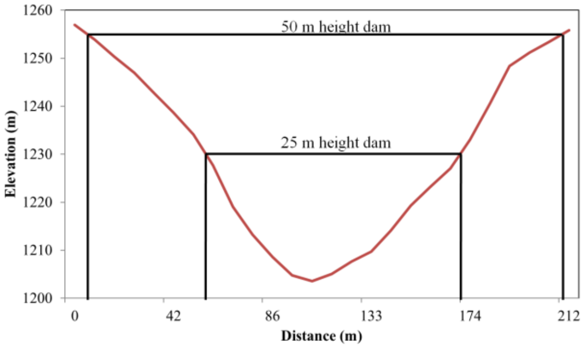

Fig-5: Cross-section across the proposed dam location for RonjalKhong

The inundation area for a dam height corresponding to 25 m and 30 m across the Ronjal Kong stream is shown in Figure 6 and 7 (blue color in Figure 6 and 7 shows the inundation area). From the figure, it is evident that there are no villages inside the blue polygon which implies that there are no settlements. Hence it is safe for the construction of a dam at the proposed location. Table 3 shows the inundation area and storage volume for the proposed dam of 25 m and 50 m across Ronjal Kong stream.

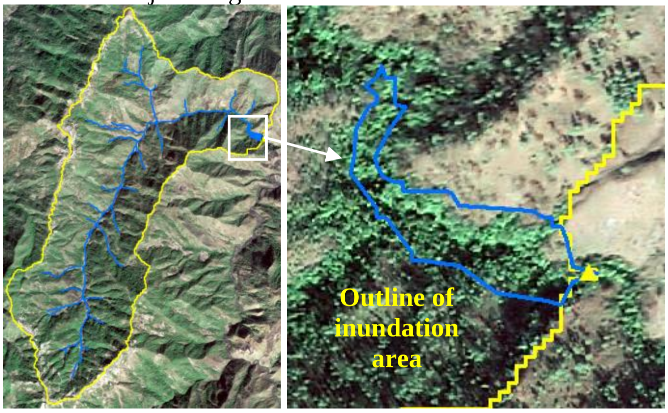

Fig-6: Inundation area for the dam height of 25 m

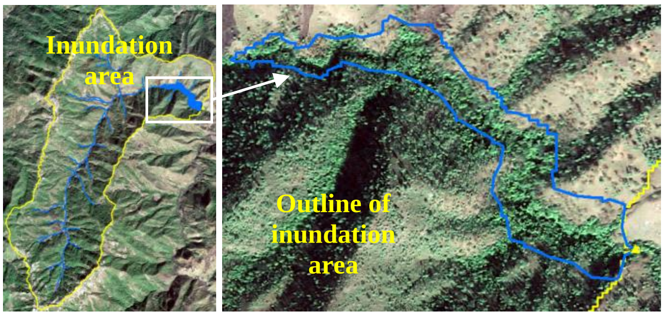

Fig-7: Inundation area for the elevation of 50 m in the dam

TABLE 3: INUNDATION AREA AND STORAGE VOLUME FOR THE SPECIFIC DAM HEIGHT

Dam height (m)	Inundation area (m^2)	Storage volume (m^3)
25	22,364	2,49,854
50	1,19,392	19,87,995

From the study, it is said that with the construction of 50 m dam height across Langdang Kong and Ronjal Kong stream, the storage volume of 1,31,79,620 m^3 and 19,87,995 m^3 could be obtained.

IV. DISCHARGE COMPUTATION AT THE INFLOW OF DAM

The computation of discharge for both the dam could be an important input towards the assessment. The simple and easiest way of computing the discharge is using the lumped model i.e. using a rational method for the catchment. More detailed analysis can be carried out by building a semi-distributed model (i.e HEC-HMS) by considering the dam location at the outlet of the catchment. HEC-HMS model is a data comprehensive and time consuming model building and requires different spatial datasets such as LULC and soil data, many variables, parameters, etc. when compared with a simple rational method. Hence to understand the difference in the discharge computed from HEC-HMS and rational method a comparative study has been carried out for two catchments Langdang Kong and Ronjal Kong. This analysis will eventually help the user in deciding the effective methods for the computation of discharge. The methodology involved in discharge computation at the inflow of the dam using a semi-distributed model and rational method is shown in Figure 8.

