IMPROVEMENT OF APPLICABILITY OF SNOW HYDROLOGICAL MODEL BY USING CORRECTION FACTOR IN THE GILGIT BASIN

Sohail Babar Cheema*
MEE 14636

Supervisor: Toshio Koike***
Mohamed Rasmy**

ABSTRACT

In order to estimate spatial and temporal distribution of snow cover and associated discharge in Gilgit basin. We developed a physical based snow hydrological model (WEB-DHM-S). We investigated the influence of several forcing data and developed correction method for them. The simulated results were assessed by introducing different efficiency tests such as Nash Sutcliffe Efficiency (NSE), Relative Volume Error (RVE) and Root Mean Square Error (RMSE). A grid to grid comparison was also done using Kuipers Skill Score and False Alarm rate by two contingency table. The gridded data deficiency of JRA temperature overcomed by introducing observed data with adjustment of temperature lapse rate for each model grid. As the rainfall gauges were located at lower latitude of the basin except Yasin station, precipitation was corrected with respect to with elevation by considering the fact that high elevation will get more precipitation and snowfall. Even though precipitation correction provided better results, but still simulated snowmelt process was delayed. This issue was solved by changing fresh snow albedo from 0.90 to 0.80. Glacier contribution is necessary for accurate discharge.

Keywords: Temperature Lapse Rate, Precipitation Correction Factor, Gilgit River Basin

1. INTRODUCTION

Pakistan is a home of about 5218 snow reservoir and glaciers along with the second largest Siachen glacier. The fresh water is preserved in these reservoir during the winter season and feed to the river in the summer season due to the gradual melting of ice and snow in upper parts of the country. More than 70% cultivated area lies along the Indus River. Major tributaries of Upper Indus Basin (UIB) are include Shyok, Gilgit, Hunza and Astore rivers. Sumer runoff is highly correlated with winter snow pack for Gilgit Basin as compared to all other basins. Almost 70 % area of Gilgit basin is covered with snow.

Pakistan Meteorological Department (PMD) has a limited resources for monitoring of snowfall and snow cover. There is no accurate tool or methods to measure snow cover or snowfall at high altitude. Snowfall measurement method of PMD is very old, PMD measures snow depth with scale. Marks reported in his study that energy exchange method is much better than temperature degree day method to calculate snowmelt (Marks, Dozier, & Davis, 1992).

*Meteorologist, Pakistan Meteorological Department, Pakistan

** Associate Professor, ICHARM, Public Works Research Institute, Japan

*** Director, ICHARM, Public Works Research Institute, Japan

In this study we developed a water and energy based snow hydrological model (WEB-DHM-S) including snow Parametization for Gilgit Basin. The main purpose of this paper is to investigate snowfall distribution and its contribution to discharge by using WEB-DHM-S and check its applicability for target basin.

2. DATA AND METHODOLOGY

We used two types of data sets, static and dynamic data. The static data includes land use data, topographic data of Digital Elevation Model (DEM), Soil data etc. These data were processed at a resolution of 500 meter. Other dynamic forcing data like wind, relative or specific humidity, cloud cover, air pressure, short wave and long wave incoming solar radiation. These forcing data were three hourly, six hourly, daily and monthly mean variance data with a resolution of 0.5625˚.The data were downloaded from URL https://rda.ucar.edu/datasets/ds628.0 and extracted for study area. All vegetation dynamic data were resampled according to model grid size (500). The vegetation forcing data Leave Area Index (LAI) were downloaded (http://reverb.echo.nasa.gov /).The Gilgit Basin is covered by MODIS scan of MOD10A2h23v05 and MODIS10A2h24v05, with 1-km resolution. Observed rainfall and temperature data were obtained from Pakistan Meteorological Department and Water and Power Development Authority (WAPDA). As gridded temperature data has coarse resolution and did not provide well distribution of snow cover therefore observed data were directly imported to the model. We applied temperature lapse of 7.5˚C/km and temperature data were extrapolated to each model grid based on its elevation. The temperature lapse rate equation as follows

$$T(i,j) = T_o - \{7.5 \times (Z(i,j) - h)/1000\} \quad (1)$$

In order to compensate precipitation at high elevation we used rainfall and precipitation correction factor with this concept that precipitation increased at high altitude.

