FLOOD RISK ANALYSIS BY HYDROLOGIC ROUTING AND HYDRAULIC MODELLING: A COMPARATIVE STUDY

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ABSTRACT

In a gauged basin, when a hydroelectric power project (HEP) is planned on the main river, the recorded flood at the gauge stations either on the upstream or on the downstream of the point of interest in a river becomes critical; the pre-existing stations could be located either on the main river or on the tributaries. The estimated flood values at the point of interest need to be consistent with the already established flood values at gauge and discharge (G&D) sites in the basin. However, in hydrological practices, as there are numerous methods in flood risk analysis, it is likely that results from various methods would vary in terms of flood magnitude or flood hydrograph.

The Ratle HEP is located on the downstream (d/s) of confluence of Marusudar River and Chenab River. On the upstream (u/s) of this confluence, two major HEPs, Dulhasti HEP on Chenab River and Drangdhuran HEP on Marusudar River, are located. In the flood risk analyses of Ratle HEP, a comparative study of hydrologic routing by Muskingum method and one-dimensional unsteady hydraulic modelling of the river system has been carried out. Initially, the probable maximum flood (PMF) hydrographs at Dulhasti and Drangdhuran have been established by unit-hydrograph method considering the probable maximum storm (PMP) of adopted k-day temporal distribution of storm. Later, in hydrologic routing, by holding some justifiable assumptions, the PMF hydrographs are combined and further routed through Ratle by applying Muskingum channel-routing method. Using the cross-sections of the Chenab River from Dulhasti and of the Marusudar River from Drangdhuran through Ratle, a river model has been developed using one-dimensional hydraulic modelling software- HEC-RAS. With the PMF hydrographs as u/s boundary conditions and normal depth as d/s boundary condition, the model run generates PMF flood hydrograph at Ratle. The comparative analysis of both the said methods illustrates the advantages of one method over the other, which pertains to the case under study.

Keywords: *HEP, one-dimensional, Muskingum, routing, PMP, PMF, hydrograph.*

1. INTRODUCTION

The consistencies of gauged basins data are vital for any hydropower project planning. While estimating the design flood of hydropower projects to be developed on a river, the available flood records either on the upstream or on the downstream of the river become often becomes cumbersome to deal with, especially when the catchment areas are large and the design flood values estimated for the project are found to be inconsistent. Therefore, it is vital to check the derived flood by more than one method to assess the design flood reasonably, thereby scrutinizing the consistency and validating the methods applied. The methods could be solely hydrologic or hydraulics based or integration of both. In the present study, an example of Rate HEP has been cited, where the flood risk analyses by hydrologic routing and hydraulic modelling have been carried out to draw attention towards the results of each method and a comparison has been made.

The catchment area of Ratle circumscribes the catchment areas of Dulhasti HEP and Drangdhuran HEP having the mouth of the catchment at project locations. The Dulhasti hydroelectric project is located on the river Chenab, whereas Drangdhuran hydroelectric project is located on the river Marusudar. The confluence point of the Chenab River and the Marusudar River is on the downstream of these two projects; Marusudar River being the tributary of Chenab River. Further, towards the downstream after the confluence, the Ratle HEP is located as displayed below:

