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Use of Climate Change Projections for Resilience Planning: A case study of Kathmandu Valley

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Abstract

Climate change is predicted to inflict damage on agriculture, water resources, infrastructure, and millions of people's livelihoods. In the context of climate change, the impacts of urbanization on the future air conditions of cities around the world are still undefined. We used the latest climate models from the Coupled Model Intercomparison Project Phase 6 to project future climate risks over the Kathmandu valley in terms of precipitation and temperature changes (CMIP6). We used multiple datasets, including APHRODITE, ERA 5, and Bias corrected CMIP6 for the SSP585 scenario, to estimate future projections. This study examined how projections may affect the future climate of the Kathmandu valley and develops adaption techniques for expected precipitation and temperature in Kathmandu, with the goal of enhancing climate change policy. According to this analysis, by the end of the twenty-first century, annual mean precipitation, monsoon precipitation, extreme precipitation occurrences, and annual mean temperature will have increased by 17.7%, 72.31%, 26.69%, and 0.083 ^{o}C sequentially under SSP585 scenarios. Based on the recent impact of climate change as projected by the CMIP6 model, there is a growing political interest in decreasing the danger of urban climate change through adaption techniques. The findings of this study suggest that a unique vision of future warming has the most impact on urban livelihood and development. Because the number of available CMIP6 models is currently limited, more CMIP6 models will need to be evaluated in the future.

Keywords

Climate change, Resilience Planning, CMIP6, Kathmandu Urbanization, Temperature, Precipitation

1. Introduction

Climate change is predicted to enhance urban people exposure to associated dangers, which are already increasing in low- and middle-income nations [1]. Since 2008, more than half of the world's population has lived in cities, and this proportion has been increasing [2]. Furthermore, urbanization has local atmospheric consequences that might amplify the effects of global climate change [3]. According to [3] from 1961 to 2010, mean annual temperatures in 39 major cities rose by 0.12-0.45 °C over a decade. Meanwhile, urban regions have been observed to be warmer than adjacent rural areas [4] and climate change is anticipated to bring many more hot evenings in the future. The utilization of cooling power, thermal waves, sea wind, and excessive urban rains will all be affected by such urban consequences. and are expected to experience many hot nights in the future under climate change [5]. There is growing international concern about how to cope with the effects of climate change in cities, particularly in developing nations where cities are quickly expanding and a high percentage of urban residents are impoverished or otherwise vulnerable to climate change [6]. According to research from throughout the world, heavily populated metropolitan regions are currently at danger of catastrophic occurrences, and this risk is likely to increase in the future [7].

Temperatures have been rising in Nepal over the past few decades. Between 1978 and 1994, the highest temperature in Nepal increased by 0.06 ° C per year, with higher concentrations at higher altitude stations. The evidence of warm winter has been undeniable [8]. Similarly, the trend toward declining days on cold and cold nights as well as an increase in warm nights, has been recorded [9]. Under the SSP scenarios, the annual mean temperaature over Nepal is expected to rise by 1.3-4.5oC in the far future. Previous research has also suggested that by the end of the twenty-first century, the annual mean temperature in Nepal will have risen by 1.7-3.6oC [10, 11]. The term "Urban resilience to Climate change" refers to a city that is resilient on three levels: the city's systems survive shocks and stresses; people and organizations are able to incorporate these stresses into their decisions and choices; and the city's institutional structures continue to support people and organizational capacity to meet their needs. The Kathmandu valley is Nepal's urbanization epicenter Nepal will stay among the top ten fastest urbanizing countries in the world from 2014 to 2050, with an annual urbanization rate of 1.9 percent. The Kathmandu valley is home to 24% of the city's total Population [12].

CMIP provides for a better understanding of past, present, and future climate change with a diversity of model contexts under the climatic conditions of the World Climate Research Program (WCRP) Performance Group on integrated models. The Integrated Assessment Model (IAM) community generated Representative Concentration Pathways (RCPs) for CMIP5 (2007–2013), which were based on socio-economic scenarios and provided the forcing for future forecasts. Following significant public participation, a replacement structure for CMIP6 and subsequent phases was adopted with the goal of reducing the burden on, and increasing flexibility for, the multiple modeling groups, as well as providing better long-term continuity [13].