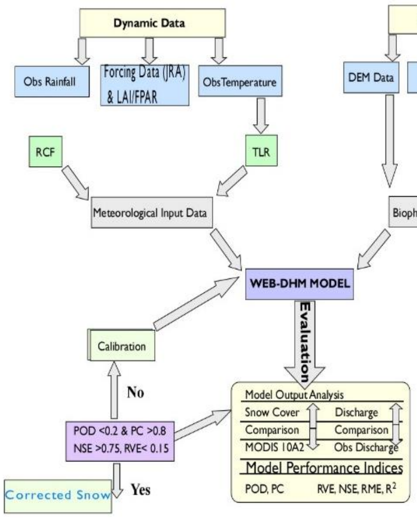

Figure 1 Methodology for Study

Since there was no direct correlation between precipitation and elevation, we applied following equation with different factors (values).

$$P_{h(i,j)} = P_o \times \{1 + (Z(i,j) - 1000) \times P_{cf}\} \quad (2)$$

where i,j are latitude and longitude for each grid above than 1000 m.a.s.l, Z (i.j) is the two dimensional elevation, P_{cf} is a precipitation coefficient factor and P_0 observed precipitation (mm/hrs). In this equation value of P_{cf} varies from 0.0005 to 0.001 for better improvement for discharge and snow cover area. The model performance was evaluated by using observed discharge data and 08 days composite Moderate resolution imaging Spectroradiometer (MODIS) data. For this purpose we used different indices and confirm the improvement in the applicability of model against each factor. The overall methodology is shown in Figure 1.

3. RESULTS AND DISCUSSIONS

We performed simulation for gridded JRA temperature and rainfall data. The simulated snow cover area was not distributed in reliable. The whole basin was divided into two patches snow or no snow as shown in Figure 2(a). This was because of coarse resolution of temperature gridded data. Thus we imported the observed temperature and rainfall data by applying zero elevation correction method which was used by Shresta in his study (Maheswor Shrestha, Wang, Koike, Xue, & Hirabayashi, 2012). But still the output simulated snow was highly underestimated as shown in Figure 2 (b).

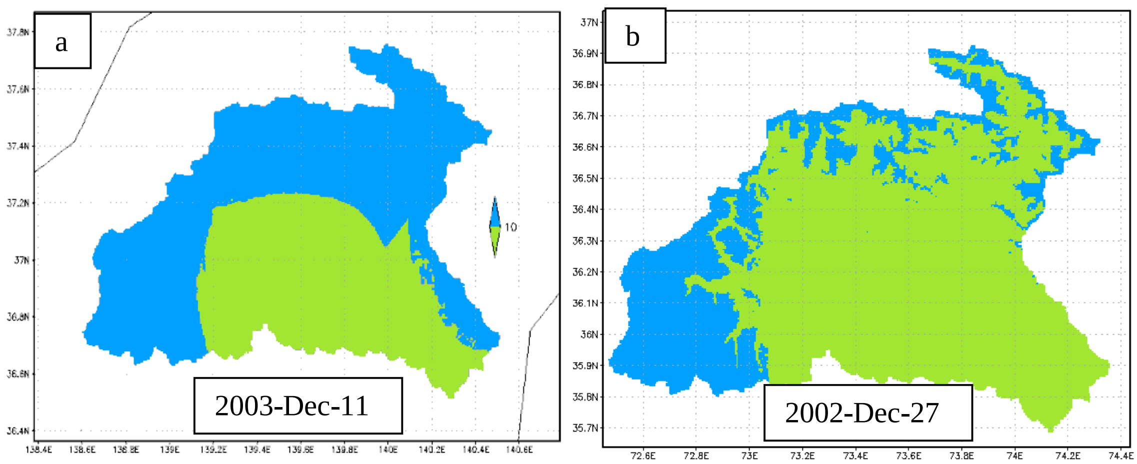

Figure 2 Simulated snow cover area.