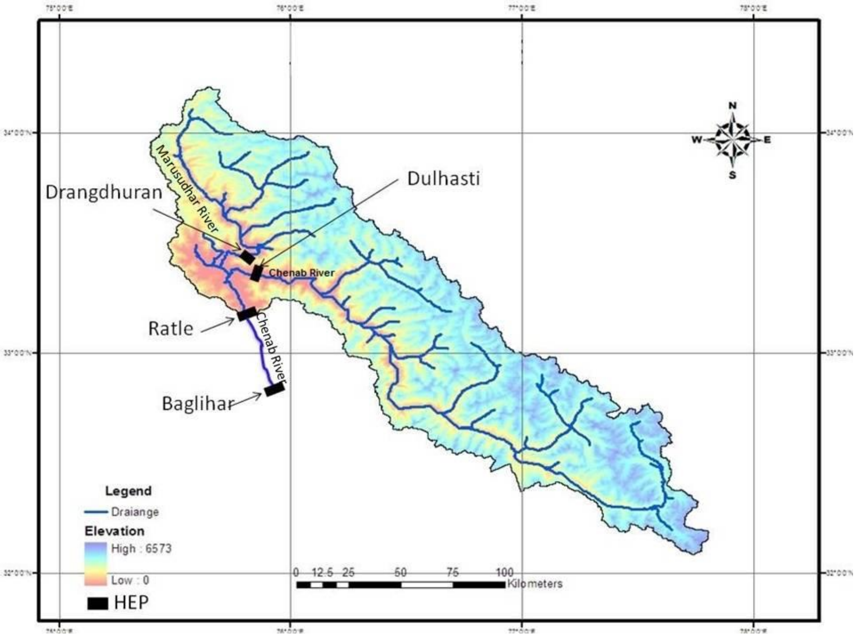

Figure 1. Catchment elevation map and location of Ratle HEP (Location of Baglihar is schematic and not to scale)

In the present study, in order to check the consistencies of derived flood values at Ratle HEP, it is essential to study the upstream catchments, Dulhasti and Drangdhuran to understand the impact of flood during an event of PMF at these two locations on the downstream project of Ratle HEP.

The catchment area of Ratle has been worked out to be 14209 Sq Km. It is divided into three sub-catchments, viz., Dulhasti, Drangdhuran, and Lower Sub-Catchment (the remaining area till the mouth of the catchment at Ratle). The sub-catchment details have been tabulated below:

Table 1. Sub-catchment details of Ratle Catchment

Sub-catchment	Sub-catchment area (Sq Km)	Rainfed area (Sq Km)	Snowfed area (Sq Km)
Dulhasti	10500	2510	7990
Drangdhuran	3379	1944	2011
Lower Sub-Catchment	330	330	-

1.1 Overview of probable maximum flood values at Ratle

Initially, with the hydro-meteorological approach, the PMF values derived by adopting the storm data of Ratle, supplied by Indain Meteorological Department (IMD), have been found to be on a higher side; even higher than the PMF of Baglihar, which is located on the downstream. Secondly, by adopting the PMP of Baglihar, the corresponding PMF at Ratle has been estimated to be about 11100 m^3/sec; higher of the values obtained from SCS and Snyder’s method.

It has been observed that the PMFs derived for the upstream projects, Dulhasti HEP and Drangdhuran HEP, are significant to substantiate any conclusion to PMF at Ratle. Therefore, the PMF of Ratle by adopting the storm of Baglihar is validated from the inferences of PMF values of Dulhasti and Drangdhuran hydroelectric projects based on hydraulic modelling and flood routing. To illustrate this analysis, a further study has been carried out to validate the PMF of Ratle HEP derived from the storm of Baglihar. The abstracts of the present study are:

i. PMF hydrographs determination of Dulhasti HEP and Drangdhuran HEP;
ii. hydrologic flood routing by Muskingum method;
iii. hydraulic modelling of river reaches initiating at the locations of Dulhasti HEP and Drangdhuran HEPs through Ratle on the downstream with an objective to find out the outflow at Ratle Dam site; and
iv. comparative study.

2. PMF Hydrographs Determination at Dulhasti HEP and Drangdhuran HEP

The Snyder's UH approach has been applied to determine the flood hydrographs at Dulhasti HEP site and Drangdhuran HEP site by adopting the PMP values as asserted in the previous studies of NHPC (Source: Section-6.2.2 and Section-6.2.5, DPR, NHPC). The results featuring the unit hydrographs have been shown below:

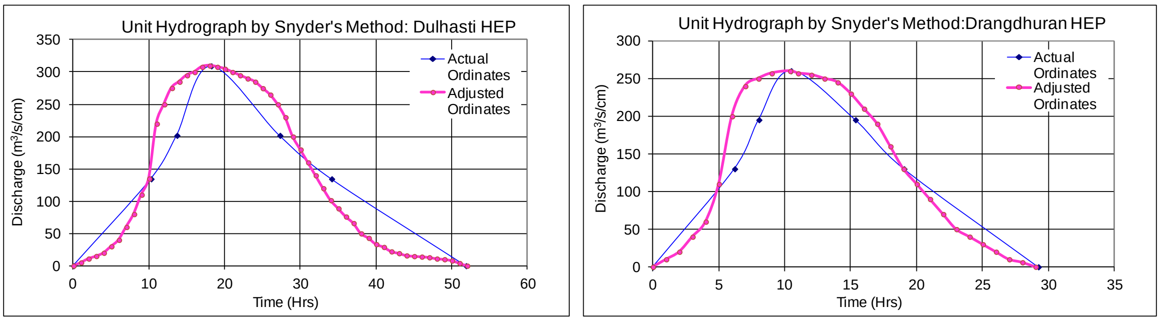

Figure 2. Unit hydrograph for Daulhasti HEP and Drangdhuran HEP

From the above unit hydrographs, the total base time for both the stations, Dulhasti and Drangdhuran have been found to be 52hours and 29 hours, respectively. Therefore, the 2-day storm has been adopted. The 2-day PMP storm values for Dulhasti and Drangdhuran as mentioned in the previous studies by NHPC are 18 cm and 29.64 cm respectively. The base flow inclusive of snowmelt recommended for the two catchments have been adopted as 2500m^3/s and 500m^3/s for Dulhasti and Drangdhuran respectively duly referred from the same report of NHPC.

Since the PMF values of Dulhasti and Drangdhuran have already been approved, no alterations have been made in the peak flood. However, while estimating the flood peak of Dulhasti, the PMF has been found to be in the order of 6000 m^3/s. The application of Collin's method by NHPC, which is based on observed direct runoff hydrograph and rainfall excess, might be one of the reasons for deviation in results. The other reason might be the adopted 2-day distribution co-efficients of Ratle, which have been applied, in the present study, for PMF estimation at Dulhasti and Drangdhuran sub-catchments using 4-bells concept. Since the direct runoff hydrographs and the rainfall excess are not available, in the present study, the Collin's method has not been used to compare the results.

With the available information, a conservative and an optimal approach has been followed to design the required PMF hydrographs. By applying Snyder's unit hydrographs method, the flood values of Dulhasti and Drangdhuran stations have been worked out to be 7706 m^3/s and 4331 m^3/s, respectively, The PMF hydrographs have been shown below:

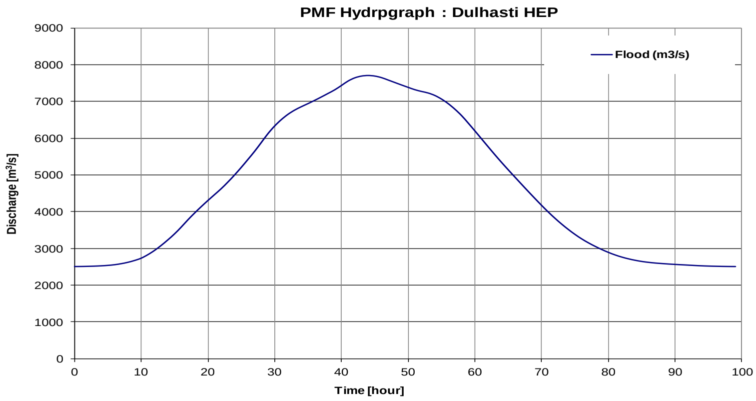

Figure 3. Flood hydrograph with an event of PMF for Dulhasti HEP

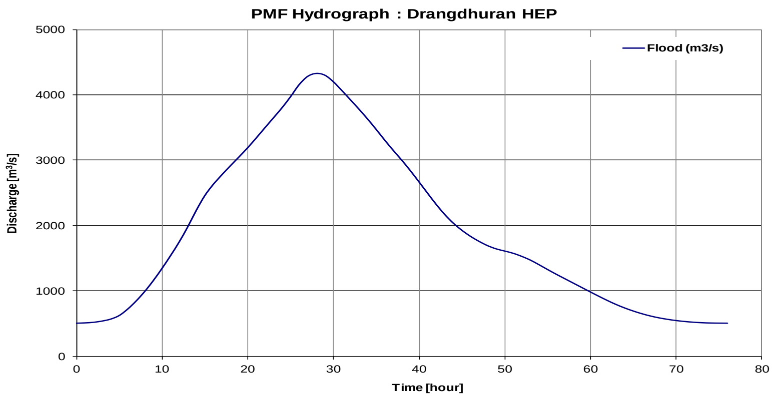

Figure 4. Flood hydrograph with an event of PMF for Drangdhuran HEP

4. HYDROLOGIC ROUTING OF FLOOD BY MUSKINGUM'S METHOD

The Muskingum hydrologic routing has been attempted to route the PMF hydrograph through downstream at Ratle. The Muskingum"K" value has been assumed to be one hour.

