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Projection of extremes in Fiji and Nepal

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Abstract: Record-breaking typhoons and prolonged widespread flooding are examples of extremes linked to climate change. Since extremes are rare and devastating, understanding the likelihood of its occurrence in the context of future climate conditions is relevant for policymakers to design mitigation measures and adaptation strategies. To understand climate change, scientists have developed Global Circulation Models (GCMs) that simulate the earth's climate system with numerical representations of the physical processes (i.e., atmosphere, ocean, cryosphere, and land surface) on a computer. GCMs use a grid to divide the earth into small square areas, and then make predictions for each of these squares. However, these squares are too big to make detailed predictions of the likelihood of extremes for specific city or locality. To address this, researchers from the SENTAN Program downscaled the GCM outputs to a finer grid size. This paper discusses the downscaled products of estimating the impacts of extreme tropical cyclone in Viti Levu, Fiji and extreme precipitation at Bagmati River Basin in Nepal under future climate conditions. It also analyzes challenges and options of downscaling.

Keywords: Climate change, downscaling, extremes, GCM, SENTAN

1. INTRODUCTION

Extremes like typhoon Haiyan in 2013 and Pakistan flood in 2022 exhibit record-breaking wind speed and rainfall. Its intensity deviates from the norm, exceeding the expected climate variability far beyond what is typical for the region or locality. While the occurrences of extremes are rare, its impacts are devasting to society and economy. Considering these, local policymakers, whose cities are exposed to hydrologic hazards, would be interested to assess the likelihood of extremes in their areas so that they can introduce adaptation strategies and mitigation measures.

The basic assumption in estimating extremes is that its occurrence is linked to climate change (IPCC, 2023). As observed, climate has been changing. Compared to the pre-industrial times (1850-1900), the current global average surface temperature has risen by 1ºC and the global sea levels have risen by 20cm (8 inches). Under this condition, the oceans absorb 90% of excess heat (NOAA, 2025). One of the effects of climate change is warmer waters that fueled stronger typhoons, floods, storm surges, and extreme events (CCES, 2025).

To assess the likelihood of extremes in certain city or locality under future climate conditions, it is essential to estimate the impact of climate change. To do this, institutions, government agencies, and universities worldwide have developed the General Circulation Models (GCMs) that simulate the earth's climate system with numerical representations of the physical processes (i.e., atmosphere, ocean, cryosphere, and land surface) on a computer (Nakaegawa, 2024). GCMs use a grid to divide the earth into small square areas, and then make predictions for each of these squares. Hypothetically, what if the global surface temperature will increase by 4ºC in 2100, how will it affect the rainfall patterns in Asia? With GCM data, researchers will be able to look at the grids covering Asia and get a simulated estimate of future rainfall patterns under the 4ºC increase in global surface temperature scenario. In reality, GCMs are used to simulate different scenarios of climate change based on the levels of greenhouse gas (GHG) emissions, societal choices, and policy actions. Considering these factors, the prominent scenarios that scientists use are the *Representative Concentration Pathways* (RCPs) that describes the levels radiative forcing (extra energy trapped by green house gases) and the *Shared Socioeconomic Pathways* (SSPs) that describes how society, economy, and policy are influencing emission levels (USDA, 2025). RCPs and SSPs were used by the Intergovernmental Panel on Climate Change (IPCC) in the Fifth Assessment Report (AR5) and Sixth Assessment Report (AR6) respectively (IPCC, 2025). By using these scenarios, policymakers and practitioners are provided with different possible climate futures based on various levels of greenhouse gas emissions, societal choices, and policy actions.

However, direct use of GCM data is not suitable for estimating the likelihood of extremes in certain city or locality. GCM grids (or squares) are too big, having coarse resolution information that it cannot make detailed estimates on local temperature, precipitation, and other climate variables. Therefore, downscaling is required. Downscaling is the process of deriving a finer resolution (spatial and temporal) from GCM data to estimate the climate change impact that captures the variations in climate conditions at the local level (Figure 1).