3.1 Rainfall and Elevation Relationship

Wanger (2009) reported that south west Himalaya was influenced by the annual precipitation ranging from 150 mm to 500 mm at altitude of 1500-3000 m.a.s.l whereas more than 1700 mm at an altitude of 5500 m.a.s.l (wanger et al., 2009). In this study a correlation was found between altitude and total precipitation as well as the average precipitation amount for five years data sets. The calculated co-efficient of determination was only 0.003 which mean there was not a good correlation between them. So, different attempt were done to enhance rainfall and precipitation. In first attempt rainfall was increased by 1.5 times but the simulated results of discharge and snow cover was not good correlated with observed discharge and MODIS snow cover.

Table 3-1 Snow covered pixel error comparison

	Oct-Dec		Feb-Apr		Jul-Sep	
Indices	KSS	FAR	KSS	FAR	KSS	FAR
TLR	0.41	0.74	0.52	0.53	-0.08	0.81
RCF1.5	0.47	0.62	0.64	0.49	0.02	0.77

In Table 3.1 Kupier Skill Score (KSS) and False alarm Rate (FAR) were far than their absolute value which is 1 for KSS and 0.0 for FAR. It conclude that simulated results were not good synchronized with MODIS snow cover.

3.2 Precipitation Correction Factor

The relationship between altitude (z) and hourly precipitation is given in equation 2. First of all we performed simulation for P_{cf} 0.0005, then we applied P_{cf} 0.0007 and P_{cf} 0.001respectively.The simulated discharge was analyzed for temperature lapse rate and each precipitation correction factor by different statistical indices like Nash Sutcliff Effecency (NSE), Root Mean Square Error (RMSE), Degree Index –d Relative Volume Error (RVE), Perecentage Bias (PBIAS) and coefficient of determination R^2 . The performance for each factor is shown in Table 3.2 and discharge represented in Figure 3. The Figure 3 (a) portrays discharge comparision for Pcf 0.0005, 3(b) for Pcf 0.007, 3(c) for albedo 0.80 and Figure 3 (d) represents for Pcf 0.001 and albedo 0.80.

Efficiency test	TLR	RCF 1.5	Pcf (0.0005)	Pcf (0.0007)	Albedo	Pcf (0.001)
NSE	-0.09	0.20	0.46	0.53	0.64	0.72
r	0.52	0.67	0.75	0.76	0.80	0.86
RMSE	633.03	543.65	445.76	427.91	357.00	312.00
R^2	0.27	0.44	0.58	0.62	0.77	0.84
Index-d	0.44	0.60	0.78	0.79	0.82	0.88
RVE	-0.68	-0.56	-0.43	-0.36	-0.32	-0.15
PBIAS	-68.44	-55.60	-43.36	-36.21	-32.12	-15.41

Table 3.2 Efficiency test for discharge comparison between observed and simulated