Enhancing the overall resilience of development plans to climate risk is a deliberate and proactive action that necessitates assessing predicted climate threats prior to implementing plans so that mitigation measures can be included into the plan itself. Increasing our understanding of the interconnections between climate variability, climate-change hazards, variability, and development is a prerequisite for recognizing climate risks, which is essential for climate resilient planning [14]. Consolidation can be defined as "the ability of the system, community, or community exposed to the risks of coping, absorbing, accepting and reversing the effects of an accident in a timely and effective manner, including the maintenance and restoration of its critical infrastructure." a collection of new buildings and processes" [15].

Kathmandu thrives on hills, swamps, mangroves, and disaster-prone areas. Forest oppression, unsustainable use of natural resources and unmanaged urbanization has greatly increased those area's vulnerability to various disasters such as landslides, floods, earthquake, and urban heat waves. Global climate change exacerbates these dangers, putting residents of precarious communities in particular at risk [7].The land use and land cover of the Kathmandu Valley are altered dramatically over the previous four decades [16]. Between 1976 and 1989, the Valley's average annual urban growth rate was 7.34 percent, 7.70 percent between 1989 and 2002, and 5.90 percent between 2002 and 2015 [17]. The valley has expanded by 412 percent, with the majority of land convert to industrial and residential area from agriculture land [18]. Flooding in the Kathmandu Valley has been on the rise since 1971, wreaking havoc on the infrastructure, health, and agriculture sectors. In the Kathmandu Valley, Lalitpur has the largest number of deaths and buildings destroyed due to floods, with 67 people killed, 1,857 people impacted, 255 houses demolished, 121 houses damaged, Rs. 4,655,000 in property losses and 131.32 hectares of crops damaged. The valley's existing drainage system may not be able to cope with the growing severe rainfall in the coming years, resulting in waterlogging and inundation [19]. The most aggressive kind of urban growth in the Kathmandu Valley occurred between 1999 and 2009, coinciding with a growing real estate market powered mostly by an influx of migrants from the countryside displaced by political unrest and/or stalled growth in the agricultural sector. The Kathmandu Valley experienced a 117 percent increase in built-up areas from 1999 to 2009. Since 1984, the amount of agricultural land in the Kathmandu Valley has been shrinking. Since 1999, around 18 percent of fertile and productive agricultural land has been lost to urbanization, industrialization, and soil, sand and stone [20, 21]. During this period, the valley also observed loss of forest cover whereby about 36% of the tree-covered area were cleared up for agricultural purpose [22].

The main objective of the research is to use of climate change projection for resilience planning of Kathmandu valley. And to fulfill the main objectives we have set the specific objectives as to analyze historical changes in temperature and precipitation through APHRODITE and ERA5, to examine future change in temperature and precipitation using CMIP6 under SSP 585 Scenario of Kathmandu Valley, to analyze future precipitation extreme events to prepare future prospects of climate resilience urban planning.

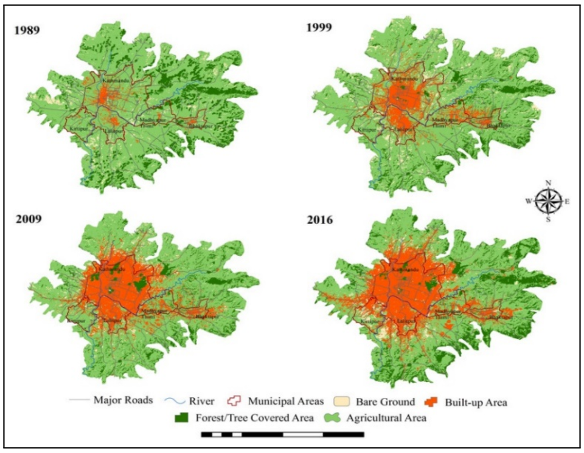

Figure 1: Land use land cover map of Kathmandu Valley (1989-2016).

