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Implications of Inter Basin Transfer Projects of Koshi River Basin

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Abstract

In this study hydrological model of Koshi River basin was developed in Soil and Water Assessment Tool (SWAT) to access the hydrological impacts of inter basin transfer projects of the basin. Calibration and validation were done at multiple sites within the basin to extract better results. The results of calibration and validation in all 4 stations were found good/ acceptable. Melamchi Water Supply Project (MWSP), Sunkoshi Marine Diversion Multipurpose Project (SMDMP), Sunkoshi Kamala Diversion Multipurpose Project (SKDMP) and Tamor Chisyang Diversion Multipurpose Project (TCDMP) were considered for the study. Average annual and seasonal (Winter, Spring, Summer and Autumn season) results were compared for the analysis. Average annual flow reduction due to MWSP (Stage I), SMDMP, SKDMP and TCDMP in the immediate downstream sub station are 8.68%, 13.18%, 8.81% and 29.29% respectively and in Koshi outlet Chatara are 0.12%, 4.44%, 4.87% and 5.84% respectively. Flow reduction (%) in downstream sub basin were higher during winter and spring as compared to summer and autumn season. Both the seasonal and average annual impact shows higher value in the immediate downstream basin with gradually reduction in the impact towards the lower sub basins.

1. Introduction

Water is the most abundant on earth and is also an essential component of environment and for people. Growing reliance on water resources is a result of economic and societal advancements on a global scale. Fresh water is becoming an increasingly rare natural resource in water-scarce locations because of the unequal geographical and temporal distribution of water resources [1]. Due to rapid growth in population and expansion of industry and agriculture, the demand of fresh water resource is also increasing. To meet the food needs of its rapidly expanding population, Nepal must increase agricultural productivity by improving and expanding its reliable and appropriate irrigation infrastructure [2]. The government needs to develop dependable year-round irrigation systems, particularly in rural areas to enhance agricultural production in order to assure food security and reduce levels of poverty.

Inter basin transfer projects are one of the effective engineering counter measures that would supply water in the water deficit zone by withdrawing from the supply zone thus mitigating the uneven distribution and balancing the inter basin water distribution. Water transfers between river basins are complicated, multi-disciplinary issues that could result in issues including changes to the hydrologic conditions, water quality, and aquatic ecological structure. Government of Nepal has started implementing projects for inter-basin transfer in Nepal. In spite of significant effect of these inter basin transfer project, there were only a few studies conducted in Nepal to understand the behavior of the hydrological regime and the response of the inter basin project in the downstream end. Hence this study intends to imitate inter-basin water transfer systems for evaluating the hydrological impacts these project impose in the downstream sub basins and in the already operating Sunsari Morang Irrigation Project.

2. Study Area and Input data

The Koshi River Basin is one of the largest river basins in Nepal. The Koshi is 720 km long and drains an area of about 74,500 sq.km in Tibet, Nepal and Bihar. Nearly 80 percent of the Koshi catchment is in Nepal and Tibet. It lies in the eastern region of Nepal between latitudes 27° 06' 23" to 28° 09' 50" N and longitudes 88° 22' 36" to 88° 23' 37"E. It consists of seven major rivers hence also known as Saptakoshi River. All these seven rivers, namely, Indrawati, Sunkoshi, Tama Koshi, Likhu, Dudh Koshi, Arun and Tamor, from west to east, originate from the High Himalaya. Most tributaries originate within the territory of Nepal and flow in a northeast to southwest direction. Koshi basin is ecologically and topographically diverse and covers Terai, mid-hills and high hills. Altitudes within the basin varies from about 100 m to above 8,000 m amsl including the Mt. Everest at 8,848 m amsl. The region's temperature varies significantly with elevation. A significant portion of Nepal's Koshi basin, which is situated in the southern part of the Himalayan range, receives roughly 1,800 mm of precipitation on a yearly average [3].

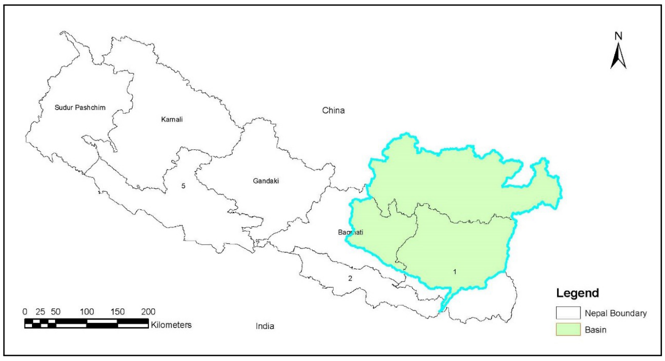

Figure 1: Location of the Study area (Koshi Basin)

Weather data and hydrological data were collected from Department of Hydrology and Meteorology. A total of 4 stations hydrology data were used for calibration and validation.