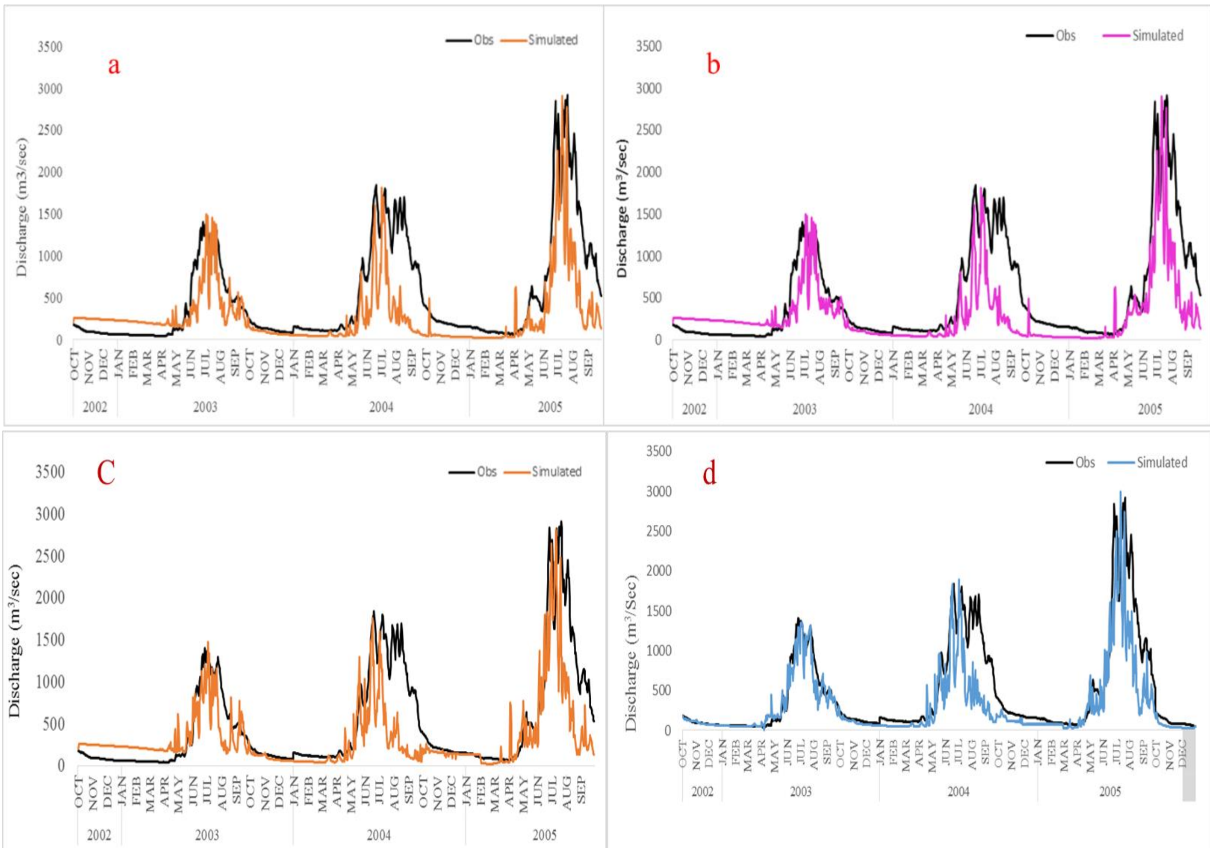

Figure 3A Comparisons between observed and simulated discharge.

After applying precipitation factor with value 0.0007, simulated discharge was enhanced but the change was not significant. However discharge was highly underestimate during June, July. This underestimation is due to no proper snow melting during this season. In all previous simulation default albedo value of 0.90 was used. Although albedo change according to grain size and shape. Hence, in June, July snow grains are larger as compared to January, February, therefore albedo parameter was calibrated for albedo 0.80. The output simulated result shown in Figure 3(C).

For all those grids above than 1000 m.a.s.l precipitation increased by 0.001 times as observed one as described in equation 3. A low increase in discharge start from start of May, since snowpack start melting in May and this discharge got its maximum peak in July-August due to large intensification of solar radiation. The simulated hydrograph coincide well with the observed discharge from accumulation to ablation period. Now model capture the seasonal variation well which was due to sufficient precipitation and more energy budget provided for accumulation and melting as shown in Figure 3(d).

$$P_{h(Gilgit)} = P_h\ (1+(elev_{2d}(I,j)-1000)\ X\ 1.0/1000) \qquad (3)$$

Simulated discharge was well replicated with observed discharge, however observed discharge was still underestimated for peak discharge. This is due to glacier covered area as model was simulated only for snow dynamics but not for glacier.

