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Article · December 2022

DOI: 10.12691/aees-10-9-5

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Applied Ecology and Environmental Sciences, 2022, Vol. 10, No. 9, 588-594
Available online at http://pubs.sciepub.com/aees/10/9/5
Published by Science and Education Publishing
DOI:10.12691/aees-10-9-5

Climate Change and Mountain Environment in Context of Sustainable Development Goals in Nepal

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Received August 11, 2022; Revised September 15, 2022; Accepted September 25, 2022

Abstract Climate has significantly changed during last few decades. The mountain environmental change is the visible indicator of climate change. Being, Nepal is a mountainous country, the temperature and precipitation change during last three decades were studied using in-situ meteorological data sets. The Mann-Kendall Test and Sen's slope method were used to find out the changing trend of climate in time series temperature and precipitation data sets in response to different ecological zones. The missing data obtained from stations record were filled using nearest average weighted method in XLSTAT Software. The field survey was conducted in Gorkha (Highland district) and Chitwan (Lowland district) to find out climate change impact on existing environment. The Human foot print pressure on mountain environment was also analyzed using satellite HFP data sets for the period of 1993 and 2009. In the meantime, the nexus between climate change and sustainable development goals were evaluated. The results showed that annual temperature has significantly increased by 0.002°C yr^{-1} but precipitation has decreased by 3.957 mm yr^{-1} in Nepal during 1990-2020. During the same time span, temperature in hills and mountain showed significantly increased with positive but insignificant change in Terai. Similarly, all ecological regions were found negative precipitation trends though it was found insignificant. The field survey in Gorkha and Chitwan as vulnerable districts indicated significant climate change impacts in existing environment. Human foot print pressure was also found increased towards central regions and moving northward in 16-years interval. These changes in temperature and precipitation have affected Sustainable Development Goals (SDGs) i.e. People, Planet, Prosperity, Peace and Partnership related goals in Nepal. This study helps to know the climate change pattern, mountain environment and its nexus with SDGs which is very useful to built up sustainable integrated mountain development framework and environment management in Nepal.

Keywords: *climate change, mountain environment, sustainable development goals, human foot print, Nepal*

Cite This Article: Jaya Ram Karki, Prabhat Kumar, and Binod Baniya, "Climate Change and Mountain Environment in Context of Sustainable Development Goals in Nepal." *Applied Ecology and Environmental Sciences*, vol. 10, no. 9 (2022): 588-594. doi: 10.12691/aees-10-9-5.

1. Introduction

The climate is the contemporary issues in the mountain environment. The mountains are the live museum and visible indicator of climate change. In 20th century, the climate showed unprecedented warming by increasing anthropogenic greenhouse gases [1]. The average temperature has been increased and projected to increase more in 21st century [2]. The water originated from mountainous regions due to glacier melt and variation of temperature and precipitation are highly vulnerable to environment which may later cause the fluctuation in stream flow causing either floods or droughts [3]. The snow transitions to glacier ice causing drastic shifts in overall runoff although the continued shrinking would increase the seasonality of runoff impacting irrigation and hydropower and alter the hazards [4]. Nepal is a mountainous country having similar mountain specification and development constraints. Nepal has very diverse climatic condition, ranging from tropical in the south to alpine in the north. So, temperature varies with topographic variation and decreased from South to North. Nepal produces 3.04 million tons of Carbon dioxide per year. It is 0.0126% CO_2 emission shared globally [5]. Nepal is responsible for only about 0.025% of the total greenhouse emission of the world. Though, It has low global shared, the emission rate is higher in comparison to before. The country rank of Nepal is 138th position in term of Carbon dioxide emission [6].

