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Research Article

Climate Change and Water Resources in Nepal: Assessing the Impact of Glacier Meltwater on Hydrological Dynamics

Sadiksha Rai[1*], Aashish Khadka[2]

[1] *Department of Water Resources & Irrigation, Jawalakhel, Lalitpur, Nepal*
[2] *Department of Civil and Natural Resource Engineering, University of Canterbury, New Zealand*

Keywords

Meltwater, Rain Impacts, Glacier-fed rivers, Gridded Glacio-hydrological Degree-day Model (GDM).

Abstract

The study focuses on understanding the flow characteristics of glacier-fed rivers in Nepal, particularly in the Seti River basin, employing the Gridded Glacio-hydrological Degree-day Model (GDM). The model, which considers components such as snow melt, ice melt, base flow, and rainfall, demonstrates satisfactory performance during both calibration and validation periods. The research contributes valuable insights into the relative contributions of these factors to the total river discharge. This information is crucial for comprehending the hydrological dynamics of glacier-fed river systems and has potential implications for climate change impact assessments, particularly in relation to glacier melt. Furthermore, the study's findings can inform water resource management strategies in Nepal, aiding in the sustainable utilization of water resources. The consistent model performance over different time periods enhances its reliability, and the spatial distribution of temperature and precipitation data could have broader regional applicability for areas with similar hydrological characteristics. Overall, the research provides a foundation for informed decision-making in water resource planning and highlights the potential of the GDM as a robust tool for assessing river flow in glacierized regions.

1. Introduction

Water, an indispensable natural resource, forms the lifeblood of Nepal, sourced from its diverse landscapes including glaciers, rivers, rainfall, lakes, and ponds. This abundance, however, belies a significant challenge—the uneven distribution of both water resources and population across the country's various basins. Approximately 42% of the populace resides in major basins, 18% in medium basins, and 40% in the Terai region, each facing distinct water availability scenarios. While some basins experience water surplus, others grapple with deficits, presenting a complex interplay of natural resources and human settlements [1].

Most of the portion of Nepal covers rural areas and these the most vulnerable to environmental shifts, are expected to bear the impact of alterations in water availability, food security, infrastructure, and agricultural incomes. Economic losses are poised to escalate with rising temperatures, presenting challenges for poverty reduction and food security. Climate change is anticipated to increase displacement of populations, with the most vulnerable being those lacking the resources for planned migration, particularly in low-income developing countries. [2]

Poor Environment Performance Index, massive deforestation, and destruction of resources along the Chure range, massive disasters, loss of biodiversity, etc. have

* Corresponding Author: Sadiksha Rai
E-mail address: sadiksha11133@gmail.com, ORCID: https://orcid.org/0009-0001-3392-8142

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become our eternal problems and climate change has become an undeniable issue at present impacting nook and corners of our country. In fact, Climate Change Risk Atlas 2019 has ranked Nepal as the fourth most vulnerable country in terms of the impacts of climate change. Though its impacts are observed in several sectors of Nepal, water resources are one of the hardest hit sectors.70 % of the world's freshwater are frozen in glaciers. Glacier melt buffers other ecosystems against climate variability. Very often it provides the only source of water for humans and biodiversity during dry seasons. Moreover, it covers 2.86% of Nepal's area [3].

Glacier meltwater plays important role in water resources of Nepal as these resources are utilized in various purposes such as hydropower production, irrigation, and water supply. The snow and glacier dominated stream contributes as reservoir which stores the water and release them as discharge, and significantly affecting the hydrological characteristics of the stream [4]. Global rise in temperature hugely influences glaciered catchment due to acceleration in [5] as a result the Himalayan region presents a huge threat for future water availability. The widespread glacial retreat in Nepal can have two direct consequences: changes in the hydrological regime and glacial lake outburst floods [6]. In this context, the purpose of this research is to highlight the complexity of climate change impacts on water resources in Nepal, with a particular emphasis on glacier meltwater. It intends to give significant insights for creating sustainable policies and practices to conserve Nepal's water resources and alleviate the broader impacts of climate change by delving into the hydrological repercussions of glacial retreat and the associated dangers.