3. Methodology

SWAT is used for set up of hydrological model of koshi basin. The overall methodological framework is shown in fig 3. The SWAT model was created to anticipate the effects of land management techniques on water, sediment, and agricultural chemical yields in sizable, complicated watersheds with a range of soils, land uses, and management circumstances over extended periods of time.[4].

3.1 Model Set up

The Watershed Delineation dialog is divided into five sections: DEM Setup, Stream Definition, Outlet and Inlet Definition, Watershed Outlet(s) Selection and Definition, and Calculation of Subbasin Parameters. The delineation process requires a Digital Elevation Model (DEM) in ESRI grid format. In inlet and outlet definition section, 6 point source discharges point were added for Melamchi Water Supply Project (MWSP) (Stage I, II and III), Sunkoshi Marin Diversion Multipurpose Project (SMDMP), Sunkoshi Kamala Diversion Multipurpose Project (SKDMP), Dudhkoshi Storage Hydropower Project, Tamor Chisyang Diversion Multipurpose Project (TCDMP) and Sunsari Morang Irrigation Project (SMIP) by manually adding the points in the watershed. An outlet point was fixed at the slightly lower point of Chatara Station taking the spatial address of DHM hydrological gauging station. The whole basin is divided into 55 sub basins as shown in Figure 2.

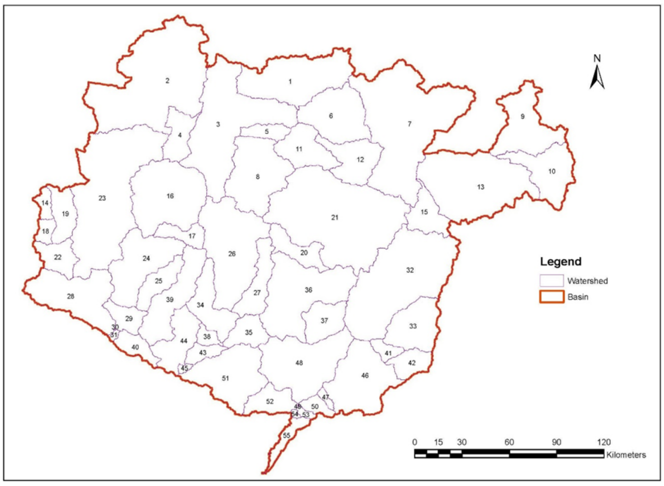

Figure 2: Watershed Delineation of the basin

A total of 413 HRUs were created in the SWAT model for the basin. For multiple HRUs selected, sesitivities for the land use, soil, and slope data was specified as 5%, 20% and 20% respectively and used to determine the number and kind of HRUs in each watershed. Daily temperature, Relative humidity, Solar radiation and Wind data from Department of Hydrology and meteorology Nepal was used.