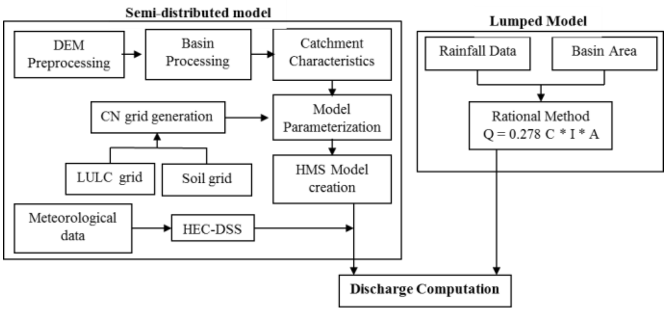

Fig-8: Methodology for computation of discharge using the semi-distributed and lumped model

A. *Rational Method*

The standard Rational method is used for computation of discharge for both the catchments. Discharge is computed using the equation,

$$Q= 0.278\ C * I * A \qquad (1)$$

Where Q is the discharge in m^3/sec, C is the runoff coefficient, I is rainfall intensity in mm/hour, A is an area of the catchment in sq.km.

The rainfall data for both the catchments is obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) datasets with a resolution of 0.125^0. The total rainfall for Langdang Kong and Ronjal Kong is 1575.68 mm and 1647.04 mm respectively for the year 2017 using ECMWF data. From the literature, the standard runoff coefficient of 0.25 is considered [20] for the rational method.

B. *HEC-HMS model*

HEC-HMS (Hydrological Engineering Centre–Hydrological Modeling System) model is hydrological modeling software, empirical and theoretical, lumped and semi-distributed, event and continuous time step based model. Hydrological modeling is one of the important tools for understanding the behavior of various environmental and ecological impacts towards river flow generation and

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estimate the flow volume basin wise for integrated multipurpose water supply and management.

In the present studies over the two small sized basins, direct runoff was computed using the transform method, the SCS unit hydrograph. The SCS unit hydrograph is an empirical, lumped, event and fitted parameter [7]. The direct runoff generated flows toward the plain of the main channel which ultimately routed using one of the routing methods, i.e. Muskingum-Cunge method.

Surface Runoff

Surface runoff is computed using the most commonly available equation, SCS curve number method [19]. This method is simple and used for estimating rainfall excess or effective rainfall from rainfall events [8] and is represented in the following equation,

$$Q_{surf} = \frac{[R_{day} - 0.2S]^2}{[R_{day} + 0.8S]} \qquad (2)$$

Where Q_{surf} is the collected runoff (mm), R_{day} is the precipitation depth for the day (mm), S is the retention parameter (mm). I_a is the initial abstraction loss (mm). The retention parameter S is calculated using the following equation,

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \qquad (3)$$

Where CN is the curve number for the day and it is computed using the following equation,

$$CN = \left(\frac{25400}{S + 254}\right) \qquad (4)$$

Routing

The Muskingum Cunge method defined a simplified relationship between the continuity equation and the relation among storage, inflow and outflow of the reach [4] which is given below

$$O2 = C1 \,.\, I1 + C2 \,.\, I2 + C3 \,.\, O1 \qquad (5)$$

Where, $O1$ and $O2$ are outflow discharges at time 1 and time 2 (m^3/s), $I1$ and $I2$ are inflow discharges at time 1 and time 2 (m^3/s). $C1$, $C2$ and $C3$ are dimensional parameters and are represented in the following manner.

