Hydrologic Modeling of Khanpur Dam Watershed Using Snowmelt Runoff Model

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Abstract-The flow contribution to Haro River is from the three main sources i.e. rainfall, snowfall and groundwater. Certain models like HBV (HydrologiskaByrånsVattenbalansavdelning) model, UBC (University of British Columbia) watershed model and SRM (Snowmelt Runoff Model) are available for the watershed modeling accounting the process of snowmelt. This particular studies utilizes SRM. Khanpur watershed was selected as study area and the watershed was calibrated for the hydrologic year 2005. The daily river discharge and daily precipitation data were used in calibration of the study area. The area was divided into five elevation zones. Moderate Resolution Imaging Spectroradiometer MODIS remote sensing product was used to predict snow cover area of Khanpur dam watershed. The calibration results show high efficiency value of 88% but the validation results were not very encouraging. The poor efficiency of validation results were highly believed to be as result of low snow cover in the watershed. From the results it was concluded that SRM cannot work well for low snow covered watersheds.

Keywords-Snowmelt Runoff Model, MODIS, Model Calibration, Snow Cover

I. INTRODUCTION

Snowmelt is main source of water for many rivers in Northwest Pakistan. The rivers of Northern Pakistan play an important role in socio financial development of the country. Normally the flood damages are always severe in this part of the world. Therefore, proper water resource management system is required to check and mitigate the floods. A very vital approach in order to estimate the floods is through watershed modeling. The use of appropriate model is very important for estimation of flood discharge over a watershed. It is desired that the model used must understand the meteorological and climatological aspects of the watershed. Most of the computer watershed models are fairly capable of doing that. Snowmelt Runoff Model (SRM) is also a very useful model for modeling the river discharges over such watersheds where snowmelt runoff adds to the river discharge as a major contributor. The changing climate and global warming phenomenon has caused the glacier of the world to retreat followed by change in precipitation patterns. The continuous decreasing of glacier and snow melting at a higher rate is affecting the climate and such effect can definitely change the dimensions of local and socio economic progress of a country.

The changes in the climate of a region can be estimated from the depletion of glacier and snow present there. For the last 20 years the glaciers are facing the crumple and it is reported that the decrease of glacier extent and snow is an indication of active global warming over that watershed [i-ii]. The SRM has been extensively used to a large number of watersheds of various sizes i.e. (76 - 120,000 km^2) all over the world with elevation range of (305 - 7690 m a.s.l) [iii]. The SRM is very useful for water resources planning and management, hydropower generation and flood warning in those areas having snowmelt contribution [iv]. Simulations for such watershed where snowmelt is a major contributor to the flow need a bit more attention in the case that accurate estimates for snowmelt rate are required for water resource planning and management.

Snowmelt Runoff Model (SRM) is one of the most commonly used models to simulate and estimate the daily stream flows in such mountainous catchments [v]. The model uses the approach of simple degree-day method to account snowmelt runoff. The daily rainfall, daily temperature and daily snow cover area are the major inputs to the model. In addition, the information of catchment features such as basin area, zone area, and the hypsometric (area elevation) curve is also required. The daily water produced from the snowmelt and rainfall is added on the calculated recession flow and converted into day-to-day discharge from the catchment.

In the light of above discussion it is very significant to model a watershed for flood estimation. SRM can be used for such watersheds where there is a contribution from snowmelt by using the dataset as mentioned before. The current research describes the snowmelt modeling for the catchment of Khanpur dam using SRM. In order to achieve the calibration results through SRM techniques of remote sensing (RS) and geographical information system (GIS) were also used.

II. STUDY AREA

Khanpur dam watershed is situated in Khyber Pakhtunkhwa of Haripur district. It is located about 50 kilometers Northwest of Islamabad at River Haro. Haro River drains runoff from western slopes of Murree Hills and southern slopes of Nathiagulli mountain and also receives partial runoff from Margalla Hills. The Khanpur dam is situated in Pakistan with a latitude 33°48' and longitude 72°55' and covers an area of about 308 square mile. The location map of the study area is shown in Fig. 1. Pakistan Meteorological Department PMD has only one station i.e. Khanpur station in the study area. The maximum elevation reaches 2755m in the watershed. The analysis of Moderate Resolution Imaging Spectroradiometer MODIS daily data revealed that around 15 to 20% of Khanpur catchment remains covered with snow in winter season.