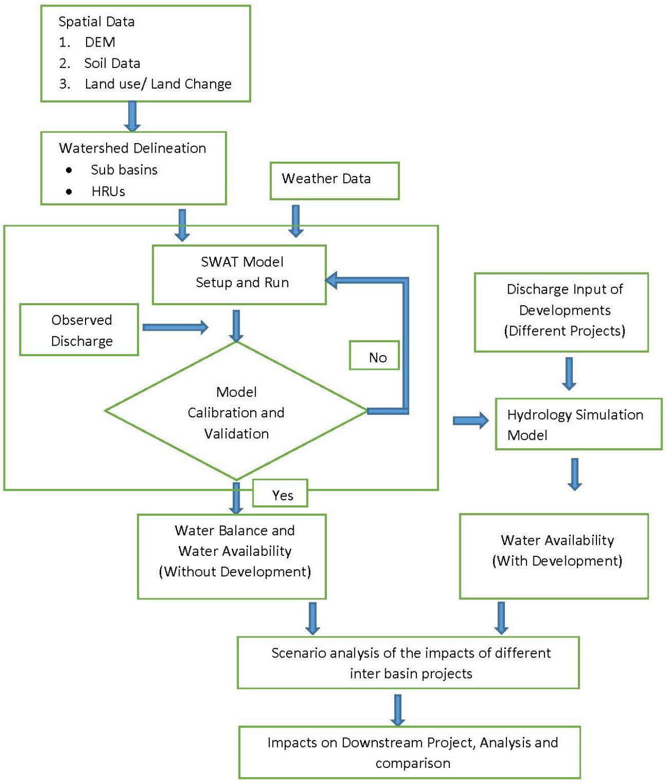

Figure 3: Methodological framework

3.2 Sensitivity analysis and model calibration and Validation

Based on previous studies on the region and literature on SWAT calibration/ validation, different set of parameters were selected at different calibrated stations and then, their initial value ranges were defined. Global sensitivity analysis was used to select the most sensitive parameters . Through calibration and validation, the model's applicability for a watershed is assessed. Calibration at one or more sites can be used in SWAT model calibration to determine basin parameters. Several researches shows that the efficiency of single site calibration has been found to be limited [5] because it is unable to convey the geographic diversity of a heterogeneous watershed. So for the calibration of the model in the basin, multi-site calibration is applied.

For the multi-site calibration, first the calibration was done at upstream gauging station i.e. Khurkot Station. The parameters fulfilling the performance criteria were fixed for the sub basin upstream of the Khurkot station. Then another set of calibration is performed at Hampuwachaur station. For this the parameters for the sub basin upstream of Khurkot stations are fixed and the parameters were optimized for the remaining sub basin upstream of Hampuwachaur Station. Similarly, calibration is performed at Mulghat stations and parameters were optimized only on the sub basins supstream of the calibrated station. Lastly, calibration at Chatara is performed after fixing the sub catchments of Khurkot, Hampuwachaur and Mulghat station.

3.3 Update of Parameter in model

Once the parameters were fixed for different set of sub basin upstream of the selected hydrological stations, the parameters obtained from SWAT-CUP is then updated in the SWAT model using manual calibration helper. Once the parameters are fixed in SWAT hydrological model, the model was again run/simulated and the flow discharges were calculated without any intervention due to inter basin projects. Original set of flow discharges is derived from the simulation of the model.

4. Results and discussion

4.1 Evaluation of SWAT model

Multi-site calibration and validation was done for flow data at Sunkoshi at Khurkot, Sunkoshi at Hapuwachaur, Mulghat and Chatara stations. Calibration and Validation was done at sub basin level. Warm up period of 2 years was taken from 2000-2001 for all the stations. The performance of the SWAT model was found to be acceptable for all stations as shown in Figure 4 and Figure 5 for calibration and validation of the model respectively.

4.2 Spatial Distribution of water balance

Spatial variations of components of water balance are seen across the sub basins of the hydrological model of the Koshi Basin. Figure 6 shows the spatial distribution of average annual precipitation of the Koshi Basin as simulated by the model for baseline period from 2002 to 2015. The average annual precipitation of the entire Koshi Basin is 2241.85 mm. The average daily precipitation ranges from 1.38 mm/day to 11.02 mm/day. The high rainfall range of 3250 mm - 4023 mm occurred in some parts of Arun, Indrawati and Sunkoshi region. Rainfall range of 1750 mm - 2500 mm occurred in parts of Arun, Tamakoshi, Dudhkoshi and Tamor region. While the lower rainfall range of lesser than 1000 mm occurred in parts of Tamor region.

Figure 7 and Figure 8 shows the spatial distribution of AET and NWY across the sub basin. The average annual AET and NWY across the basin are 196.74 mm and 1000.66 mm respectively.

4.3 Scenario analysis and impact assessment on downstream sub basins

The Melamchi Water Supply Project (MWSP) is designed to divert about 170 MLD of fresh water to Kathmandu Valley from the Melamchi River in Sindhupalchowk district. . MWSP (Stage I) will reduce the average annual outflow in sub basin 18 by 8.69%. The reduction in flow will gradually decrease from sub basin 18 with results to 0.12 % of average annual outflow reduction in sub basin 54 .

Seasonal results shows that average outflow reduction in sub basin 18 due to MWSP (Stage I) for Winter, Spring, Summer/Monsoon and Autumn are 38.26 %, 27.46%, 4.03% and 7.92% respectively. The reduction in flow will gradually decrease from sub basin 18 with are 0.39%, 0.23%, 0.06% and 0.12% respectively for Winter, Spring, Summer/ Monsoon and Autumn in sub basin 54 . The results shows that MWSP has significant impacts on the immediate downstream sub basin while the impacts seem to be negligible at the Koshi basin outlet at Chatara. Figure 9 and Figure 10 shows annual and seasonal average water flow reduction in the subsequent downstream sub basin up to the Sunsari Morang Irrigation Project due to MWSP (Stage I).