2. Research Questions and Objectives

The research questions of the study are as follows:

I. What is the contribution of snow, ice melt, rain and baseflow to the discharge in Seti River?

II. What will be the simulated discharge in the Seti River basin?

The general objective of the study is to estimate discharge using Glacio-hydrological Degree-day Model (GDM). in Seti River basin, Kaski, Nepal. The specific objectives of the study are:

- To estimate the discharge at intake site in Seti River using GDM.
- To estimate the hydrological component viz; snowmelt, ice melt, rain and baseflow contributions on river discharge.

3. Methodology

The information and data were collected from Department of Hydrology and Meteorology, Nepal (DHM) where the precipitation and temperature data were collected to estimate the hydrological component. GDM is used to estimate the discharge of the Seti River basin and to calculate the future scenario of the climate change on the study area.

3.1. Study Area

The Seti Gandaki River, also known as the Seti River or the Seti Khola, is a river of western Nepal, a left tributary of the Trishuli River It is one of the holiest rivers of Nepal, River.

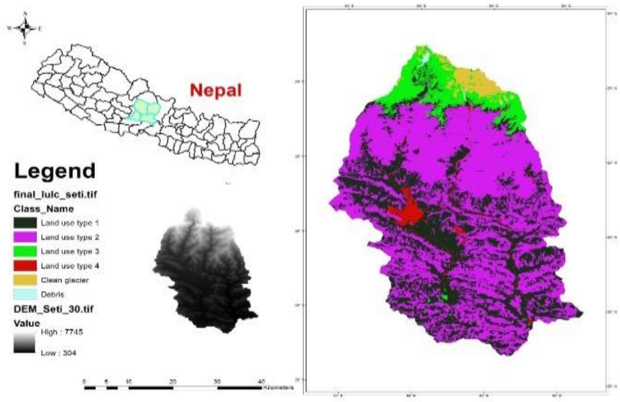

Figure 1. Location Map of the Study Area of Seti River Basin in Gandaki

3.2. Data Collection

3.2.1 Topographic Data

The DEM of all the countries of the world is available in both ArcInfo ASCII and Geotiff format to facilitate the user to perform image processing and spatial analysis by using various Geographical Information System (GIS) application tools. Downloaded data was first projected to WGS 1984 UTM Zone 45N and then clipped to obtain the Digital Elevation Model (DEM) of the study area by using Arc GIS.

3.2.2 Climatic Data

The process of data collection includes collection of primary data, as well as secondary data. The data collected from DHM is presented in Table 1 below which shows the list of Meteorological station at Seti River basin and Table 2 shows the hydrological station.

Table 1. List of Meteorological Station at Seti River basin.

S.N.	Station Name	Index No.	Types of Station	District
1	Pokhara Airport	0804	Aeronautical	Kaski
2	Malepatan (Pokhara)	0811	Agrometeorology	Kaski
3	Khairini Tar	0815	Agrometeorology	Tanahun
4	Damauli	0817	Climatology	Tanahun
5	Lamachaur	0818	Precipitation	Kaski
6	Siklesh	0824	Agrometeorology	Kaski

Table 2. List of Hydrological Station at the Seti River Basin.

S.N.	Station Name	Index No.	Types of Station	District
1	Seti River	430.5	Gandaki	Tanahun

3.3. Modelling Approach

A Glacio-hydrological Degree-day Model (GDM) Version 1.0 is a gridded distributed glacio- hydrological model to simulate the contribution of hydrological components in the river discharge. The GDM is based on the positive degree- day approach which calculates snow and ice melt using positive degree-day factors and then estimates total discharge from a glacierized river basin. A positive degree day factor is a simplification of complex process that are more extensively described by the energy balance of the glacier surface and overlaying atmospheric boundary layer [7]. It estimates snow and ice melt from the debris-free areas as well as ice melt under debris layers with minimal requirements for incorporation of field data. This approach is appropriate in regions with scarce data as it requires fewer input data and uses simple equations to estimate melt [8];[9]. The detailed methodology and processes involved in GDM is shown in Figure 2.