Table 2. Routing parameters and co-efficients

Routing Parameters	Value	Unit	Remarks
x	0.2	--	weighing factor; 0<x<0.5
K	1.0	hour	travel time of flood wave between channel reach
Δt	1.0	hour	duration

Table 3. Muskingum's Routing co-efficients

Routing Co-efficients	Equation	Value of Co-efficients	Remarks
C_0	$C_0=\{(\Delta t/K)-2x\}/\{2(1-x)+(\Delta t/K)\}$	0.231	$C_0+C_1+C_2=1$; Okay
C_1	$C_1=\{(\Delta t/K)+2x\}/\{2(1-x)+(\Delta t/K)\}$	0.538	
C_2	$C_2=\{2(1-x)-(\Delta t/K)\}/\{2(1-x)+(\Delta t/K)\}$	0.231	

The flood ordinates of both the stations, Dulhasti and Drangdhuran for a corresponding duration has been added to from a combined hydrograph as inflow and then this inflow has been routed by applying Muskingum method to obtain hydrograph at Ratle on the downstream. While considering the combination of flood hydrographs of Dulhasti and Drangdhuran, it has been observed from that the lower sub-catchment area is about 330 Sq Km. The lower sub-catchment with mouth at the confluence is about one-third of the total lower sub-catchment area. Since the intermittent catchment at confluence is very less as compared to the three sub-catchments, it is least likely that any significant flow contribution from this area would impact on the flood peaks at the confluence during the event of PMF. Therefore, while routing the flood hydrographs from Dulhasti and Drangdhuran, the combination of flood hydrograph at the confluence is justifiable by assuming no lateral flow at the confluence and further through Ratle. The results of the Muskingum's flood routing have been discussed in the later section.

3. HYDRAULIC MODELLING WITH ONE-DIMENSIONAL MODEL, HEC-RAS

The physical laws which govern the flow of water in a stream are expressed mathematically in the form of partial differential equations:

Conservation of mass (continuity) equation:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q_1 = 0 \tag{1}$$

Conservation of momentum equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \tag{2}$$

where:

Q = discharge,
A = total flow area,
q_1 = lateral inflow per unit length,
x = distance along waterway,
t = time,
V = velocity,
g = acceleration due to gravity,
z = water surface elevation, and
S_f = frictional slope.

These one-dimensional differential equations also describe the transport of sediment, salinity and other constituents. The software, HEC-RAS is designed to perform one-dimensional hydraulic computations numerically for a full network of natural and constructed channels. The schematic network to set up the model in HEC-RAS has been displayed below:

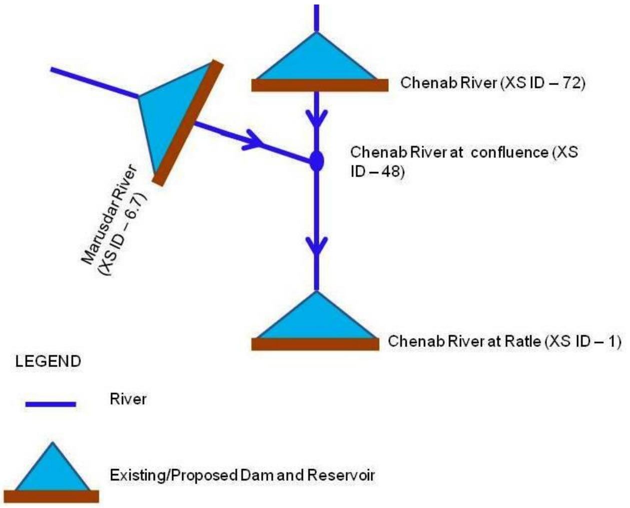

Figure 5. Modelling scheme of river network

The HEC-RAS model comprises two major components; steady flow and unsteady flow. In the present study, the steady and unsteady flow component of HEC-RAS has been used to model the Chenab River and Marusudar River as shown above. The steady component has been used to calibrate the model, whereas the unsteady component has been used to model the river reaches initiating at the locations of Dulhasti HEP and Drangdhuran HEP through Ratle on the downstream with an objective to find out the outflow hydrograph at Ratle.