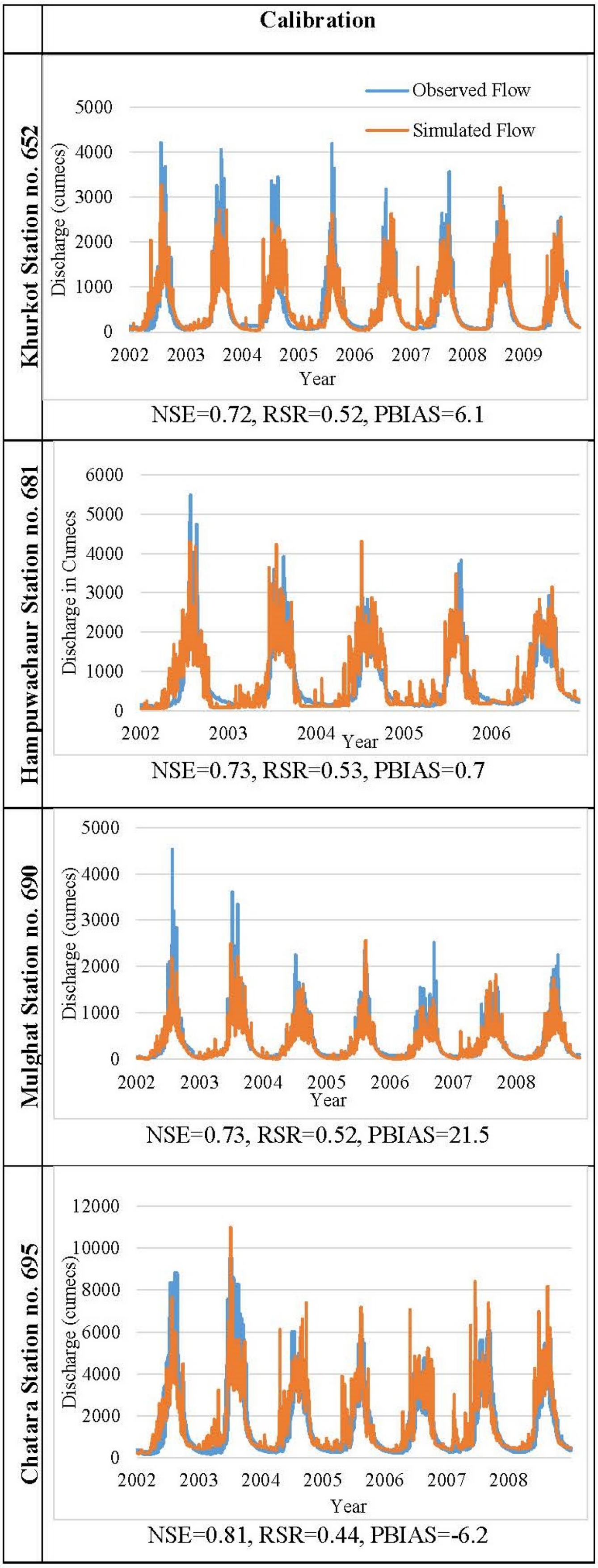

Figure 4: Calibration of the model

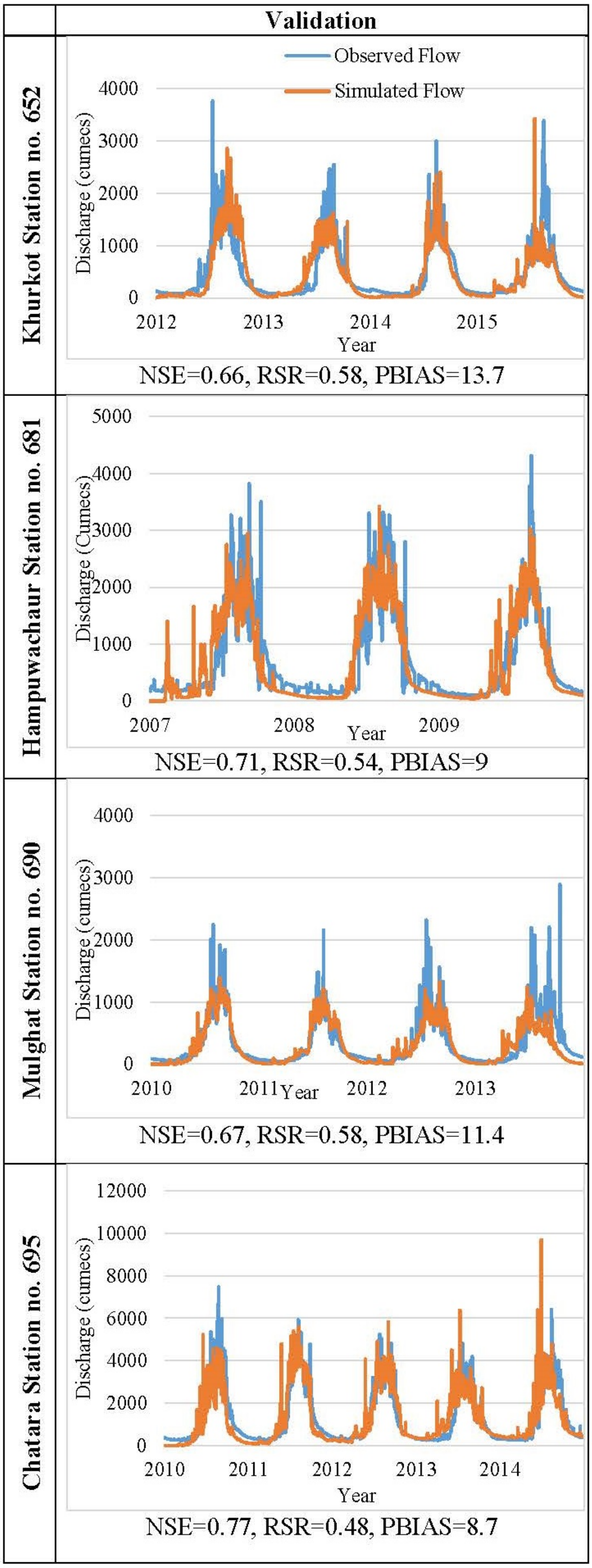

Figure 5: Validation of SWAT model

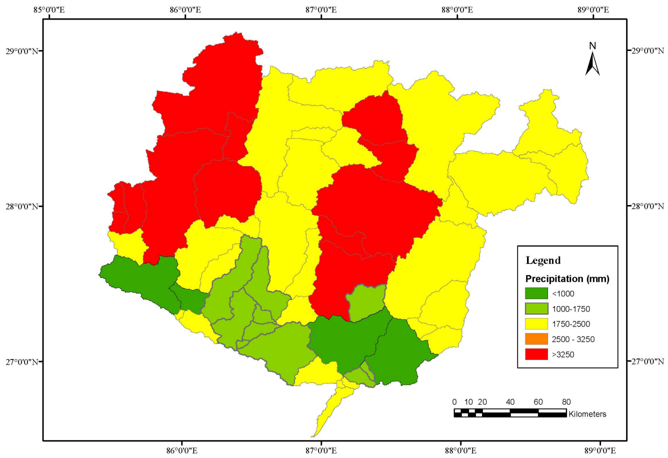

Figure 6: Spatial Distribution of average annual precipitation across sub-basins in Koshi Basin

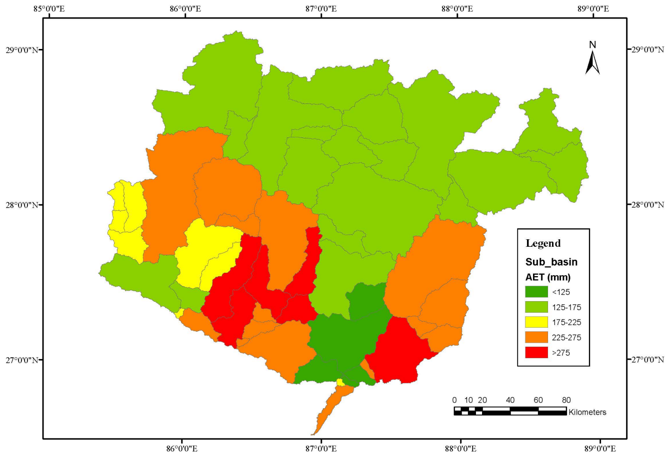

Figure 7: Spatial Distribution of average annual Actual Evapotranspiration (AET) across sub-basins in Koshi Basin