Climate has remarkably changed in the history of earth evolution. Human activities are more responsible to alter the composition of the global atmosphere over long period of time [7]. Climate change risk Atlas in 2010 ranked Nepal as one of the 4th most vulnerable country in the world indicating the extreme level of vulnerabilities [8]. Nepal's temperature has increased by 0.06°C [9] during 1977-1994, 0.04°C in 1975-2007 [10] and 0.03°C yr^{-1} from 1982 to 2015 [11]. Precipitation presents temporal

and spatial variations in Nepal [12]. There were spatial and temporal variations in the precipitation and drought development patterns in Nepal. The summer monsoon dominates total precipitation while the winter precipitation contributes only 3% of total annual precipitation [13]. Nepal possesses a diverse climate ranging from tropical in the South to alpine in the North. Almost, 80% of precipitation occurs during monsoon season mainly on June, July and August. There was no significant trends of precipitation in Nepal [14]. The observed trend is very uncertain and the inter-annual variation of monsoon precipitation is large. In Nepal, the impacts are more serious which has been directly related to the major livelihoods base of common people [15]. The major vulnerable sectors of climate change impacts are agriculture, food security, forest and biodiversity, water resource, energy, public health, urban settlements and infrastructures [15]. In Nepal, climate change is not just an environmental phenomenon but also economic, social and political issues. The vulnerability projection shows Nepal is under significant vulnerability category for static adaptation capacity [16]. The groups who are already discriminated and marginalized are experiencing the worst increase in vulnerability [17].

Previous studies were focused to find the trends of climate changes and sectoral impacts using limited number of stations. Here, we have investigated trends of temperature and precipitation patterns until 2020 using large number of stations data in response to ecological zones. At the same time, impact of climate change, Human Foot Print Pressure on natural system and its nexus with SDGs in Nepal were identified which is directly related to the sustainable integrated mountain development. This study helps to explore the climate change phenomenon and the mountain environment and it's interlinked with sustainable development goals (SDGs). The climate change is possible to influence the livelihood of 20% people living in Himalayan region [18]. Despite the marvelous assets of Himalayas, there have been only few facts explored about the actual change in temperature and rainfall as critical climatic components. The climate change phenomenon has strong influence that can impair 16 SDGs whereas on copping up with climate change, it can substitute all 17 SDGs. So it needs collaboration with integrated approach to achieve SDGs. Hence the climate change domain and sustainable development governance have to be synchronized for its achievement [19]. The SDG 15, emphasized on conservation, restoration and sustainable use of mountain ecosystem and its services. It targets to achieve 70% of the mountain ecosystem to be covered by protected areas [20]. The ongoing trend of climate change, weather and climate extremes; biodiversity and land ecosystem are being vulnerable in different extents. The developing countries suffer from strong impact of climate change as people are most vulnerable and have least adaptive capacity. The cultivable land has been diminished in upper Mustang region of Nepal by combined effect of temperature rise and snowfall decline [21].

In this context, our study analyzed the trend of climate change pattern in three different ecological zones i.e. Terai, Hills and Mountain regions of Nepal. This study is carried to explore and identify the nexus of climate change and sustainable development goals in Nepal. The SDGs has been prioritized to be achieved by all nations by 2030. The Agenda 2030 is the common understanding approach among nations. The changing climate made uncertain to achieve SDGs target by 2030. Therefore, identifying climate change, human pressure on natural system and impact of climate change in mountain environment in attaining SDGs is considered as one of the most important issue in Nepal. This study helps to identify and explore climate change in mountain environment (Terai, Hills and Mountain). Thus, mountain environment (Terai, Hills and Mountain) and climate change phenomenon i.e. physical environmental dynamics has to be taken into consideration for integration of climate change aspects to attain SDGs in this study.

2. Study Area and Data

Nepal is located between 26°22' and 30°27'N latitude and 80°04' and 88°12'E longitude in the central part of the Himalayan region surrounded by India in the West, South and East and China in North. The total area of the country is 1, 47,181 km^2 with 800 km average length from West to East and 200 km average width from North to South. According to the Topographic survey department of Nepal, the country has plain areas in the South, hills and valleys in the middle and lofty Himalaya in the North. Nepal consists of five major physiographic zones i.e. high mountains, middle mountains, hills, Siwaliks and Terai and under three broad categories of ecological zones i.e. Terai, Hill and Mountains.