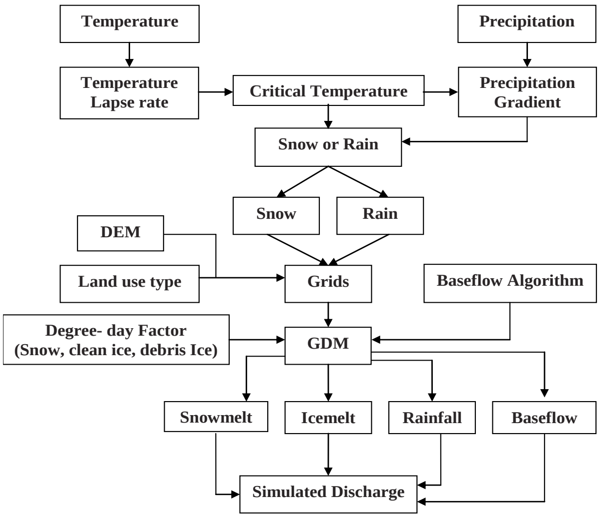

Figure 1. Flowchart of GDM.

3.4. Modelling Process

The GDM model was calibrated with 7 years observed data from 2000 to 2007 using Pokhara Airport Station as base station. The calibrated parameters of the model were then used to validate the observed data 2008 to 2015. The calibrated model after validation was then used to project future discharge of Seti River basin from 2021 to 2100 using bias corrected daily temperature and precipitation data. The relative contribution of snow and ice melt in the future was calculated and decadal hydrograph analysis was done. The details parameter of calibration and validation are as below in the Table 3.

Table 3. Details of calibration and validation Parameters for GDM.

Parameters		Values
Critical temperature		2˚C
Temperature lapse rate		0.63˚C
Precipitation gradient		1≤4000m
		30 % increased > 4000m
Recession coefficients, X& Y		0.95& 0.001
nd constants	Land use type 1 (Grass land) (Agriculture land)	0.14 (Rest of month) 0.5 (June, Jul Aug & Sept)
	Land use type 2 (Shrub land) (Forest)	0.08 (Rest of month) 0.25 (June, Jul Aug & Sept)
	Land use type 3 (Barren land)	0.01 (Rest of month) 0.3 (June, Jul Aug & Sept)
	Land use type 4 (Settlement) (Water bodies)	0.7 (Rest of month) 0.95 (June, Jul Aug & Sept)
Degree day factor	Snow melt	6 to 10 mm/˚C/day
	Ice melt	4 to 8 mm/˚C/day
Rain coefficients		0.001 to 0.1
Snow coefficients		0.001 to 0.1
Ground water constants	δgw,sh	10
	αgw,sh	0.5
	δgw,dp	85
	αgw,dp	0.97
	βdp	0.8
Initial recharge		20 mm

For the precipitation gradient and temperature lapse rate for the model input, data of climatologically stations installed within the Seti River basin was used. DHM data are processed and used for the precipitation gradient and temperature lapse rate.

4. Result & Discussions

4.1. Observed Climatic Data and Trend Analysis

4.1.1 Temperature

The temperature data of the Seti River basin were collected from the DHM for the input of the GDM. The main three stations of Pokhara Airport station (804), Malepatan (811) and Khairini Tar (815) is used for trend analysis of the temperature and further study.

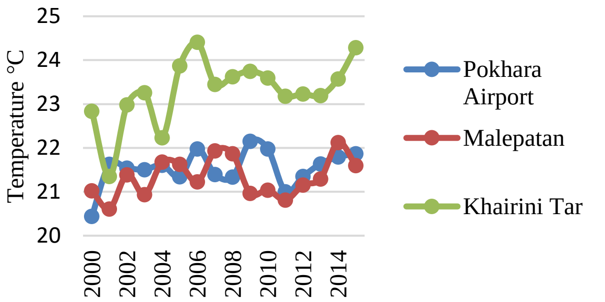

Figure 2. Variation of observed annual temperature from 2000 to 2015.