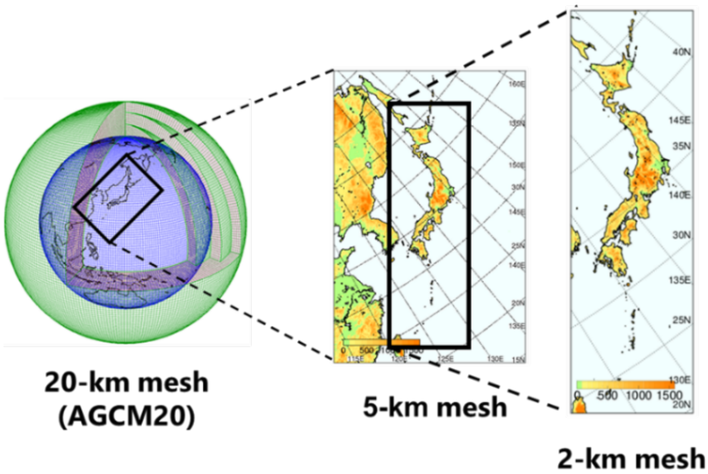


Figure 1 Image of downscaling (Murata, 2024)

In other words, it is through downscaling that researchers will be able to project extremes at the local level. Although useful for policymakers and practitioners, access to high-resolution downscaled data can be a challenge to small cities with limited resources, as downscaling process can be costly (Murata, 2024). Additionally, local officials often need technical training to interpret and apply complex climate data to inform their adaptation strategies and mitigation measures.

(1) Objectives

The main objective of this paper is to discuss the contributions and challenges of downscaling in estimating the impacts of extremes in Fiji and Nepal. It specifically aims to explain:

- Why is the projection of extremes undertaken?
- What are the estimated impacts of extremes?
- How does the downscaled data inform adaptation strategies and mitigation measures?

(2) Methodology

As a member of Area Theme 4 of the MEXT-Program for The Advanced Studies of Climate Change Projection or SENTAN (JAMSTEC, 2025), the Asian Disaster Reduction Center (ADRC) has been co-hosting the Webinar Series on Climate Change Impact Projection for Disaster Risk Reduction in Asia-Pacific Region (ADRC, 2025). In this webinar series, scientists and experts who are working under Area Theme 4 of SENTAN Program share downscaled projections of extremes of various cities and localities in Asia-Pacific region. Since 2023, four webinars have already been organized (i.e., with Fiji, Nepal, Cambodia, and Malaysia). This paper reviews the materials presented at the webinars with Fiji and Nepal. It analyzes the contributions and challenges of downscaled data.

2. SENTAN PROGRAM AND DOWNSCALING

SENTAN is a program funded by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan. Its main goal is to conduct application-oriented research to meet the needs of different users and contribute to the realization of a decarbonized society. SENTAN has four research themes under a unified research framework: Area Theme 1 Predictive understanding of earth system changes based on physical evidence; Area Theme 2 Biogeochemical modeling and climate simulations for carbon budget assessment; Area Theme 3 Increasing the sophistication of climate change projections around Japan; and Area Theme 4 Development of an integrated hazard projection model (JAMSTEC, 2025).

(1) Overview of Area Theme 4

SENTAN's Area Theme 4 is centered on the development of an integrated hazard projection model, represented by Kyoto University's Disaster Prevention Research Institute (DPRI). One of its research activities focuses on the projection of extremes and provide support to policymakers in formulating adaptation measures tailored to local conditions. Over 100 scientists from four participating organizations and 43 cooperating organizations, including ADRC, are working together under Area Theme 4 (DPRI, 2025).

According to Mori (2023), Area Theme 4 puts emphasis on Climatic Impact Drivers (CIDs) following the IPCC Sixth Assessment Report (AR6). The integrated model of Area Theme 4 connects the *Physical Science Basis* (Working Group 1) and the *Impacts, Adaptation, and Vulnerability* (Working Group 2) of the IPCC. Area Theme 4 generates future projections of weather-related hazards, water resources, and ecosystems using datasets from Area Themes 1–3. Most importantly, there are five sub-themes under Area Theme 4, namely: (i) Integrated hazard modelling and nationwide future projections; (ii) Elaborate hazard model development and hazard mechanism elucidation, and under this sub-theme are a) hazard assessments of wind hazard, water-related disasters and water resources, and b) hazard assessments of forests and coastal ecosystems; (iii) Quantification of climate change factors in extreme hazards; (iv) International collaborations; and (v) Flexible adaptation strategies to the future changes in hazard and society (Figure 2).