3.1 Model Set UP

River geometry:

The river reach in the model has been divided into three parts, viz., Marusudar Upper, Chenab Upper and Chenab Lower. The river cross-sections have been generated by using the survey drawings and Google Earth. The cross-sections generated by Google Earth have been further calibrated with respect to the available surveyed cross-sections.

The uppermost cross-sections in the Marusudar Upper and Chenab Upper have been assigned with station XS IDs- 6.7 and 72, respectively. After the confluence, the uppermost cross-section in the Chenab Lower has been assigned with XS ID- 48 and the downstream cross-section at Ratle Dam site has been assigned with XS ID- 1.

Calibration:

The available historical inflow data at Dulhasti, Drangdhuran, and Premnagar (Gauge and discharge station located on the downstream of Ratle) have been utilized to calibrate the model. The roughness parameter (Manning's n) has been found to be sensitive in the model and therefore, with a number of iterations, the optimum value n = 0.04 has been observed to exhibit less errors while comparing the modeled outflow hydrograph and the observed hydrograph at Premnagar. Hence, Manning's n =0.04 has been applied in the model.

Initial and boundary conditions:

The initial conditions and the upstream and the downstream boundary conditions have been tabulated below:

Table 4. Initial and boundary conditions

Station ID	Station name	Initial condition	Upstream boundary condition	Downstream boundary condition
XS ID – 72	Dulhasti	Base flow	PMF hydrograph	-
XS ID – 6.7	Drangdhuran	Base flow	PMF hydrograph	-
XS ID – 1	Ratle	-	-	Normal depth

The initial conditions have been kept same as the aforementioned base flows. As the intermittent catchments between Dulhasti and Ratle as well as Drandhuran and Ratle are comparatively smaller than the catchment area of Ratle, it has been assumed that no lateral flow would be significant in that would significantly alter the results; which is reasonably a good approximate.

With the above configurations, the model has been simulated for the duration of the hydrographs and the details of results have been discussed in the subsequent section.

4. RESULTS AND DISCUSSIONS

The results of flood routing by Muskingum's method have been displayed below:

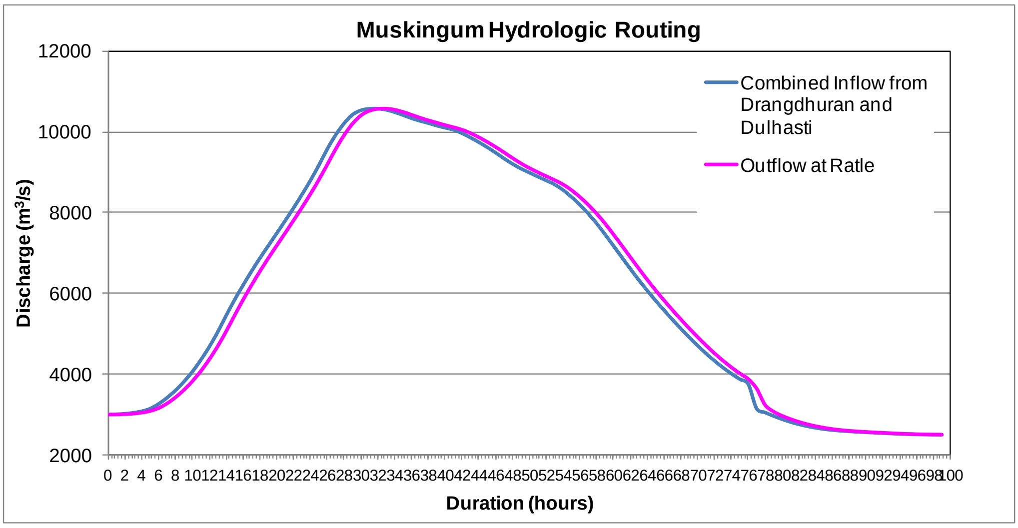

Figure 6. Flood hydrograph routing by Muskingum's method

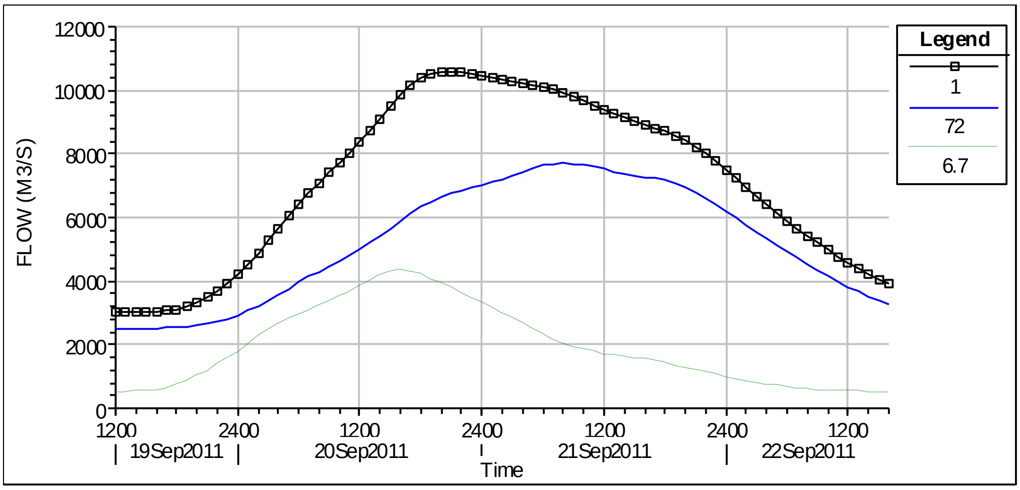

Figure 7. Hydraulic modelling results: flood hydrograph routing

While routing a flood from upstream to downstream of a river, peak flood would always result in lower magnitude at the outflow against the inflow unless there is a contribution of any lateral inflow into the main river. In the case of Ratle catchment, the main river is Chenab, whereas the Marusudar River is a tributary of Chenab River.

The comparative analysis between the two methods for outflow generation suggests that the outflow peak flood from the method of Muskingum routing is 10562 m^3/s, whereas from hydraulic modelling; the outflow peak flood is 10589 m^3/s. It means that results from both that models have least difference in terms of peak flow magnitude. This validates the methods to be appropriate and good measures to check if the results are consistent. However, it may be noted that the roots of the PMF hydrograph are same for both the tested methods. Also, the aforesaid results have merely been used in the project planning to check the performance of the models.

Further, to strengthen the study, the annual maximum observed flood data of Premnagar (Catchment area = 15490 Sq Km) has been utilized. In the flood frequency analyses, the observed peak flood values have been increased by 10% to account for instantaneous flood peak of

Premnagar. The 10,000 year flood has worked out using various flood frequency distributions, such as normal, 2-Par log normal, Log- Pearson Type-III, 3-Par log normal, and Gumbel Type-I. From the Anderson-Darling goodness-of-fit ranking criteria, the flood value of Q = 14738 m^3/s from Log-Pearson Type-III has been selected. Applying modified Dicken's formula, the same flood value has been transposed to Ratle Dam site, which works out to be Q = 13814 m^3/s. Among all the other methods, this flood value has been found to be higher than others and it is reasonably consistent with upstream and downstream established flood values of Dulhasti and Baglihar, respectively. Therefore, for the project planning and design works, the design flood of Ratle has been concluded to be Q = 13814 m^3/s.

4. CONCLUSIONS

The intent of the paper is to describe the methods, hydrologic routing and hydraulic modelling, as an important part of study in order to establish consistency in the project flood estimation. The comparison of both the methods is as equally important as the estimation of flood itself. The hydrologic routing exercise only includes the fluvial storage losses and gain processes, whereas the hydraulic modelling takes all possible losses, such as friction loss, head loss et al into considerations. Therefore, one method may be graded better than the other. However, both the methods, in principle, are assumptions based. The important is to evaluate the assumptions based on comparative judgments so that the qualities of results remain not negotiable. The results from the applied models validate the same.

In the project planning of the study, due to availability of peak flood data in the vicinity of the project site it has been possible to apply other methods and to do numerous comparisons additionally. However, the availability of data is often scarce. Therefore, in such scenarios, the best possible comparisons may be made from the methods discussed in this paper. The extent of application may be wide and it blossoms the possibility of future research.

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