A grid to grid analysis for different season was done by 02 contigency table and results are shown in Table 3.3 for each precipitation factor. The KSS indices values improved upto significant level and similarly value of FAR indices also decreased. After Pcf 0.001 FAR was less than 45 that is acceptable. A grid to grid comparison between MODIS and simulated show that model predict well for accumulation season but in peak season it was not g*ood as compared to other seasons. But the KSS indices more than 0.75 and FAR less than 0.45*

Table 3-3 Snow cover comparison between MODIS and simulated for different precipitation factor

	Oct-Dec		Feb-Apr		Jul-Sep	
Indices	KSS	FAR	KSS	FAR	KSS	FAR
PCF(0.0005)	0.6	0.57	0.76	0.46	0.32	0.66
PCF(0.0007)	0.66	0.52	0.84	0.37	0.55	0.54
PCF(0.001)	0.77	0.41	0.91	0.23	0.74	0.42

3.3 MODIS and Model Snow cover area Comparision

The simulated results were processed in Grid Analysis and Digital Display System (GrADS) for comparison with MODIS imaginary. A spatial distribution of snow cover area is shown in Figure 4. The Figure 4 depicts that the correction factors are helpful in improvement for model applicability for a complex topographical region like Gilgit. The simulated snow cover area distribution after fresh snow albedo 0.80 and P_{cf} 0.001 was well captured by model with significant KSS greater than 0.70 for all the months of the year. The FAR index also was below than 0.25 for February to April. Hence a grid to grid analysis shows that model predict snow in a good manner. For optimized P_{cf} 0.001 the snow depth increased 69 % as without P_{cf} correction.

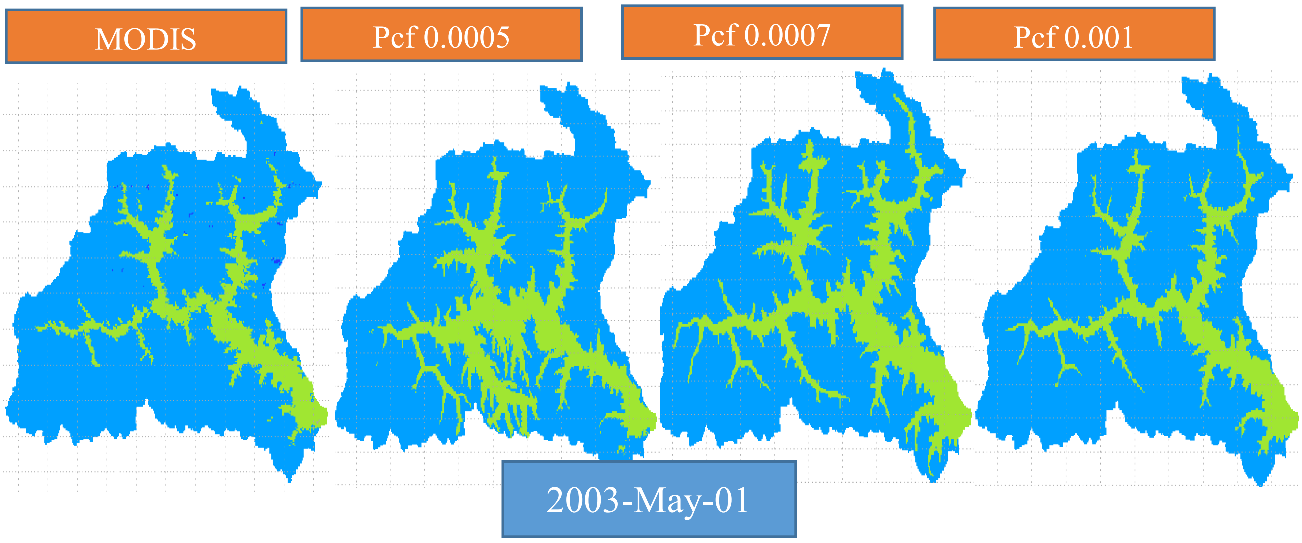

Figure 4 A spatial distribution comparisons of simulated and MODIS snow cover area.

4. RECOMMENDATIONS

The future scope of this study is to expand the applicability of model for other basins for number of years to sketch a good picture of simulated snow and discharge. The correction factor approach can be used for forecasting summer run off in snow fed river. The simulated discharge was still underestimate in July, August and September, therefore glacier dynamics should be added in new version as it was not addressed in the current version.

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