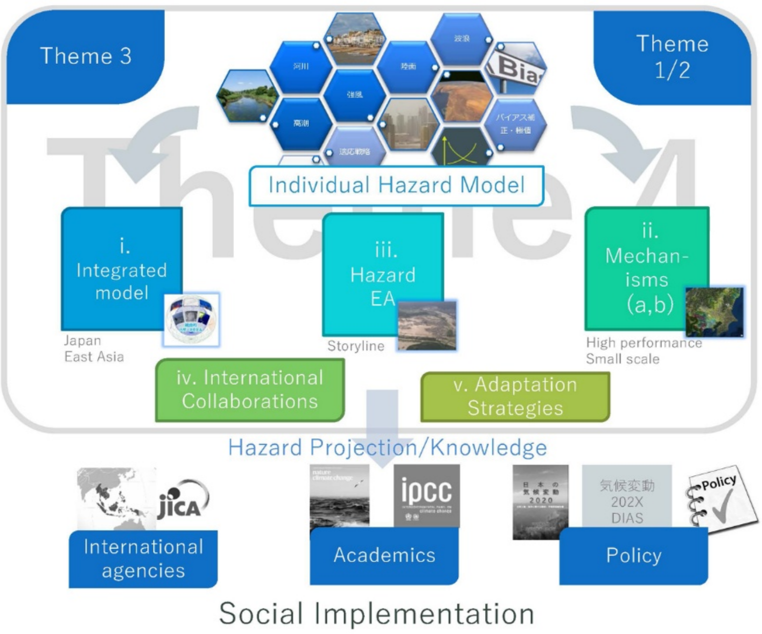


Figure 2 Research Framework of Area Theme 4 (Mori, 2023)

The Webinar Series on Climate Change Projection for Disaster Risk Reduction is one of the activities under sub-theme (iv) International Collaborations. The objectives of the webinar series include: sharing the products of climate change projections; improving climate change literacy among practitioners, researchers, and engineers; and fostering greater cooperation through sharing of knowledge and technology.

(2) Basic Steps of Downscaling

The main purpose of downscaling is to project future climate on local scales (e.g., city or municipality). According to Murata (2025), the common types of downscaling are statistical downscaling (based on statistical knowledge) and dynamical downscaling (based on numerical simulations using earth simulator made of high-speed supercomputers). Regardless of which type is used, the basic steps of downscaling include the following:

Step 1 Obtain GCM data
For Asia-Pacific region, the common sources of GCM data are MRI-GCM, CMIP5, CMIP6, and CORDEX. It is also important to identify under what scenarios (e.g., RCP and SSP) the GMC data is simulated.

Step 2 Define the time slice (time period) for projection e.g., 2080 – 2100.

Step 3 Use downscaling method (dynamical or statistical) to correct GCM simulated data by comparing it with observed data of the locality of interest.

After getting the results, analyze and apply the downscaled projections for local planning, and use the findings to inform climate action policies.

3. VITI LEVU, FIJI

In the webinar with Fiji, Mori (2023) presented the projected impact of magnitude 100-year return period tropical cyclone (TC) to various locations of Viti Levu, Fiji. Under the climate change scenarios RCP2.6 (very low GHG emissions, strong climate policies that will result to projected warming by 1.0 - 2.0^{o}C in 2100) and RCP 8.5 (very high GHG emissions "business as usual" that will result to projected warming by 3.2 - 5.4^{o}C in 2100), d4PDF – a large ensemble climate simulation database – is utilized to simulate the occurrence of extreme TCs in Viti Levu in the past and future climate conditions. Simulated historical TCs data from d4PDF are corrected by comparing it with the observed data. Using the corrected data of extreme TCs, the impacts of future 100-year return period TCs are estimated in terms of areas to be inundated and number of exposed populations in different locations of Viti, Levu.