$$C1 = (\Delta t / K) + 2X) / C0 \qquad (6)$$

$$C2 = (\Delta t / K) - 2X) / C0 \qquad (7)$$

$$C3 = (2(1 - X) - \Delta t / K) / C0 \qquad (8)$$

$$C0 = \Delta t / K + 2(1 - X) \qquad (9)$$

Reference [4] developed equations to compute X and K from hydraulic behavior of the reach. The mathematical expression is condensed and presented by Reference [16]. The equations are given below:

$$X = \frac{1}{2}\left(1 - \frac{Q}{BSc\Delta x}\right) \;\&\; K = \frac{\Delta x}{c} \qquad (10)$$

Where c is the flood wave celerity (m/s), Δx is the distance increment (m), B is the bottom width (m).

C. Datasets and model setups

To generate the flow discharge at the pre-defined outlet, hydrological modeling is performed which in turn require certain important spatial data such as DEM, soil layer, land use land cover (LULC) layer and temporal data such as rainfall data. In these two basins, the DEM used is CartoDEM v3 of 10 m resolution. The LULC data layer has been generated using supervised classification at 1:10,000 resolution and the soil data at 1:50,000 resolution has been used. The most important variable data, i.e. rainfall is obtained from the ECMWF for the period of 1 year (i.e. for the year 2017). The model has been calibrated and validated using the runoff data obtained from ECMWF. In order to represent the model in the actual scenario, LULC and soil data are used to generate CN grid (as shown in Figure 9 and 10) which is very important to basin response towards the extent of flow generation.