III. LITREATURE REVIEW

The climate impact has been studied by many researchers. In a study Naeem et al., (2013); concluded the reduction in Chitral River flows under assumed reduced glaciated extents by using UBCWM [vi]. River Kunar watershed was modeled by using the data of snowpack water equivalent and total winter rainfall in Kunhar Basin through SRM where it was found that about 65% of flow is generated due to snowmelt in Kunar River measured at Talhatta [vii] . Snow cover of Gilgit catchment was found by using NDSI on MODIS daily images. The images having high cloud cover were excluded for the analysis and the cloud cover days were interpolated linearly by plotting conventional depletion curve. Later on these snow cover depletion values were used in SRM to simulate flows of Gilgit River [viii].

In another study SRM was used for modeling and the results obtained were utilized for flood forecasting in Swat River. The snow cover area was extracted by using MODIS images having free from cloud cover. First the Model was calibrated for the melting season of year 2004 with model efficiency of 0.90 and verified for years 2005 & 2006 with coefficient of model efficiency of 0.95 and 0.080 respectively. After application of Model it was concluded that SRM model can efficiently be used for water resources planning, management and flood forecasting [ix]. Similarly, another study was focused on the reduction in Astore River flows under assumed reduced glaciated extents with the help of Landsat data and UBCWM [x].

SRM Model was also used in Astore catchment to simulate snowmelt runoff. Landsat-TM monthly satellite images data were used to map snow cover area and coefficient of model efficiency remained 0.91 [xi]. Application of temperature index approach along with extracted snow cover data from remote sensing can be successfully applied to Upper Indus basins for snowmelt simulation.

It is stated in an Interim Report that Mangla Basin comprises of catchment area of 33460 km^2 and 50% of the catchment lies outside line of control. Therefore, MODIS daily snow cover product is encouraged to use to extract the snow cover area of huge basins and further use in the hydrological models to simulate and forecast flows of the catchment. In this particular research, SRM was applied on Khanpur dam catchment with a major objective to observe the change in the flows under different climate scenarios. For this purpose, the temperature and precipitations trends of the catchment was observed for the past data.

IV. SNOWMELT RUNOFF MODEL (SRM)

SRM (snowmelt runoff model) is a temperature index hydrologic model which was used to perform simulation in this study. The Snowmelt Runoff model also called Martinec Rango model was first developed in 1973 at the Federal Institute for snow and Avalanche Research in Davos, Switzerland. The generation of satellite remote sensing data enhanced the possibility of simulating even huge watersheds. SRM has been used to simulate the Gangas River basin with catchment area of 917,444 Km^2. This Model has been used to more than 100 basins located in different 29 countries by universities, self-governing operators and institutes etc. [xii].

The three main variables of the model are daily temperature, precipitation, and daily snow covered area. SRM calculates the daily quantity of water from snowmelt and rainfall, adds it to the calculated recession flow, and transfers it to the daily discharge from the basin. The area has been divided into different elevation zones. Particular basin characteristics include runoff coefficients, degree-day factors and historical recession coefficients and the zonal mean hypsometric elevation.

The strong point of SRM is its primary dependence on snow cover areal degree which is arranged as a depletion curve at the end of snowmelt period. This feature allows the model to work even with limited data, as the snow covered area data can be found today from readily available Remote sensing Snow data by several agencies.

V. DATA ACQUISITION AND PRE-PROCESSING

A. *Daily Discharge*

Daily inflow data at Khanpurstream gauging station was gathered from Khanpur dam WAPDA office for the years 2003 to 2013. This flow data has no role in running the simulations. The flow data is used to find the efficiency of the calibration of the model.