(1) Why estimate the impact of extreme tropical cyclone?

Intense TCs have been disastrous to Fiji. For instance, Cyclone Winston (Category 5) made landfall on Fiji on 20 February 2016, and caused damage and loss equivalent to 20% of the country's GDP and affected 62% of the population, predominantly in the western Viti Levu, killing 19 people on this island (Mansur et. al., 2017). Fiji is located in the tropical cyclone belt and experiences frequent tropical cyclones characterized by damaging winds, rain, and storm surge. Moreover, Fiji suffers from extreme events associated with climate change, such as sea-level rise, temperature extremes and droughts (Sabuenas et al, 2021). The country experiences on average one cyclone per year, and since 1980 the various disasters have resulted in adverse social and economic impacts, estimating an annual average loss of 2.6% of GDP per year from fluvial floods and 1.6% of GDP per year from pluvial floods (World Bank, 2021). However, if climate change is considered, the impacts of flooding by extreme TCs could be worse under the future climate.

(2) Results

To have greater understanding of the projected impact of 100-year extreme storm, Mori (2023) briefly explained the d4PDF tool (Figure 3) at the webinar. It is a large ensemble projection database that can simulate historical climate for the past 6,000 years as well as over thousands of years of future climate conditions under different climate change scenarios. Also, according to Ishii (2020), d4PDF specifically contains the results of ensemble simulations conducted over thousand years respectively for past and future climates using high-resolution global (60 km horizontal mesh) and regional (20 km mesh) atmospheric models. It can satisfactorily simulate the past climate in terms of climatology, natural variations, and extreme events – such as heavy precipitation and tropical cyclones. With d4PDF, data users can obtain statistically significant changes in mean states of weather and climate extremes (e.g., TC) between the past and future climates via a simple arithmetic computation without any statistical assumptions. In other words, the d4PDF tool is essential for climate and risk assessment as well as bases for climate adaptation policies.

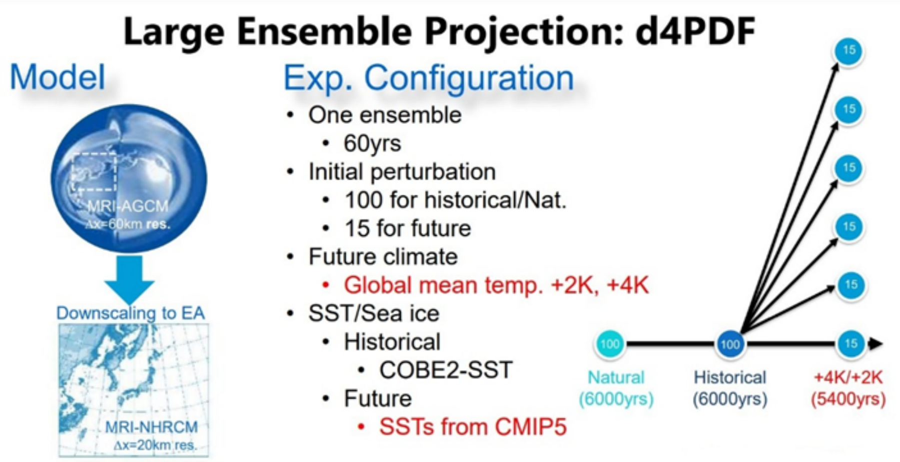


Figure 3 Basic concept of d4PDF (Mori, 2023)

In the case of Viti Levu, Fiji, d4PDF was used to simulate historical TCs and the simulated data was corrected using observed data (Figure 4). Simulated historical data from d4PDF shows the following: (i) since 1978, Fiji recorded a total of 101 TCs, averaging 2.4 TCs/year; (ii) the number of TCs has decreased by 72% during the decade 2011-2021 compared with the decade 1978-1988; and (iii) 74% of all TCs approached Fiji from northwest direction.