2. Research Material and Method

2.1 Study Area

The Kathmandu Valley is the research area, which spans approximately 665 Sq. Km. and is bounded by the Bagmati watershed. The valley comprises a complex bowel- shaped valley with elevations ranging from 1100 to 2700 meters above sea level. The valley is divided into five administrative urban regions (Kathmandu, Lalitpur, Bhaktapur, Kritipur, and Madhyapur Thimi) and 97 peri urban and rural villages, Kathmandu accommodated 32.4 percent of the country's total urban population according to 2011 census.

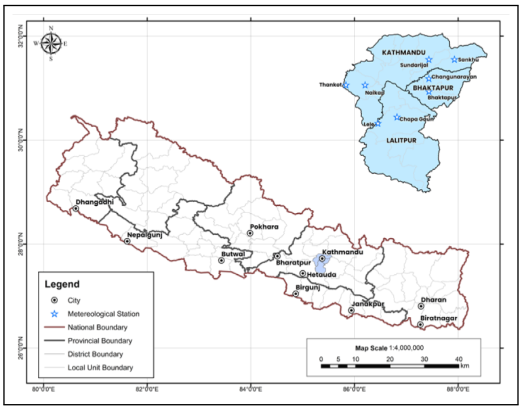

Figure 2: Study Area (Kathmandu Valley)

2.2 Methodology

The CMIP6 models were used to create a corrected dataset of daily precipitation maximum and minimum temperatures, which was used in this study. For the period 1980- 2020, we acquired observed precipitation, minimum and maximum temperatures for the Kathmandu Valley. Future urbanization scenarios were examined using the worst urban adaptation tactics. The SSP585 scenario, as represented by the CMIP6 model, has the worst adaptation approach, with high air pollution levels, unsustainable energy use, and poor urban development. People would be forced to relocate to the suburbs in the worst-case scenario, resulting in horizontal expansion away from the city center. As a result of the low adaptation and mitigation strategy used in the SSP585 scenario, future urban expansion is limited [23].

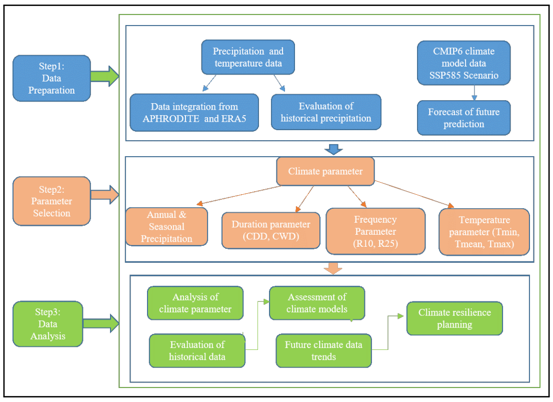

Figure 3: Research framework

2.3 Observation Datasets

Shared Socioeconomic Pathways (SSP) and radiative forcing stages at the end of the twenty-first century are combined in the CMIP6 scenarios. The output from the datasets is the climatic scenario SSP585, which is based on an emission scenario with SSP 5 and radiative forcing of 8.5 at the end of the twenty-first century. Biased-corrected precipitation and temperature from CMIP6(Climate Model Inter-Comparison predict 6th Phase) data regenerated by [24] were used to project climate scenarios in this work, providing more details on the scenarios utilized in the CMIP6.

At each station, high intensity linked catastrophic occurrences were estimated using daily records and two indicators that are heavy rainfall ($\geq$ 10 and $<$ 25mm) and extreme rainfall ($\geq 25mm$) events in the year are represented by R10mm and R25mm respectively. Since they detect strong precipitation events, these techniques frequently induce flash floods and landslides. Five consecutive dry days with less than 1 mm of rainfall and greater than 1 mm of rainfall are referred to as "consecutive dry days" (CDD) and "consecutive wet days" (CWD), respectively [25].

Table 1: Comparison between datasets used.