The study covers entire Nepal. However, field observation was conducted in two climate vulnerable districts i.e. Gorkha (Highlands) and Chitwan (Lowlands). These climates vulnerable two districts lie in central Nepal covering all three Mountains; Siwaliks, Mahabharat Range and Himalaya Regions of Nepal which are considered as highly vulnerable as per Vulnerability Ranking of Nepal [15].

2.1. Data Sets Used

The monthly precipitation and temperature data during 1990-2020 was collected from meteorological stations obtained from Department of Hydrology and meteorology, Nepal. The climate change impacts were summarized from the information obtained from field visit in two vulnerable districts. The HFP data at a spatial resolution of 1km produced by satellite images were used for the year 1993 and 2009 [22]. The human pressure is measured using eight variables including built-up environments, population density, electric power infrastructure, crop lands, pasture lands, roads, railways, and navigable waterways. Similarly, National Climate Change Impact Survey (NCCIS) 2016 linked with indicators related to climate change and its impact was used. The survey enumerated 5,060 households from entire the country. The local unit, ecological data and other accessory layer data of Nepal were collected from Department of Survey, Government of Nepal.

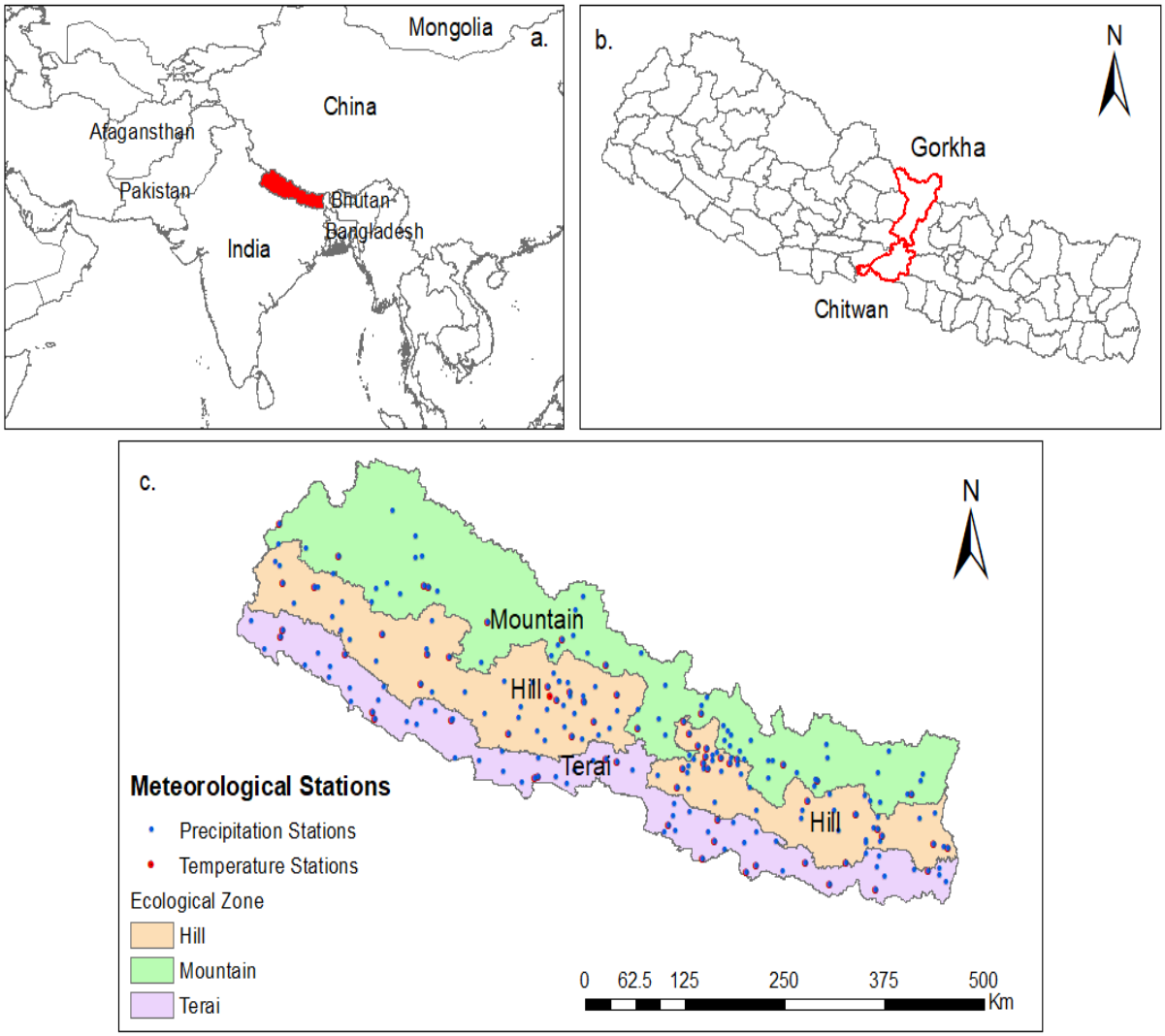

Figure 1. Study area map; a. location map of Nepal in world map; b. Two vulnerable districts (field observed sites) and c. Ecological zones and meteorological stations (Temperature: red color dots (66) and Precipitation: blue color dots (228) used for this study

3. Methods

The annual trends was calculated using Sen's slope method. The Mann-Kendall test was also used for significant test analysis. This method was applied for temperature and precipitation for different time periods in XLSTAT statistical software. National Climate Change Impact Survey 2016 data and field observation were used to find the climate change and its impact on environment.1 km gridded Human footprint pressure map in natural system in Nepal was developed in GIS software using global HFP data sets and analyzed accordingly. The values of global human footprint pressure ranges from 0 to 46 in which high values corresponds with the high level of human pressure and vice versa [22]. Finding climate change, its impacts and human pressure were linked with 17 agendas of SDGs based on Nepalese context.

3.1. Mann-Kendall Test and Sen's Slope