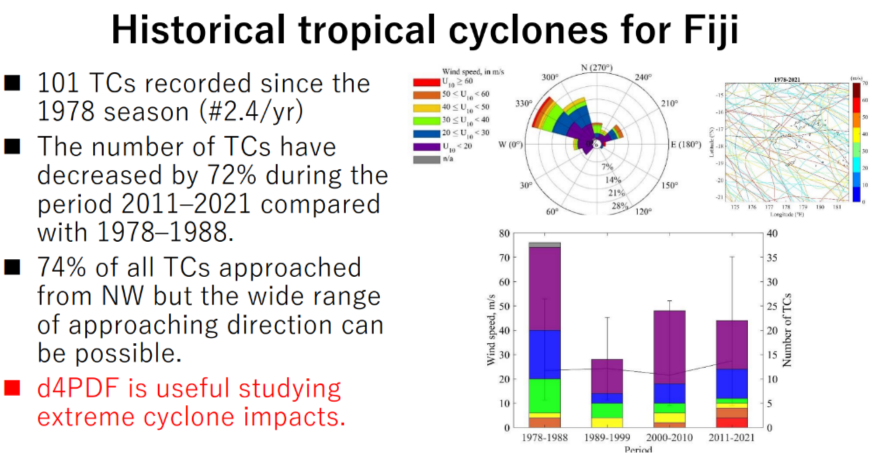


Figure 4 Historical tropical cyclones for Fiji (Mori, 2023)

To proceed with the analysis, the GCM bias of TC historical data was corrected by comparing it with observed data. In this way, the estimated impacts of 100-year return period TC between GCM data (non-corrected, coarse resolution) and downscaled data (corrected, high-resolution) can be compared (Figure 5).

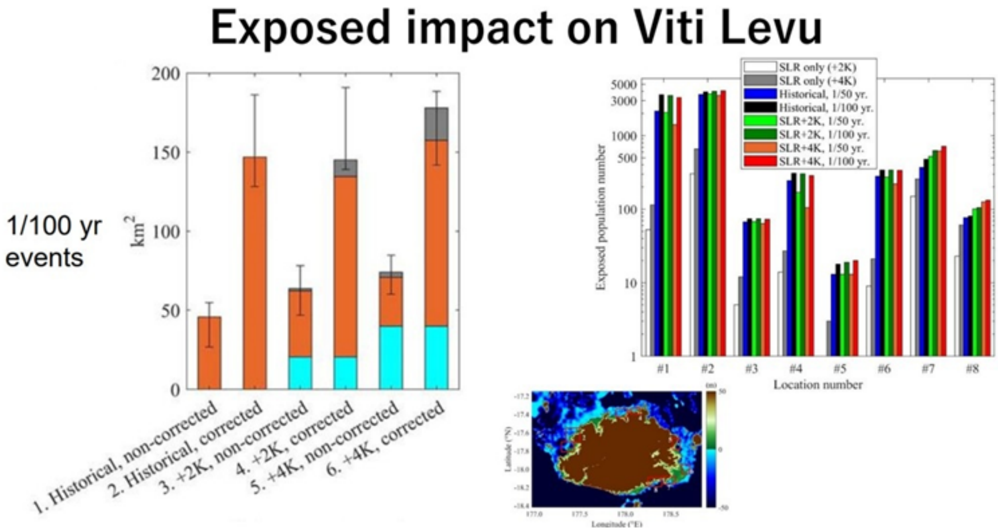


Figure 5 Projected areas of inundation and number of people to be affected by locations (Mori, 2023)

As shown in Figure 5, impacts of the 100-year return period TC in Viti Levu can be projected under different scenarios and resolutions. For instance, in terms of areas to be inundated, the following projections can be compared:

- Historical (projected areas of inundation in past climate condition): GCM projection is 50km^2 areas of inundation while downscaled projection is 150km^2 areas of inundation.
- Future climate (2ºC warming): GCM projection is 65km^2 areas of inundation while downscaled projection is 150km^2 areas of inundation.
- Future climate (4ºC warming): GCM projection is 70km^2 areas of inundation while downscaled projection is 170km^2 areas of inundation.