4.1.2 Precipitation

The precipitation data of the Seti River basin are collected from the DHM for the input of the GDM. There are total of six numbers of meteorological data which are Index No. 0804, 0811,0815,0817,0818 & 0824 whose station name are Pokhara Airport, Malepatan (Pokhara), Kairini Tar, Damauli, Lamachaur and Siklesh, respectively. The trend analysis of precipitation data of different station is presented as below in Figure 4:

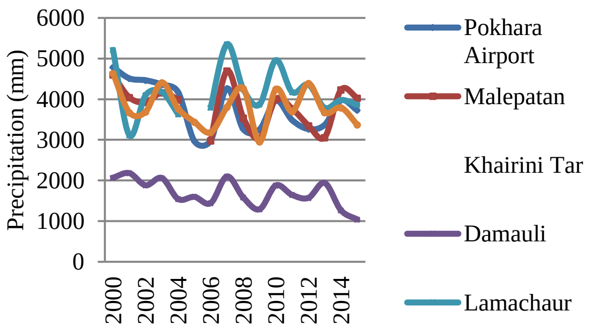

Figure 3. Variation of observed annual precipitation from 2000 to 2015 at different stations.

4.2. Calibration

The GDM model is calibrated with observed hydro-meteorological data for the period from 2000 to 2007. The observed and simulation discharges during calibration year are 445.27m^3/s and 478.84 m^3/s, respectively. During the calibration year, satisfactory model performance was found with 80.5 % Nash Sutcliffe value (NSE) and -6.44% volume difference (VD). The Figure 5 shows the distribution of discharge of Seti River during the calibration period.

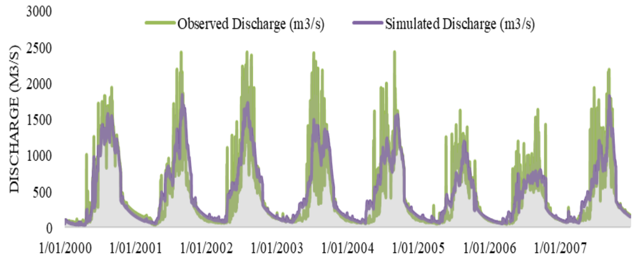

Figure 4. Distribution of discharge of Seti River during the calibration period from 2000 to 2007.

4.3. Validation

The GDM model is validated with observed hydro-meteorological data for the period 2008 to 20015. The observed and simulation discharges during calibration year were 401.16 m^3/s and 419.84 m^3/s. Figure 6 shows the simulated and observed discharge during the period of validation. During the validation year, satisfactory model performance is found with 80.4 % NSE and -4.66 % VD.

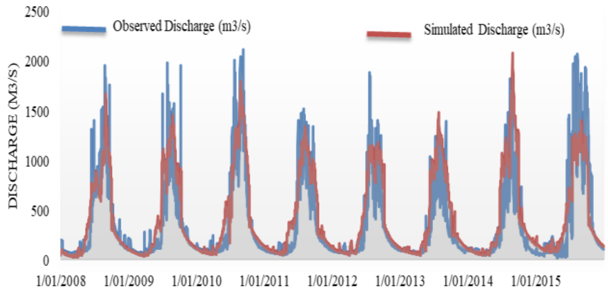

Figure 5. Distribution of discharge of Seti River during validation period from 2008 to 2015.

4.4. Contribution from Stream flow components for Baseline Period

GDM can simulate daily discharge along with rainfall, baseflow, snow and ice melt contributions. Simulated discharge follows the seasonal pattern of basin streamflow, the model shows the extreme peaks during high runoff season. The model also has difficulty simulating discharge during pre-monsoon (March - May) season.