The Mann-Kendall (MK) test is a nonparametric test which has been widely used for the analysis of trends in climatology and hydrological time series. This test is simple, robust and can cope with missing values. Therefore, the Mann-Kendall test [23,24,25] was used to evaluate the statistical significance of the trends. The null hypothesis will be tested at 95% confidence level. The univariate MK statistics for a time series (Z_k, k = 1,2,……,n) of data is defined as:

Where, Z_i and Z_j are the annual climate values in the year i and j respectively, i>j

$$S = \sum_{j<1}^{n} \operatorname{sgn}\left(Z_i - Z_j\right) \quad (1)$$

Where, Z_i and Z_j are the annual climate values in the year i and j respectively, i>j

$$\operatorname{sgn}\left(Zi - Zj\right) = \begin{cases} 1, & if \quad Zi - Zj > 1 \\ 0, & if \quad Zi - Zj = 0 \\ -1, & if \quad Zi - Zj < 0 \end{cases} \quad (2)$$

The null hypothesis (H_o) is that there is no trend in the series whereas alternative hypothesis (H_1) is that an increasing or decreasing monotonic trend exists in the series. The presence of a statistically significant trend was judged based on the *p* value. H_o (no trend) is rejected if the *p* value is less than a predefined significance level of 0.05. The slope of a trend is estimated by Sen's slope i.e.

non-parametric index [26], which is based on the assumption of a linear trend as follows

$$Sen's\ slope = Median\left\{\left(x_i - x_j\right)/\left(i - j\right)\right\}, i > j \quad (3)$$

Where, x_i and x_j are the changing climate values at the time i and j, respectively. An annual slope of trend is computed as an average change; negative value indicates negative trend and positive value indicate positive trend. In addition, Kendall's tau statistic obtained from Mann Kendall test measures the strength of relationship between two variables. The values ranges from -1 to +1 with a positive tau indicates that as the rank of both variables increase together whilst a negative tau indicates that as the rank of one variable increase and other decreases.

4. Results and Discussion

4.1. Climate Change and Its Impact on Environment

The average annual temperature was found 20.23°C (Max 26.004°C and Min 14.45°C) and average annual precipitation was found 1784.92mm during 1990-2020 in Nepal. The result showed that temperature has increased but precipitation has decreased in Nepal and all three ecological regions except precipitation showed positive trends in mountain (Table 1). The temperature has significantly increased in Nepal with 0.08°C yr^{-1} increased in Mountain and 0.02°C yr^{-1} increased in hills. The precipitation has decreased by 3.95 $mmyr^{-1}$ in Nepal with higher negative trends in hills i.e. 6.527 $mmyr^{-1}$. However, the negative precipitation trends are insignificant. The detail MK test results and Sen Slope are given in following (Table 1).