Also shown in Figure 5 are the projected impacts on population at eight different locations of Viti Levu. These projections consider the compounding effects of sea-level rise and storm surge. The results indicate that the downscaled data (i.e., bias-corrected projections) provides locality-specific estimates of impacts as compared to the coarse data of GCM. Mori (2023) mentioned that while the 100-year magnitude TC is projected in the next 40-50 years, its intensity will decrease under two future climate scenarios (i.e., 2ºC warming & 4ºC warming). Additionally, the amount of exposure of the general population will not be high enough to threaten a significantly large portion of people to loss their lives.

(3) Adaptation strategies and mitigation measures

For Fiji, these projections are relevant to inform adaptation strategies and mitigation measures of the government. Anticipating that the inundation from the combined effects of extreme TC and sea-level rise will increase with climate change, it is important to regulate the exposure of population to the likely affected areas. As reported by Chandra (2023), houses that are exposed to inundation by seawater in the coastal villages of Veivatuloa and Vunidogoloa have been relocated to elevated places in consideration of the combined effects of sea-level rise and extreme TC event under future climate. He also mentioned, as an example, that the sea level at Lautoka Wharf has been increasing at 4.3mm/year between 1993 and 2022. With this information, the respective local governments that are exposed and vulnerable to the combine effects of sea-level rise and extreme TC will benefit from downscaled projection data for their climate action policies.

3. KATHMANDU VALLEY, NEPAL

In the webinar with Nepal, Mishra (2024) presented the projection of extreme precipitation in Upper Bagmati River Basin for future climate (2080-2100). It used the climate change scenario SSP5-8.5, which means very high GHG emission. In doing the projection, dynamical downscaling was performed by [1] comparing the MRI-AGCM3.2 precipitation data of the present climate (1980-2000) with observed precipitation data of the present climate (1980-2000) of Upper Bagmati River Basin to correct the bias in GCM data; and [2] using the corrected data, the frequency and intensity of extreme precipitations are estimated for future climate (2080-2100).

(1) Why estimate precipitation extremes?

According to Mishra (2024), Nepal has high climatic variation, where annual precipitation could be less than 300mm to more than 5500mm. He also noted that changes in temperature and precipitation in Nepal have been showing faster rate than the global average. In view of this, understanding the changes in precipitation is important since it has implications on river discharge as well as flooding disaster. For instance, there has been an increasing flooding events in Kathmandu Valley that are attributed to extreme precipitation in Bagmati river basin (ACAPS, 2024). These flooding events always affect the lives, livelihoods, properties, and infrastructure of the population living in Kathmandu Valley. To help estimate the impacts of flooding, rainfall-runoff modeling of Bagmati River Basin (Figure 6) has been developed. The model is useful in showing the low elevation areas, where houses, agricultural livelihoods, and critical infrastructures are likely to be impacted by flooding. In addition to this, estimating the intensity of future extreme precipitation is needed to inform adaptation strategies and mitigation measures for Kathmandu Valley as well as improve the management systems of water resource, agriculture, flood, and storm.

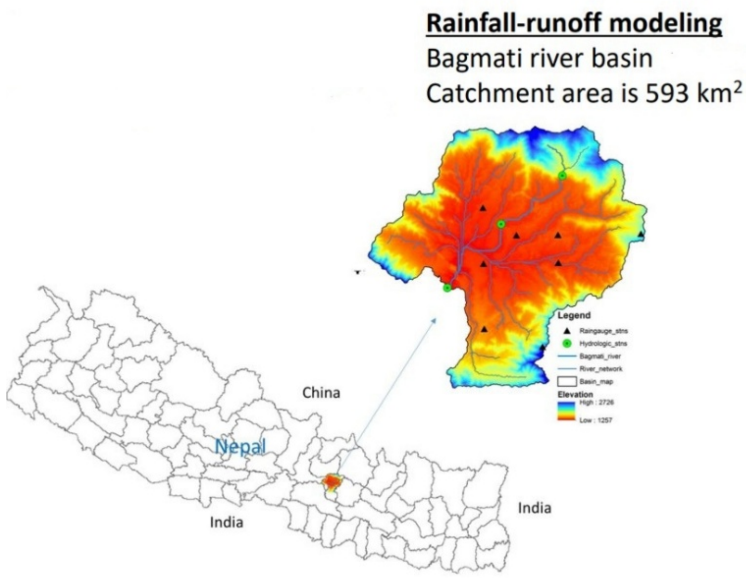


Figure 6 Modeling for Bagmati River Basin (Mishra, 2024)