Datasets	Period	Spatial Resolutions	References
DHM observed data • Temperature • Precipitation	1980-2020	9 Stations	http://www.dhm.gov.np
APHRODITE • Temperature • Precipitation	1980-2015	25km	http://aphrodite.st.hirosaki-u.ac.jp/
ERA 5 • Temperature • Precipitation	1980-2020	25km	https://cds.climate.copernicus.eu/
Bias corrected CMIP6 • Temperature • Precipitation	Future Projection (2015-2100)	25km	https://pcmdi.llnl.gov/CMIP6/

3. Results and Discussion

3.1 Observed and projected Precipitation

3.1.1 Seasonal Precipitation

According to the seasonal cycle, rainfall peaks during the monsoon season (June to September). The historical rainfall trends showed five wet pre-monsoon period was 1990(117.45mm), 2000(145.07mm), 2004(125.31mm), 2016(122.50mm) and 2017(148.69mm). During the monsoon season between the time 1980 to 2020 the mean observed rainfall was recorded 413.04mm. Between1980 to 2020 it is observed that the average post monsoon rainfall was 34.46 mm. The highest rainfall between the base period were 1985(82.32mm) 1987(90.56mm) 1999(86.64mm) and 2013 (89.58mm). During the winter season of past 4 decades the average precipitation was 13.79mm.

Result shows summer monsoon precipitation will increase over Kathmandu. By the end of the twenty-first century, pre-monsoon, monsoon, post-monsoon, precipitation is projected to vary by 35.08%, 72.31 %, 171 % and in winter, rainfall is projected to decreased by 23.86 %. In the near and distant future, winter precipitation is anticipated to decrease. The finding shows, overall changes in the precipitation during monsoon and post monsoon is higher than pre-monsoon and winter season. Drought occurrences may occur in the near future as a result of a precipitation shortfall combined with temperature-induced evapotranspiration in several situations. Note that negative trend of precipitation during winter season leads to droughts and water scarcity in Kathmandu valley. The details of change in pattern during different season is shown in Figure 5.

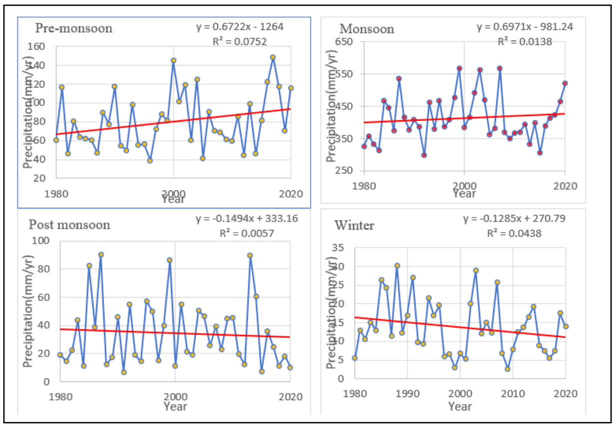

Figure 4: Linear trend and curve of Historical Seasonal Precipitation in Katmandu valley (a) Pre-Monsoon (b) Monsoon (c) post-Monsoon (d) Winter (1980-202

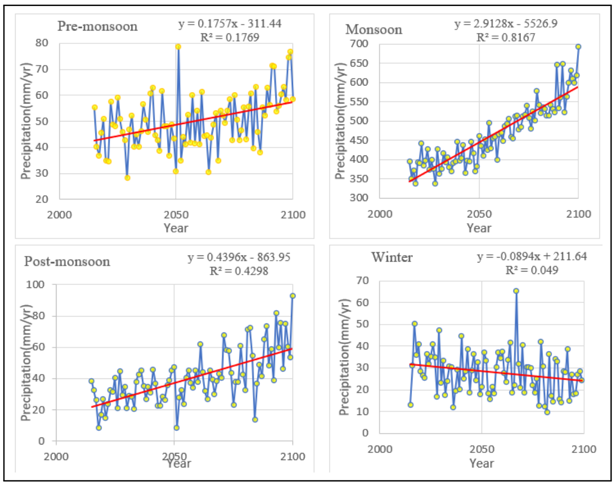

Figure 5: Linear trend of future Seasonal Precipitation in Katmandu valley (b) Monsoon (c) Post Monsoon(d) Winter (2015-2100).

