THE EFFECT OF SNOW AVALANCHES ON THE HYDROLOGIC REGIME OF KUNHAR BASIN IN THE PUNJAB HIMALAYA, PAKISTAN

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This study sets out to investigate the effect of snow avalanches on the hydrology and runoff generation in the Kunhar basin in Northern Pakistan. The Kunhar River is a major tributary of the Jhelum river in the Punjab Himalaya of the North West Frontier Province, Pakistan. The basin area is about 2,500km^2 and its elevation ranges from 800 to 5,300m. The vegetation consists primarily of coniferous forest, extensively cleared pasture, and alpine tundra. The watershed has a seasonal snow cover which develops from early November onwards, reaching a maximum depth in March or April. Also, the snowpack increases greatly at the upper elevations. Snowmelt begins in early April and lasts until July or August when it overlaps with the Indian monsoon period. Temperatures are generally high during the snowmelt period, averaging about 14°C between May and August at the Battakundi station.

The Kunhar basin experiences intense avalanche activity above an elevation of 1,850m, which redistributes the snowpack for more than 2,000m of elevation (De Scally 1992). Recent attempts to simulate and forecast the flow from the Kunhar basin failed mainly because of the inability to forecast the redistribution of flow due to snow avalanches.

The objectives of this study are to analyse the snowmelt and snow avalanche effects using the U.B.C. watershed model and to produce a flow forecasting system which takes into account the snow avalanche effects.

The U.B.C. watershed model is used by the Water and Power Development Authority of Pakistan, to forecast flows from the Himalayan and Karakoram ranges. The structure of the model is based on hydrological behavior as a function of elevation in the watershed. Also, the model can be used to simulate the redistribution of snowpack caused by avalanching. Daily values of maximum and minimum temperature, and precipitation are the necessary meteorological input data. Temperature and precipitation data from the Battakundi station (2,660m), and temperature data from the Astore station (2,630m) were used in this study.

The U.B.C. watershed model was first calibrated to nine years of flow record (1979-1988) at the mouth of the basin without the influence of avalanches. The results of the original calibration for the nine years showed that the simulated flow deviates significantly from the observed hydrograph. For this original calibration, the total volume deviated by about 4% of the observed volume and the Nash-Suttclife coefficient efficiency was about 63%.

The above deviation from the observed data was mainly because of the non-representativeness of the precipitation measured at Battakundi station. For this reason, the representative precipitation factor in the U.B.C. model, POSREP, was adjusted for each year and a significant improvement in the results was achieved. For this second stage, the volume deviation was reduced to -1.9% and the coefficient of efficiency increased to about 78% for the years 1979-1989.

De Scally (1992) documented and studied the avalanche activity in the Kunhar basin and it is believed that the distribution of snowmelt runoff will be considerably affected by the snow avalanches. For this reason, the U.B.C watershed model was used to estimate the effect of avalanches in the basin. To simulate the avalanche activity, each elevation band was separated in two sub-bands, the avalanche affected area, and the unaffected area. The U.B.C. model was calibrated again using precipitation adjustment factors, POADJ, for each avalanche-affected area of each band. The volume of snow subtracted by avalanches from the upper bands was made equal to the volume of snow avalanched to the low and mid-elevation bands.

By using the above procedure, the deviation of the flow volume was decreased to about 1.6% and the coefficient of efficiency increased to 84% for the nine years. The results of this analysis showed that the avalanchestarting zone is located at band 6 which has a mean elevation of about 4,000m. The snow then cascades downslope and the runout and track zone are located at bands 3 and 4 with mean elevations of about 2,450m and 2,800m respectively. The percentage of the affected area by avalanches in the Kunhar basin is estimated to range from 12% to 21%. These results are in agreement with the results of the previous study (De Scally 1992). De Scally studied only a small area (288km^2) in the upper valley of the Kunhar basin and extrapolated the results for the upper elevations. Furthermore, this study shows that about 16% of the snowpack at band 6 (mid-elevation 4,000m) is, on an average, subject to avalanching. The deposition of this snow occurs at bands 3 and 4.

These snow avalanches have a direct effect on the snowmelt. Firstly, the snowmelt in the runout areas starts about seven days later and lasts 20 to 30 days more than in the areas not affected by avalanches. As a result of the larger snow accumulation in the runout areas, the snowmelt volume increases by about 200 to 300%. Also, the maximum snowmelt from the avalanche runout areas is about 100% higher than the maximum snowmelt at the non-affected areas. The timing of the maximum snowmelt is delayed by about 15 days in the runout zones. These results show that snow avalanches increase both the volume and period of the snowmelt, also changing the distribution of the snowmelt.

The above results of flow simulation by using redistribution of snow were then used to produce a forecasting system for avalanche activity. This system was then used to forecast the flow from the Kunhar basin. Analysis of the results showed that the total avalanche volume and snow water equivalent due to avalanching, for each affected band (bands 3, 4, and 6), is highly correlated to the maximum snow accumulation of snowpack at band 6. Linear regression analysis was performed and the relationships for each band were estimated. The coefficients of determination of these equations were always above 90% with a maximum of 99%. This high correlation shows that there is a very strong relationship between avalanche activity and snowpack at band 6. So, if the snowpack at band 6 is measured, then the maximum snow accumulation, which occurs in late March or early April, can be estimated. From the developed equations, the total avalanche volume, the avalanched snow, and the affected area can be estimated and used in the U.B.C watershed model to forecast the flow for the coming season. The application of this procedure showed that the proposed forecasting system gives a reliable estimation of flow volume and distribution.

REFERENCE

De Scally, F.A., 1992. 'Influence of Avalanche Snow Transport on Snowmelt Runoff'. In *Journal of Hydrology*, 137 (pp73-97).