(2) Results

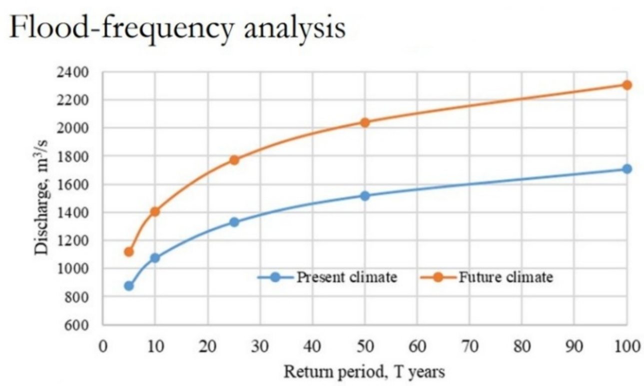
Information in Table 1 provides the background for interpreting the results that estimate extreme precipitation in Upper Bagmati River Basin under future climate condition (2028-2100).

Table 1 Background Information on Projection of Extreme Precipitation

Source of GCM Data	MRI-AGCM3.2
Climate Change Scenario	SSP5-8.5 (Very High GHG emission)
Time Period for Projection	2080-2100 (Future climate)
Downscaling Method	Dynamical Downscaling (Using Earth Simulator)

In obtaining the downscaled data for future extreme precipitation, Mishra (2024) highlighted two relevant steps. Firstly, the GCM precipitation data of present climate (1980-2000) was compared with the observed precipitation data of the present climate (1980-2000) obtained from the meteorological stations around the Bagmati River Basin. The purpose of this step is to correct the inherent bias of GCM data due to its coarse resolution. Secondly, using the corrected precipitation data, dynamical downscaling (using earth simulator) was performed to estimate the intensity of extreme precipitations under future climate (2080-2100). Figure 7 shows the results of downscaling.

Present climate		Future climate	
Year	Q (m^3/s)	Year	Q (m^3/s)
1981	1350.1	2080.0	249.1
1982	479.1	2081.0	1131.7
1983	383.8	2082.0	1189.3
1984	716.6	2083.0	533.6
1985	455.6	2084.0	1294.2
1986	541.8	2085.0	410.4
1987	793.1	2086.0	800.4
1988	415.4	2087.0	510.5
1989	1362.1	2088.0	519.8
1990	663.2	2089.0	665.5
1991	379.6	2090.0	343.7
1992	656.7	2091.0	434.3
1993	460.4	2092.0	920.2
1994	469.2	2093.0	1818.4
1995	317.2	2094.0	1180.6
1996	462.7	2095.0	1140.1
1997	713.0	2096.0	439.4
1998	458.9	2097.0	426.0
1999	397.7	2098.0	511.2
2000	817.3	2099.0	402.0



Return period, T years	Discharge, m^3/s	
	Present climate	Future climate
5	876	1120
10	1077	1408
25	1331	1771
50	1520	2041
100	1707	2308

Figure 7 Projected amount of discharge from Bagmati River Basin (Mishra, 2024)

As shown in Figure 7, the projected amounts of discharge from the Bagmati River Basin will continue to increase under future climate scenario (SSP5-8.5). If no adaptation or mitigation measures are introduced in Nepal, the extreme flooding of 100-year return period magnitude (discharge of over 1,700m^3/s) will be having a return-period of 25 years under future climate conditions.