3.1.2 Extreme and Heavy precipitation

The mean value of all the stations for the last forty (1980–2020) was collected and subjected to analyze the temporal change of heavy and extreme precipitation indices in Kathmandu Valley.

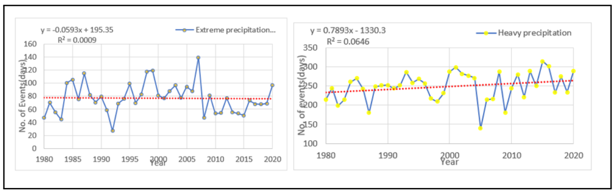

Figure 6: Observed heavy and extreme precipitation between 1980-2020.

Figure 7 shows the expected frequency of total exceptional precipitation events of R10mm (precipitation between 10 and 25 mm/day) and R25mm (precipitation between 25 and 50 mm/day) over Kathmandu for each year. The heavy precipitation events range ranges from 430 to 700 events in each year. The extreme precipitation events range from 44 to 460 events in each year. Comparing the future prediction of rate of change in frequency of extreme precipitation occurrence with the past extreme precipitation occurrence, it is predicted to rise in the rate by 26.69% under the SSP585scenario.

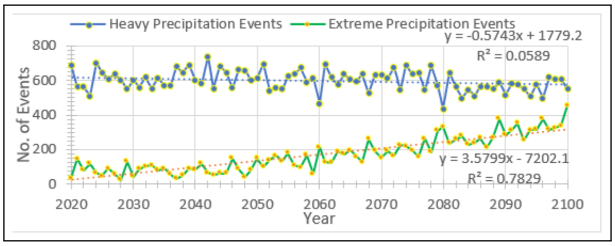

Figure 7: Temporal distribution of future heavy(R10mm) and extreme precipitation (R25mm) events (2015-2100)

Both indices, however, were found to be more intense in the Kathmandu Valley's northern and central regions. The result showed that extreme weather events will become more common during pre-monsoon and monsoon time in future around the majority of the study area. As a result, Kathmandu valley will be suffered frequently by flooding for a long period and it may cause huge economic and environmental losses in surrounding area threatening urban security.

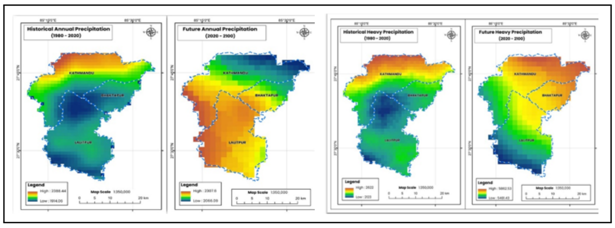

Figure 8: Spatial distribution of heavy precipitation (R10mm) & extreme precipitation (R25mm) events historical (1980-2020) & Future precipitation (2020-2100)

3.1.3 Annual mean Precipitations

Figure 8 illustrates the average precipitation anomaly from past CMIP6 simulations as well as future estimates based on the SSP585 scenario. The average rainfall at the IPCC baseline year 1990 was 2135.10mm while the mean rainfall between 2020 and 2100 for SSP585 scenario is projected to be 2196.14mm. CMIP historical dataset showed high rainfall during 1980-2007 and dryness in following year. Compared to record, CMIP6 historical dataset underestimated the intensity of rainfall. Relative to 2014, it is projected that by 2100 mean rainfall will have increased by 17.7% under SSP585 scenarios. The annual precipitation forecast for Kathmandu predicts a rise in the far future. Similarly, between 2030 and 2049, the average yearly rainfall is anticipated to decrease. There are large discrepancies between the model's early and end-of-century projections due to multiple sources of uncertainty, including (1) intrinsic variability of the climate system, (2) inter-model variability, and (3) variability among alternate emission scenarios. In this study, the inter-model spreads are observed to increase uncertainty from (2) and (3) over time in both scenarios.