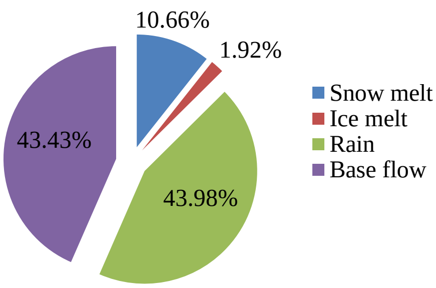

Figure 6. Contribution of snow melt, ice melt, rain and baseflow in Seti River during calibration period from 2000 to 2007

The Figure 7 shows that GDM estimates the percentage of contribution of different hydrological components like snow melt, ice melt, rain and baseflow in Seti River for the period of calibration during 2000 to 2007. Rain has the higher contribution with 43.98 % and 1.92 % ice melt has the lowest contribution in Seti River during calibration year. This shows that the rain plays the vital role in contribution in discharge during the calibration period.

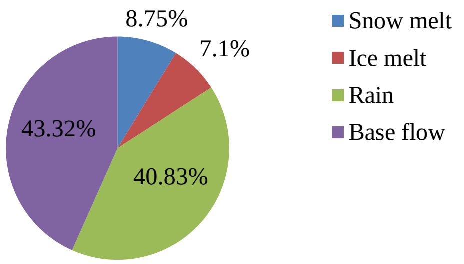

Figure 7. Contribution of snow melt, ice melt, rain and baseflow in Seti River during Validation period from 2008 to 2015

The Figure 8 shows that GDM estimates the percentage of contribution of different hydrological components like snow melt, ice melt, rain and baseflow in Seti River for the period of calibration during 2008 to 2015. Rain has the contribution of 40.83 % whereas the baseflow has contribution of 43.32 %, 8.75 % in snow melt and 7.1 % of ice melt during the validation period of 2008 to 2015.

5. Conclusion

The Glacio-hydrological Degree Day model, employed to simulate daily discharge in the Seti River basin, proves to be a robust hydrological model capable of distinguishing various runoff components, including snow and glacier melt. The model's application during both calibration (2000-2007) and validation (2008-2015) periods demonstrates satisfactory performance in replicating daily discharge dynamics.

During the calibration period, the model achieves an average discharge of 445.27 m3/s, with an 80.7% Nash Sutcliffe Efficiency Index (NSE) and a -7.54% volume difference (VD). Similarly, in the validation period, the model performs well, with an average discharge of 401.16 m3/s, an 80.4% NSE, and a -4.66% VD. The runoff components during the calibration period indicate that 10% is contributed by snow, 1.92% by ice melt, 43.98% by rain, and 43.43% by baseflow. In the validation period, the contributions are 8.75% by snow melt, 7.1% by ice melt, 40.83% by rain, and 43.32% by baseflow.

The analysis of the data reveals that rain has the highest percentage contribution throughout the decadal years, followed by baseflow, ice melt, and snow melt. The study reveals shifts in the contributions of various runoff components, including snow melt, ice melt, rain, and baseflow. These alterations in the hydrological regime suggest that climate change is influencing the water balance in the basin. The Glacio-hydrological Degree Day model indicates changes in glacier meltwater contributions. The accelerating glacial retreat, attributed to global temperature rise, is a clear indication of the impact of climate change on the hydrological dynamics of the Seti River basin.

The data highlights that rain has the highest percentage contribution in the discharge throughout the decadal years. This may indicate a shift in precipitation patterns, potentially linked to climate change, with implications for the overall water availability and distribution in the basin The study observes that the monsoon season exhibits higher discharge compared to pre-monsoon and post-monsoon seasons. This seasonality in discharge is indicative of the influence of climate change on precipitation patterns, potentially leading to more intense and concentrated rainfall during specific periods. The study observes that the monsoon season exhibits higher discharge compared to pre-monsoon and post-monsoon seasons. This seasonality in discharge is indicative of the influence of climate change on precipitation patterns, potentially leading to more intense and concentrated rainfall during specific periods.

For future research directions, it is recommended for using higher resolutions in future research emphasizes the commitment to refining methodologies for a more accurate understanding of hydrological dynamics, a crucial aspect when studying the impact of climate change on water resources.

Conflict of Interest Statement

The authors declare no conflict of interest.

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