B. *Observed Climatological Data*

SRM require daily precipitation as well as average daily temperature data as main input to the model. Both of these parameters are being observed by the glacier Monitoring research Centre of Water and Power Development Authority (WAPDA) at Khanpur Dam Station. Daily precipitations and daily average temperatures for the years 2003 to 2013 were collected from WAPDA.

C. Terrain Elevation

Digital Elevation Model (DEM) model was used to define the catchment boundaries and divide it to different elevation zones. SRTM DEM for Khanpur Dam catchment has been downloaded in tiff format from http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1. For extraction of complete catchment boundary and river system of Khanpur watershed, Arc Hydro Tools; the extension of ArcGIS was used as shown in Fig. 1. Khanpur dam catchment has been divided into different elevation zones having equal elevation difference of 500 meter.

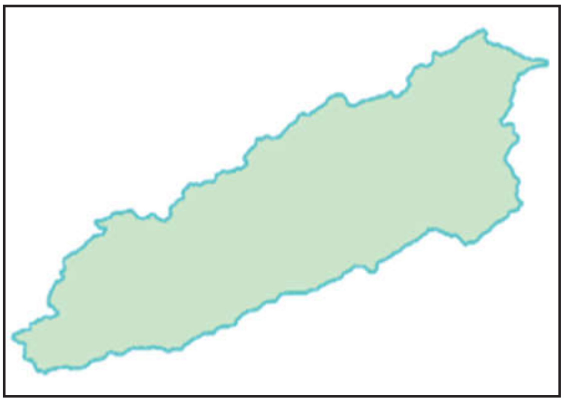

Fig. 1. Catchment area of Khanpur dam

D. Snow Cover Area

The MODIS processed data provides various data which even help to distinguish between various features such as fire [xiii] and clouds [xiv] with a certain degree of accuracy. The MODIS snow product data was used in this study which was downloaded from web of MODIS. Global MODIS data for different features types e.g. snow and vegetation are available in open domain.

The technical team of MODIS continues to develop algorithms to map snow cover over different land use types and revise again and again prior to the launch MODIS snow cover products. As a result of this continuous refinement of algorithms, MODIS daily snow product MOD10A1 is found to be 93-100% accurate [xv]. This daily product has been selected as the source data to map snow cover over Khanpur watershed. MODIS has developed snow cover products such as daily snow cover product (MOD10A1) and weekly snow cover product (MOD10A2).

SRM Model requires snow covered area input on daily basis in the form of Conventional Depletion Curve of snow cover (CDC). Therefore, temporal data is very much important in determining the snow depletion over the watershed. MOD10A1 tile was downloaded, covering Khanpur Dam catchment and was further analyzed by using special analyst tool of ArcGIS software. Figures 2 to 4 show the variation and distribution of snow cover over the Khanpur watershed.