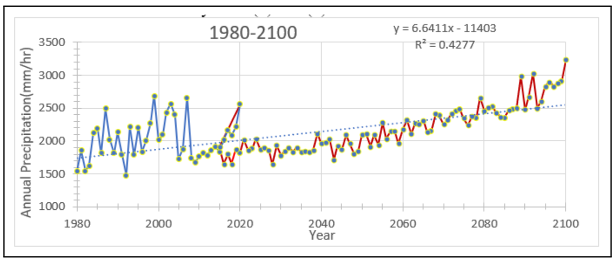

Figure 9: Evolution of future changes in precipitation for Kathmandu Valley during 1980-2100 for SSP585 Scenario

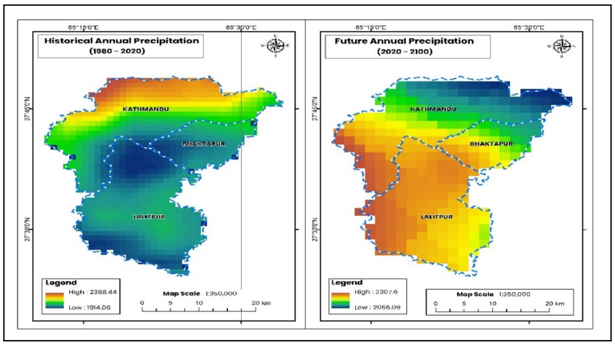

Figure 10: Spatial distribution of annual mean Precipitation climatology over Kathmandu Valley historical (1980-2020) & Future precipitation (2020-2100)

Future predicted annual mean precipitation was found in the range of 2287.86 to 2782.26 mm in the coming years. For the near-future period (2015-2029), the spatial pattern shows an increment in precipitation in the southern part of Kathmandu district and north-east part of Lalitpur and less rainfall in the Northern part of Kathmandu. In the middle future (2040-2069), the change in precipitation is predicted to expand towards the most part Lalitpur district. In the far-future period, the projected annual precipitation shows an increment in most parts of Kathmandu Valley covering the whole area of Lalitpur district and most of the part of the Kathmandu and Bhaktapur district. The spatial pattern of this index revealed that the wettest area is in the northwestern portion of Kathmandu Valley, whilst the driest area is in the southernmost part of Kathmandu Valley.

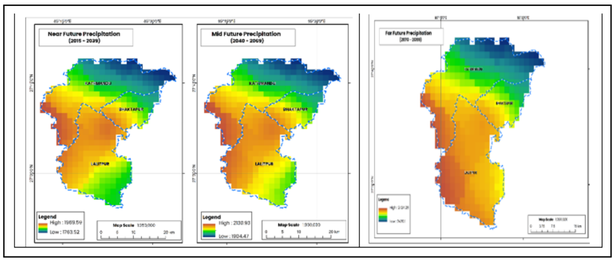

Figure 11: Spatial distribution of annual mean Precipitation climatology over Kathmandu Valley Near Future (2015-2039), Mid Future (2040-2069) & Far Future (2070-2100))

3.1.4 Consecutive Dry Days (CDD) and Consecutive Wet Days (CWD)

The future analysis of both Consecutive Dry Days and Consecutive Wet Days indices demonstrates a similar pattern of variation in these events. They will increase by 1.2 percent in the near future (2015-2049), decrease by 7.6 percent in the medium future (2050-2079), and increase by 12.8 percent in the far future (2080-2100), respectively. A recent study by [26] shows increase in frequency of droughts occurrences under SSP 585scenario. The projected result shows an increase in wet days due to high yearly average precipitation and monsoon rainfall covering most areas of the Kathmandu Valley as shown in figure 12. The CMIP6 model projected higher consecutive dry days during 2029, where dry days are more than 270 days. Similarly, Under the same scenario the year 2072 and 2098 was found extremely wet years. These results show the change in precipitation pattern have significant role on planning of climate resilient urban development.