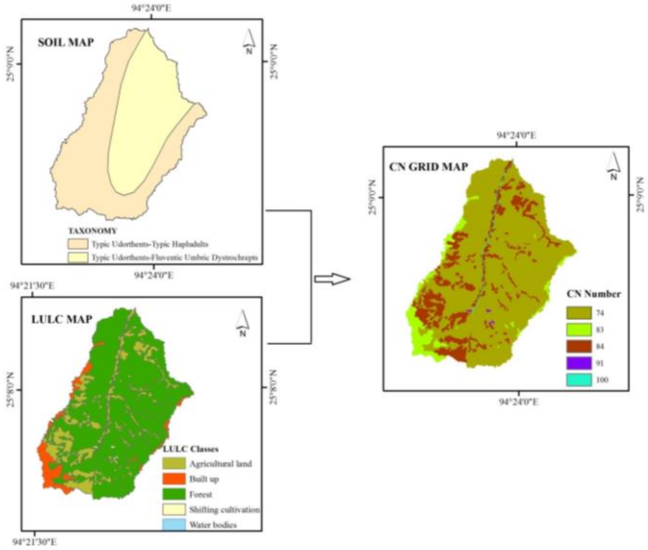

Fig-9: Generation of CN grid from LULC and soil data for Langdang Kong catchment

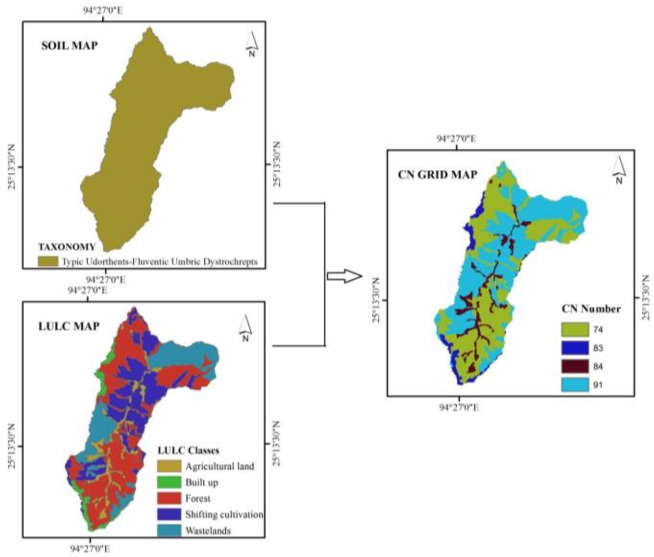

Fig-10: Generation of CN grid from LULC and soil data for Ronjal Kong catchment

D. Comparison of discharge from rational method and HEC-HMS

Table 4 shows the discharge computed using the rational method and HEC-HMS for Langdang Kong and Ronjal Kong at the outlet of the catchment (proposed dam location). Table 5 shows the correlation and Nash Sutcliffe efficiency computed for HEC-HMS and rational method for Langdang Kong and Ronjal Kong catchment. From Table 4, it is significantly clear that the discharge computed by the rational method is less than the discharge computed by HEC-HMS. It is observed that the discharge computed using HEC-HMS is 3.62 times larger than the discharge computed using the rational method for Langdang Kong and 3.82 times larger for Ronjal Kong catchment. This may be the cause of multiple reasons with respect to the consideration of catchment characteristics as a whole, its hydrological processes and parameters. In case of the rational method, parameters such as the time of concentration, lag time, the impact of rainfall occurred in the past, saturation level etc. are not considered whereas almost all the important catchment characteristics and parameters responsible for a catchment flow generation are taken into consideration in case of HEC-HMS model. Thus, the discharge computed using the rational method is very less compared to the HEC-HMS model. By taking into consideration the time factor in the computation of discharge using the rational method, it is found that the time required is 1/100 times lesser than the time required for building the HEC-HMS model. Also from Table 5, it is noted that the performance of HEC-HMS is better than rational method for both the catchments.

TABLE 4: DISCHARGE COMPUTATION USING THE RATIONAL METHOD AND HEC-HMS

Model Types	**Basins Name**	**Discharge (m^3/s)**	**Discharge (m^3/day)**	**Total discharge in a year ($m^3/year$)**
Rational Method	Langdang Kong	0.350	30,253	1,10,42,582
	Ronjal Kong	0.157	13,582	49,57,432
HEC-HMS	Langdang Kong	1.269	1,09,692	4,00,37,758
	Ronjal Kong	0.608	52,550	1,91,80,800
Observed data (ECMWF)	Langdang Kong	1.185	1,02,427	3,73,86,149
	Ronjal Kong	0.529	45,746	1,66,97,457

TABLE 5: PERFORMANCE STATISTICS OF HEC-HMS AND RATIONAL METHOD FOR LANGDANG KONG AND RONJAL KONG CATCHMENT

Basins Name	**HEC-HMS**		**Rational Method**	
	Correlation	**Efficiency**	**Correlation**	**Efficiency**
Langdang Kong	0.65	0.41	0.43	0.29
Ronjal Kong	0.54	0.36	0.39	0.25

Figure 11 and 12 shows the time series graph plotted for the discharge obtained from HEC-HMS and rational method for Langdang Kong and Ronjal Kong catchments. From the figure, it is noted that peaks are high in case of HEC-HMS compared to the rational method. This is because, in case of HEC-HMS the present flow is dependent on the past rainfall and past discharge (i.e. t-1, t-2, t-3,…), whereas in case of the rational method, only the present rainfall occurred in a day is considered and discharge is computed. It is also observed that there is a significant match between the observed data and simulated data of HEC-HMS for both the catchments as compared with the results of rational method. Therefore it is said that using rational method led to the negligence in the flow dynamics occur in a continuous time series.