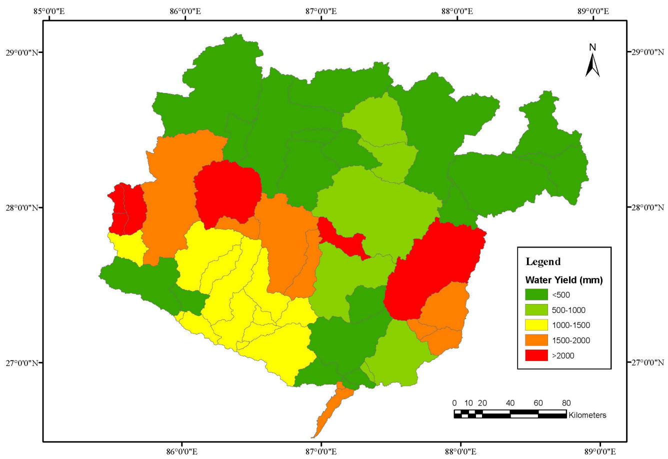

Figure 8: Spatial Distribution of average annual Water Yield across sub-basins in Koshi Basin

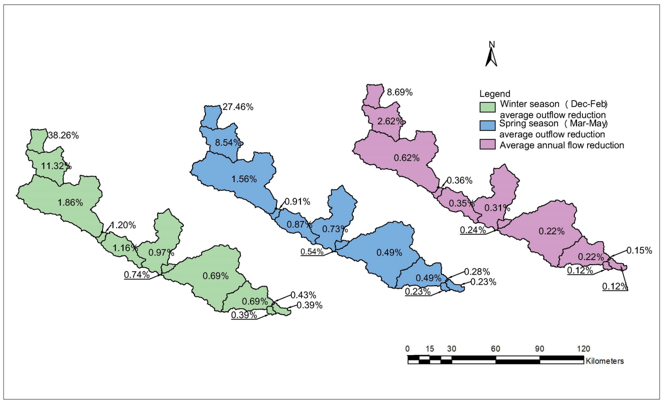

Figure 9: Flow Reduction percentage due to MWSP (Stage I) in downstream sub basin for annual, winter and spring Season

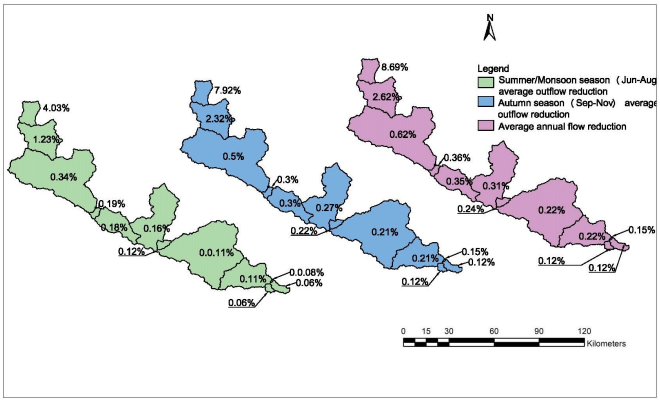

Figure 10: Flow Reduction percentage due to MWSP (Stage I) in downstream sub basin for annual, Summer/Monsoon and Autumn Season

The Sunkoshi Marin Diversion Multipurpose Project (SMDMP), with a design discharge of 67 cumecs, aims to increase the flow fed into the existing irrigation system during the lean season by diverting a portion of the Sunkoshi River's flow into the Bagmati River Basin. Water transfer from influence sub-basin 31 and all the downstream sub basins. Seasonal results shows that average outflow reduction in sub basin 31 due to SMDMP for Winter, Spring, Summer/ Monsoon and Autumn are 48.14%, 34.73%, 6.45% and 10.28% respectively. The reduction in flow will gradually decrease from sub basin 31 to sub basin 54 with 15.53%, 8.65%, 2.11% and 4.13% respectively for Winter, Spring, Summer/ Monsoon and Autumn in sub basin 54 . The implementation of SKDMP was found to reduce the average annual runoff by over 2.26 billion m^3 in the downstream. The impact of the transfer project in the subsequent downstream basin is shown in Figure 11 and Figure 12.

The Sunkoshi Kamala Diversion Multipurpose Project (SKDMP), with a design dicharge of 72 m^3/s [6], will reduce the average annual outflow in sub basin 51 by 8.81%. Likewise, in the koshi basin outlet at Chatara (Sub basin 54) the effects of water transfer plan on average annual flow is 4.87%. Water transfer from SKDMP will influence sub-basin 51 as well as all the downstream sub basins.