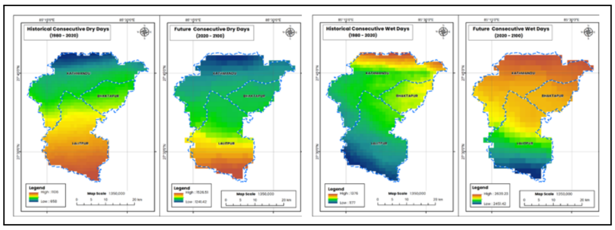

Figure 12: Historical and Projected changes in heavy and extreme spatially distributed Precipitation

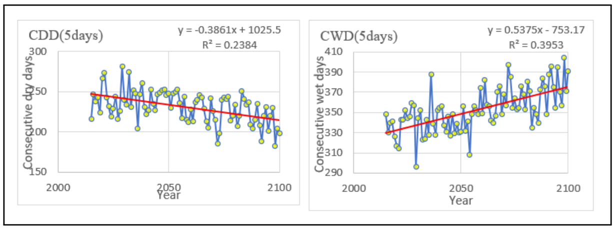

Figure 13: Future projection of temporal distribution of five Consecutive Dry Days (CWD)

3.1.5 Temperature Projection

Figure8 shows the future projected change in temperature pattern for the Kathmandu Valley in stations location based on the CMIP6 methods, from 2015 to 2100, using two SSP 585 Scenario. It is evident that for the future time period there is drastically increase in the temperature. The yearly minimum temperature, mean temperature and maximum average temperature over Kathmandu is estimated to rise by 0.049oC, 0.083oC and 0.064oC under SSP58.5 respectively. It can predict that changes in temperature from the past to the future may be due to the high-sprawl urban areas. In the future anticipated scenario, the impact of urbanization on people is strongly linked to how urban parameters and climate-induced disasters alter.

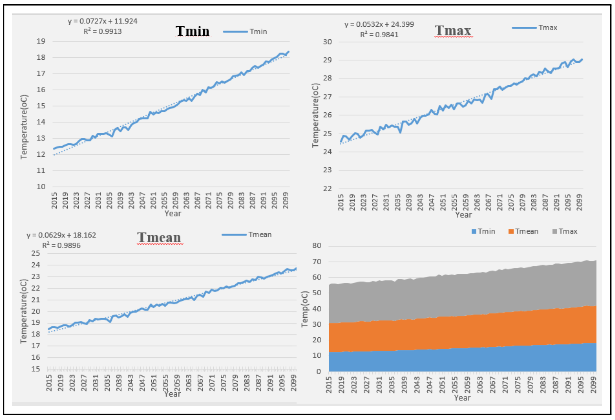

Figure 14: Temporal changes in projected annual temperature (a) Tmin (b) Tmax (c) Tmean (d) combined Projected changes in annual temperature (2015-2100)

In summary, extreme precipitation occurrence will rise in coming year, and the possible precipitation risk in Kathmandu will also increase. Due to the increased occurrence of extreme precipitation and temperature incidents, there is risk in urban development and livelihood in the future, urban construction in Kathmandu faces additional requirements to cope with extreme weather. In this context, there is an urgent need to prepare and implement the resilience planning to reduce risks and losses, to enable the city to better cope with climate change.

3.2 Discussion

Despite the overall lower average values, the result suggests that the influence of combined climate change and local urbanization is very variable at a 1-km resolution. The future urban climate appears to be about a proportional combination of future global climate change and local urbanization influence, which is consistent with earlier research [27]. We used the sixth phase of the CMIP project to evaluate the performance of available global climate models (GCMs) downscaling regional climate models (RCMs) in modeling past climate data with future predictions. The results obtained by our study on projection of climate parameter shows consistent increase change in temperature in near, medium and far future showing similar finding shown by [11]. Since precipitation forecasts are more unpredictable than temperature projections, they can induce unexpected disasters due to extreme rainfall events, with associated fatalities and financial losses as experienced by Rio de Janeiro in past decades [8]. Policymakers should consider the range of possible urban vulnerabilities to floods, landslides, and heat islands using the CMIP6 technique. While this level of uncertainty may make decision-making difficult, an early warning system with a trigger siren at the time of a disaster can protect and reduce the danger in the urban population, preventing economic and financial loss as well as death. Change in weather events will become more frequent in the future as climate change intensifies. Major changes in weather and climate forecasts of daily, weekly, and seasonal trends, as well as extreme occurrences, are already routinely used at global, national, and regional scales. If Kathmandu valley is negatively affected by heavy rainfall and flooding for a long time period, it will not only cause huge economic losses to the city, but will also seriously threatened the urban security [7, 28].