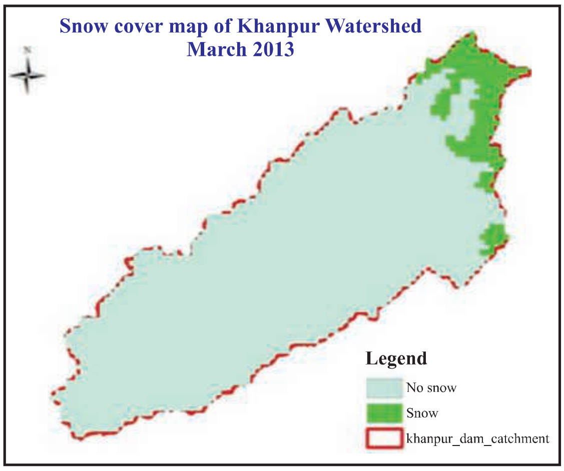

Fig. 2. Snow cover area of Khanpur dam catchment during March 2013

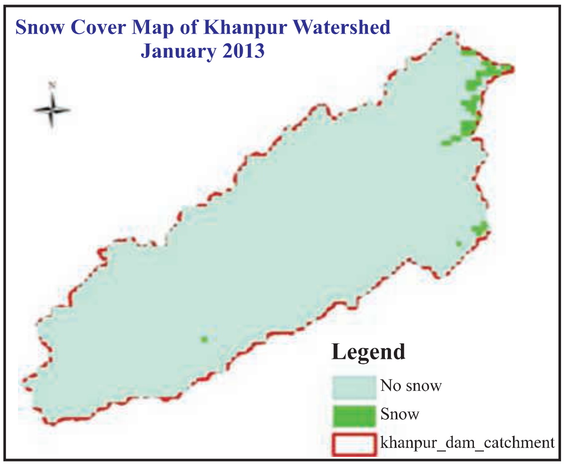

Fig. 3. Snow cover area of Khanpur dam catchment during January 2013

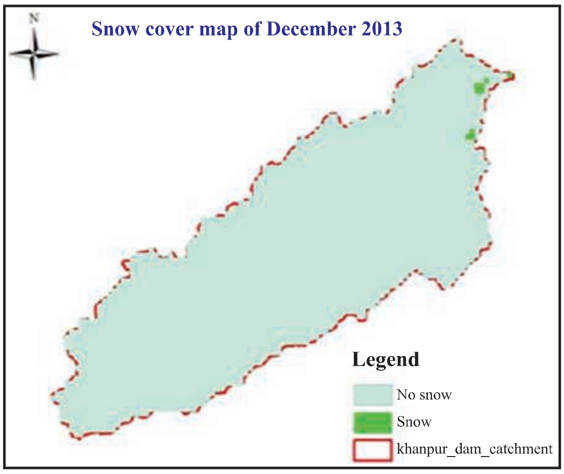

Fig. 4: Snow cover area of Khanpur dam catchment during December 2013

E. Climate Change

The mean annual temperature and mean annual precipitation data trends were analyzed over the past 10 years i.e. (2003-2011) over the Khanpur watershed. The graph were plotted between time and mean annual temperature and also plotted between time and average annual rainfall. The overall trend of the plots were found by introducing trend line. The Fig 5 and Fig 6 below show mean annual change of temperature and precipitation data respectively.

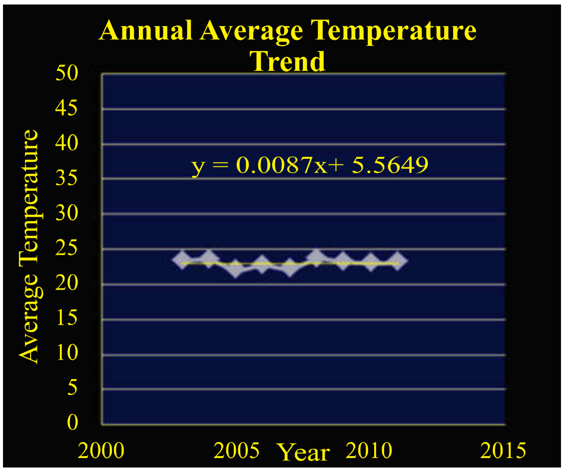

Fig. 5. Average Annual Temperature Trend

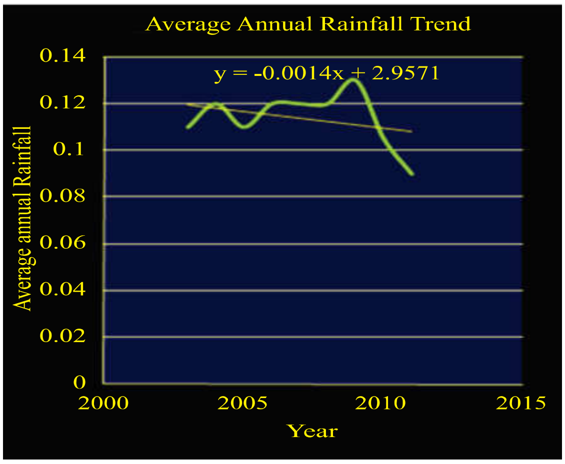

Fig 6: Average Annual Rainfall Trend

VI. Calibration of the Model

Calibration of the model was done by comparing the simulation results with the actual observed data so that the accuracy of the model can be checked. The model was calibrated for the year 2005 as shown in Fig. 7. This is carried out by adjusting the values of various parameters of model again and again to bring the simulated results closer to the actual observed data.