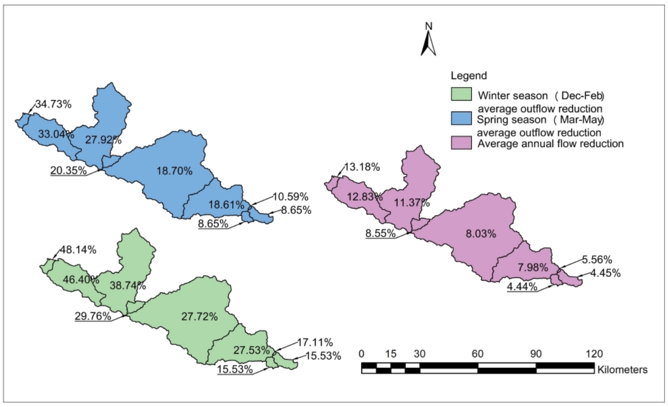

Figure 11: Flow Reduction percentage due to SMDMP in downstream sub basin for annual, Winter and Spring Season

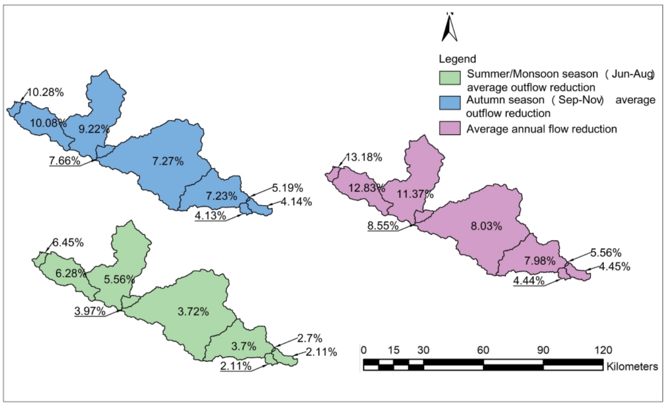

Figure 12: Flow Reduction percentage due to SMDMP in downstream sub basin for annual, Summer and Autumn Season

Seasonal results shows that average outflow reduction in sub basin 51 due to SKDMP for Winter, Spring, Summer/ Monsoon and Autumn are 30.55%, 20.71%, 4.06% and 7.93% respectively. The reduction in flow will gradually decrease from sub basin 51 to sub basin 54 with 17.11%, 9.57%, 2.3% and 4.5% respectively for Winter, Spring, Summer/ Monsoon and Autumn in sub basin 54. Figure 13 and Figure 14 shows the comparison of annual and seasonal average water flow reduction in the subsequent downstream sub basin due to SKDMP. The implementation of SKDMP was found to reduce the average annual runoff by over 2.48 billion m^3.

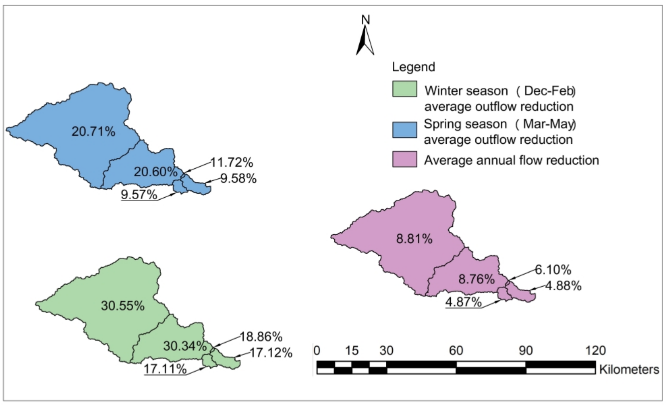

Figure 13: Flow Reduction percentage due to SKDMP in downstream sub basin for annual, Winter and Spring Season

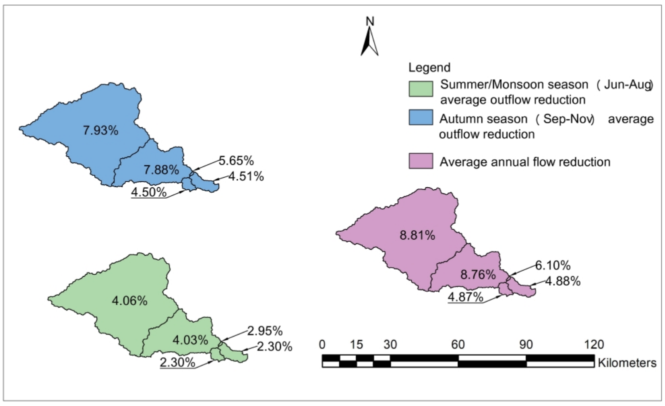

Figure 14: Flow Reduction percentage due to SKDMP in downstream sub basin for annual, Summer and Autumn Season