From the predicted results of the extreme precipitation and temperature in Kathmandu valley, it is expected that the intensity extreme weather condition will continue to reach new maximum levels, relying on natural ecological storage and mitigation strategies is difficult to implement and achieve. Urban construction in Kathmandu should take into account the whole process of the natural-social water cycle. Not only can it effectively mitigate the impact of climate disasters but it can also consider ecological protection and achievement through adaptation strategies. The city’s adaptability should be improved by spatial planning and land-use changes that maximize the use of natural resources. Decision-making practices in urban planning and urban system management, in particular, should correspond to widely held good governance principles such as transparency, accountability, and responsiveness [29].

Short- and long-term measures to support vulnerable sectors and communities may be need to adapt the urban economic framework. Low-income households, who typically lack assets or capacity to assist them cope with shocks, may be exposed more to the impacts of climate change on urban livelihood. Climate induced disasters, extreme weather patterns, and environmental degradation may all be mitigated through a green development with green infrastructure businesses [1].

The potential outcomes from the CMIP6 model are widely recommended for policymakers. Future precipitation predictions are more uncertain than those for temperatures. Studies of severe rainfall, such as forecasting consecutive wet and dry days while taking into consideration landslides and floods induced by precipitation, might be important for developing climate change resilience measures in the city [7]. Lower urban planning constraints could enable the BaU scenario, which could raise urban temperatures at a high rate over current levels, particularly in densely populated places like the Kathmandu valley. Heatwaves could significantly increase the population's vulnerability to heat stress and the energy demand for cooling [5]. Nepal has been preparing sectorial strategies to decrease socio-ecological and economic impacts of climate change, as well as mainstreaming climate change resilience planning in development plans since late 1990. The large spread of temperature and precipitation may be associated with complex topography and lack of observation over Nepal. This study agrees with the findings of previous finding of [30] based on CMIP5 models. When the results of the CMIP5 and CMIP6 models are compared, the CMIP6 model predicts higher future precipitation than the CMIP5 model. The difference in precipitation between CMIP6 and CMIP5 simulations is particularly noticeable at the conclusion of the twenty-first century. In general, the CMIP6 models across the South Asia region show stronger climate sensitivity to anthropogenic greenhouse gas emissions than the CMIP5 models.

4. Conclusion

The political interest about minimizing urban climate change risk through adaptation measures, especially in light of recent effort in promoting local climate change sensitivity assessments, such as those created by the CMIP6 model. We can achieve this goal by observing that, because they explicitly bound climatic uncertainties, urban climate predictions using different Global Climate Models or Regional Climate Models are suitable instruments for effective and efficient management of climate change risk in the Kathmandu valley. The findings are reliable enough to be utilized as a scientific evidence base when formulating climate change adaption plans in urban areas. They're also important because they help scientists, governments, non-governmental organizations, and civil society organizations engage in participatory processes. Nonetheless, as climate models improve, study on this topic should be undertaken in order to effectively incorporate climate hazards into urban development planning and to maintain successful urban climate resilience policy formulation. Designing climate adaption techniques that result in sustainable and inclusive communities will be a future issue. GCM or RCM-based urban climate simulations are valuable and effective methods for addressing this problem. The consequences of emission scenarios alone cannot be used to project the future climate of tropical, fast urbanizing cities. To conduct risk assessments, experts must look into the interactions of global climate and regional urbanization. It would also be necessary to have multiple implementations of the same urbanization policies (for example, BaU). Mitigation and adaptation initiatives based on urban planning in the Kathmandu Valley should attempt to fulfill the parameters of the low-emission scenario & Compact, since otherwise, temperature change trends would follow the results of our study. In conclusion, the findings of this research shows that future warming causes the worst effect on urban livelihood and development. In the future studies, climate change projection of urban area of different regions of Nepal can be done. It would be beneficial to investigate the differences between different climate scenario such as SSP1, SSP2, SSP3, SSP4 for impact assessments, the uncertainties associated with their implementation can be also addressed.

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