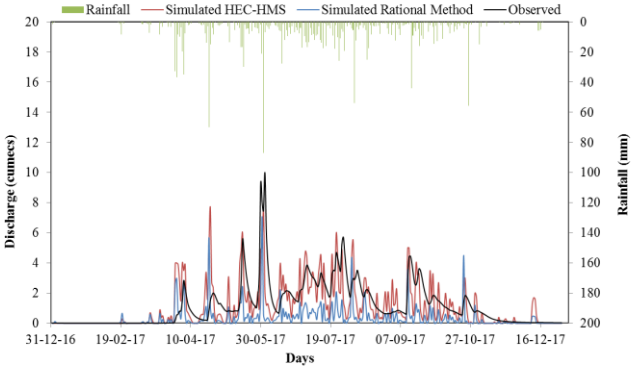

Fig-11: Discharge comparison obtained by two approaches for Langdang Kong Basin

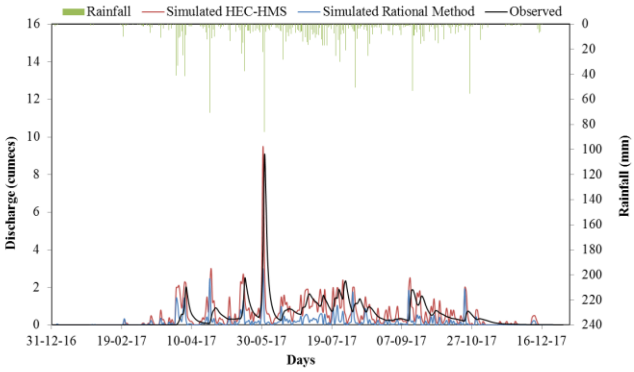

Fig-12: Discharge comparison obtained by two approaches for Ronjal Kong Basin

TABLE 6: STATISTICS SHOWING DAILY DEMAND, DISCHARGE, DAM CAPACITY

The demand for water during 2041 for population 2,05,405 (2041)	**1,19,95,360 m^3/year**
Discharge to dam annually	**3,73,86,149 m^3/year**
Storage volume of Langdang Kong dam (50 m height) Storage volume of Langdang Kong dam (25 m height)	1,31,79,620 m^3 28,13,126 m^3
Considering evaporation loss and loss due to deposition of sediments in the dam The loss at Langdang Kong dam (50 m height) The loss at Langdang Kong dam (25 m height)	7,48,029 m^3 2,50,512 m^3
The effective storage volume of Langdang Kong dam (50 m height) The effective storage volume of Langdang Kong dam (25 m height)	**1,24,31,591 m^3** 25,62,614 m^3

From the study, it is found that rational method required less time and direct application with relevance to the instantaneous intensity of rainfall for computation of discharge, but it is also said that the HEC-HMS model represents the catchment characteristics more accurately in terms of hydrological behavior. Based on the observed discharge to the inflow of the dam, the storage volume of the dam is computed (as shown in Table 6). In the computation of storage volume of the dam, evaporation loss due to storage at the rate of 110 mm annually and also the reduction in the capacity of the dam at a rate of 0.5% annually due to deposition of silt [21] has been considered. From Table 6 it is found that the yearly requirement of water for the predicted population (2041) can be met by constructing a dam across Langdang Kong at a height of 50 m. The yearly demand of the current population is 53,72,800 m^3. With the height of 25 m dam, the yearly demand of 48% of the current population can be stored in the dam. Hence it is suggested to construct a dam of 50 m height which can meet the daily requirement of water for the current and projected population of 2041.

V. CONCLUSION

In this study, the dam location has been identified based on the daily requirement of the current population and also for the projected population for the year 2041. From the study, it is found that a dam height of 50 m across Langdang Kong will meet the daily demand of water for the current and projected population of the Ukhrul town. Also, it is found that remote sensing technology can be used extensively for identification of dam location for any study site. The information obtained out of this study will be useful for the respective user agency for planning purpose for taking up projects related to the requirement of water for Ukhrul town and ultimately elevates the socio-economic life of the people.

The study also focuses on discharge comparisons computed using lumped and semi-distributed modeling approaches. The study reveals that the discharge computed using HEC-HMS is 3.62 and 3.82 times larger than the discharge of rational method for Langdang Kong and Ronjal Kong catchments respectively. It is also observed that the time required for the computation of discharge using the rational method is 1/100th times less than that of HEC-HMS model building time. Hence, it can be said that for any preliminary study, the rational method can be chosen by compromising the accuracy if there is any constraint of the availability of data and time. Otherwise, it is suggested to use a semi-distributed model which will take into consideration the catchment characteristics and dynamics that represents the near actual scenarios of flow computation as compared to the lumped model.

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