The Tamor Chisang Multipurpose Diversion Project diverts water from the Tamor River to the Chisang River in Morang District for irrigation. Design discharge of the project is 123 m^3/s [6]. Water transfer from the project will influence sub-basin 47 as well as all the downstream sub basins. The project will reduce the average annual outflow in sub basin 47 by 29.2%. Likewise, in the koshi basin outlet at Chatara (Sub basin 54) the effects of water transfer plan on average annual flow is 5.84% .

Seasonal results shows that average outflow reduction in sub basin 47 due to TCDMP for Winter, Spring, Summer/ Monsoon and Autumn are 91.72%, 56.68%, 17.76% and 34.42% respectively. The reduction in flow will gradually decrease from sub basin 47 to sub basin 54 with 8.35%, 10.31%, 3.87% and 6.92% respectively for Winter, Spring, Summer/ Monsoon and Autumn in sub basin 54. The implementation of TCDMP was found to reduce the average annual runoff by over 2.97 billion m^3. Average annual and seasonal flow reduction due to TCDMP is shown in figure 15 and figure 16.

Along with reduction of flow discharge, SKDMP and SMDMP will significantly reduce the size of Sunkoshi river ultimately the Koshi river, making it easier to tame and providing irrigation to lot more land in central part of the country. Similarly TCDMP will reduce the size of Tamor river and ultimately Koshi river.

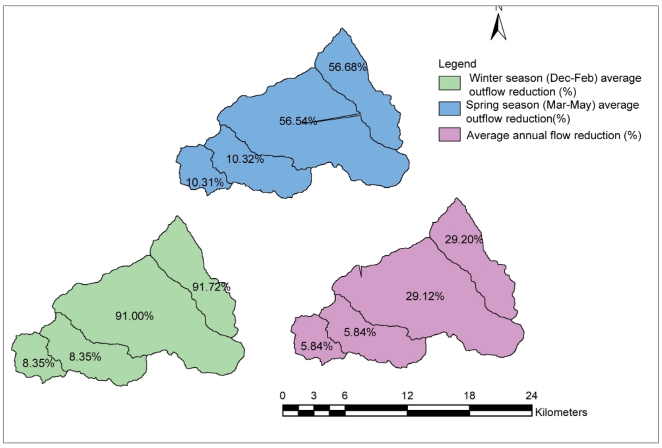

Figure 15: Flow Reduction percentage due to TCDMP in downstream sub basin for annual, Winter and Spring Season

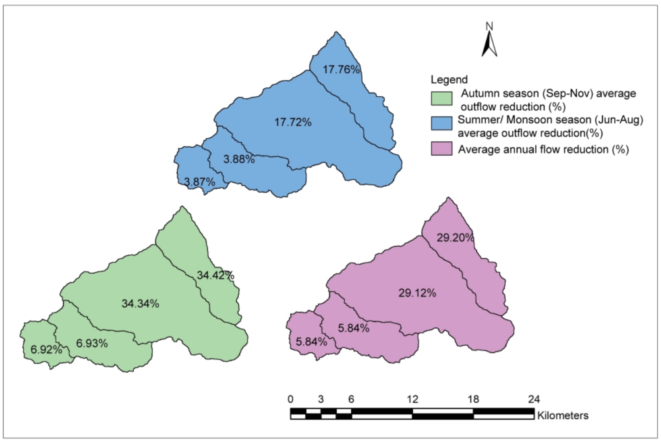

Figure 16: Flow Reduction percentage due to TCDMP in downstream sub basin for annual, Summer and Autumn Season

5. Conclusion

In this study, hydrological model was developed in SWAT with 55 sub- basins and calibration was done in multiple stations. The results of both calibration and validation were found satisfactory. The annual average precipitation, AET and net water yield across the basin from the model are 2241.85 mm, 196.74 mm and 1000.66 mm respectively. The flow reduction due to interbasin projects shows that the flow reduction has higher impact in immediate downstream sub basin with the impact being lesser in the subsequent downstream sub basins. Seasonal results depicts that the impact is more during winter and spring season i.e. dry seasons.

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