(3) Adaptation and Mitigation Measures

Extreme precipitation in Bagmati River Basin means flood disaster in Nepal's capital city, Kathmandu Valley. Since Bagmati River Basin plays a crucial role in meeting the water supply requirement of Kathmandu Valley and downstream communities, projection of extreme precipitaiton is essential. Pokharel (2024) stated that projection data is particularly relevant to key sectors, such as agriculture, water, energy, health, and disaster risk reduction for adaptation and mitigation measures. In order to mitigate the future impacts of frequent and more intense precipitation at Bagmati River

Basin, the Government of Nepal has been implementing projects to improve resilience to climate change impact. These projects includes improving water management and the river environment, flood management, river heatlh, upstream water storage, and climate change adaptation of the communities (ADB, 2012).

4. DISCUSSIONS

The products showing the projection of extremes in Fiji and Nepal are made possible through downscaling. Although GCMs can simulate future climate conditions, its resolutions are coarse – about 100km^2 per grid – which is too large to capture local climatic details. Practically, GCM output is like a digital photo that has a lesser number of pixels per inch of an image, and details are not captured. Therefore, direct use of GCM data is not suited for understanding the climate change impact on local scale. Essentially, for local scale estimates, high-resolution climate data is needed. Downscaling, either statistical or dynamical, is a method of refining the GCM data to a smaller scale to provide a more precise picture of climate variations. Downscaling allows researchers to assess climate change impacts on specific cities or locations. In projection of extremes, this paper would like to highlight two points regarding downscaling: bias-correction and multiple climate scenarios.

(1) Bias-Correction

As shown in the cases of Liti Vetu and Bagmati River Basin, the primary step in downscaling is to obtain GCM data covering the area. Since GCM data are simulation of large-scale climate processes, it has systematic biases due to its coarse resolution, parameterizations, and uncertainties in representing the complex climate dynamics. For instance, in the case of Nepal, the GCM precipitation data is generally lower (by 20%) compared to the observation precipitation data (Mishra, 2024). The same is true with Fiji, where the GCM historical TC data needs to be corrected by comparing it observed data (Mori, 2023). Bias correction of GCM data is essential to improve the accuracy and reliability of local climate projections. With bias-corrected data, the government of Fiji is able to develop a targeted adaptation strategy for vulnerable communities in coastal areas, including relocation to elevated locations. Likewise, the government of Nepal is able to target and confidently implement long-term investments in water management, flood management, and river basin management.

(2) Multiple climate scenarios

It should be emphasized that the projections of extremes, as shown in this paper, are probabilities based on multiple climate scenarios. For Fiji, the projection of extreme TC is estimated under the climate change scenarios RCP2.6 (very low GHG emissions, strong climate policies that will result to projected warming by 1.0 - 2.0ºC in 2100) and RCP 8.5 (very high GHG emissions "business as usual" that will result to projected warming by 3.2 - 5.4ºC in 2100). For Nepal, the projection of extreme precipitation is estimated under climate change scenario SSP5-8.5, which means very high GHG emission. The reason for having multiple scenarios is that future climate conditions depend on uncertain factors, including greenhouse gas (GHG) emissions, socio-economic development, technological advancements, and policy decisions. For example, it is uncertain how exactly the population will grow, the economy will develop, and the energy will be consumed in the future, as these all depend on uncertain factors. Therefore, using multiple-scenarios can help policymakers and planners understand the possible future climate trajectories and prepare for a range of outcomes.

5. CONCLUSIONS

Through downscaling, data users and policymakers are able to estimate the scope of inundation from extreme TCs in Liti Vetu, Fiji as well as estimate the frequency and intensity of extreme precipitation at the Bagmati River Basin in Nepal under future climate conditions. When projecting future climate on local scales of Liti Vetu and Bagmati River Basin, downscaling is essential to obtain a more precise picture of local climate variations (i.e., precipitation and temperature) as well as local topography and land use. Downscaled data allows policymakers to introduce a more targeted climate policy actions (e.g., relocations) in Fiji and a more climate-specific investments (e.g., water resource management) in Nepal. While downscaled climate data is useful, access can be a challenge to small cities with limited resources due to cost involved. Additionally, local officials often need technical training to interpret and apply complex climate data. Although GCMs can simulate future climate conditions, this is not suited for local scale.

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