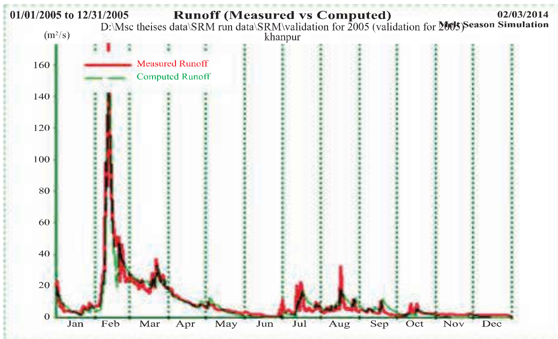

Fig. 7: Calibration of the Model for the year 2005

VII. Assesment of the Model Accuracy

The accuracy of the Snowmelt Runoff Model can be checked by two criteria, one is known as coefficient of determination, R^2, and the second criteria is volume difference, D_V. The R^2 value can be obtained as given in eq (1)

$$[R^2 = 1 - \sum_{i=0}^{n} \frac{(Q_i - Q_s)^2}{(Q_i - Q)^2}] \quad (1)$$

Where

Q_i is the measured daily discharge

Q_s is the simulated daily discharge

Q is the mean measured discharge for the given year or snowmelt season, n is the number of daily discharge values.

The volume difference between measured and simulated discharge is computed as given in eq (2)

$$[D_v = \frac{(V_R - V'_R)}{V_R}] \quad (2)$$

Where

V_R is the measured yearly or seasonal runoff volume

V'_R is the computed yearly or seasonal runoff volume.

VIII. Validation of Model

Validation of the model is carried out by applying the model for any year other than the calibration year while using the same values of model parameters as finalized during the calibration processes. The simulated flows obtained in this way are then compared with the observed flows to verify the model calibration results. It was found that the results obtained from the validation of the model were not healthy. The validation results for year (2007) are shown in Fig. 8.

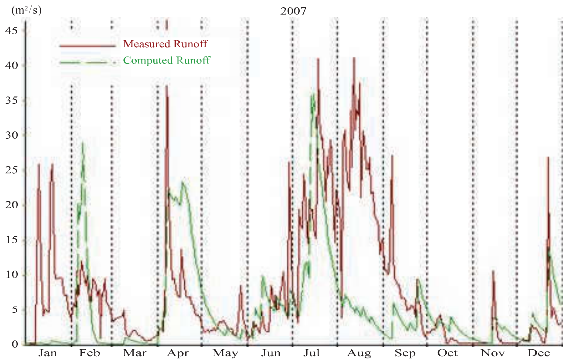

Fig. 8: Validation of the model for year 2007

IX. Results and Discussion

From the simulation results it was found that around 15% of the total flow was from snowmelt. Hence mainly the Haro river flows are from the contribution of rainfall and not because of the snowmelt. Since SRM uses daily degree approach to model the flows and was used to study the hydrology of the study area. It was found that the results of validation were not healthy. The simulated results could have been better if a rainfall runoff model has been used over the watershed. Since the contribution of snow was too low for the watershed hence SRM was not appropriate to use over such watershed.

X. Conclusions

Based on the results the following conclusions were drawn:

1. Snowmelt Runoff Model is well calibrated but not validated good for rest of the years due to very less snow cover area.
2. From above results it is concluded that Snowmelt Runoff Model does not apply in those catchments having snow cover area is very low.
3. On average basis, contribution of snowmelt-runoff in Khanpur dam Catchment at Khanpur gauging station is about 15%.

XI. Recommendations

Following Recommendations have been made depending on the results and conclusions of the study:

1. It is recommended to figure out mandatory minimum Snow Covered Area SCA of a watershed prior to use SRM. Hence in this way some reliable results of calibration and validation can be found.
2. Some rainfall-runoff model e.g. HEC-HMS should also be used to study the hydrology of the watershed.

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