The positive temperature trends (Kendall's tau-0.46) are significant but negative precipitation trends (Kendall's tau- -0.11) showed insignificant in Nepal during last three decades. The average temperature was found higher in Terai i.e. 24.67 °C followed by hills with 19.18°C and mountain by 15.56°C. Similarly, the average precipitation pattern was found higher i.e. 1866.38mm in hills followed by Terai (1747.39mm) and lower average annual rainfall i.e.1659.79mm was found in the mountain. All of the previous studies conducted on climate change based on station, remote sensing gridded and survey data showed increased temperature but precipitation was found erratic with no specific trend [9,27,28]. Study covered maximum temperature of 49 stations which revealed warming trends of 0.06 to 0.12°C in most of the middle mountains and Himalayan regions with Siwalik and Terai trends warmed less than 0.03°C. Our study showed higher warming trend in Mountain with average annual increasing trends of 0.08°C yr^{-1}. Spatially, the trend was found different in Panipokhari, the core part of Kathmandu city of Nepal with trends of 0.04°C yr^{-1} to 0.1°C yr^{-1}.

The climate change impact household survey conducted in vulnerable community/village of Gorkha and Chitwan districts showed that average temperature in the last 30 years was in increasing trend indicated by emergence of invasive species of insects/worms, water sources dry up while in winter it was very cold but with decreasing trend of fog and frost. The average precipitation was observed in decreasing trend. The wet lands and paddy farms have been converted into dry lands. The use of pesticides and insecticides was in increasing trend. The cattle rearing was shifted into goat, pig, and fowl keeping due to less water and less agro productions. Several diseases in livestock have been observed. There used to be water running in taps but now there was meter system in tap. The invasive worms have been destroying, maize, banana and fodders. The local seeds/crops were common before and now, they have been displaced by hybrid seeds with climate resistant breeds. At the same time, climate induced disasters like heavy rainfall, floods, landslides, drought, dry up, growing season of vegetation/agricultural crops and disease severity have been increasing with response to changing climatic trend. Similar kinds of climate change impacts were observed by National Climate Change Impact Survey of CBS which had enumerated 5,060 households from 253 PSUs from all 16 analytical domains of the country [29] and Himalayan regions [30].

4.2. Human Foot Print Pressure on Natural System

Human footprint on land surface in Nepal is changing spatially and temporally. Human foot print pressure in Nepal was retrieved using globally standardized measure of the cumulative human footprint on the terrestrial environment at 1 km^2 resolution from 1993 to 2009. The values of global human footprint pressure ranges from 0 to 46 in which high values corresponds to the high level of human pressure and vice versa [22]. Spatially, the footprint pressure was found increased towards western and central regions indicates the exerting pressures on natural system. Over the past one and half decade, the human footprint pressure has significantly increased in Nepal. The maximum footprints have reached to 43 mainly in the large cities such as Kathmandu, Pokhara and southern plain region. The footprints as low as 0-6 was found in the western mountain regions. On temporal pattern, the human footprint pressure was higher in 2009 compared to 1993 (Figure 3).

Table 1. Average Annual Temperature and Precipitation Change Based on MK Test, During 1990-2020 in Different Ecological Regions of Nepal

Ecological Regions	Temperature (°C yr^{-1})			Precipitation (mm yr^{-1})		
	Sen's slope	*P* value	Significant Test	Sen's slope	*P* value	Significant Test
Terai	0.004	0.617	Insignificant	-2.368	0.643	Insignificant
Hills	0.020	0.015	Significant	-6.521	0.254	Insignificant
Mountain	0.082	0.0001	Significant	2.088	0.568	Insignificant
Nepal	0.024	0.00033	Significant	-3.957	0.392	Insignificant

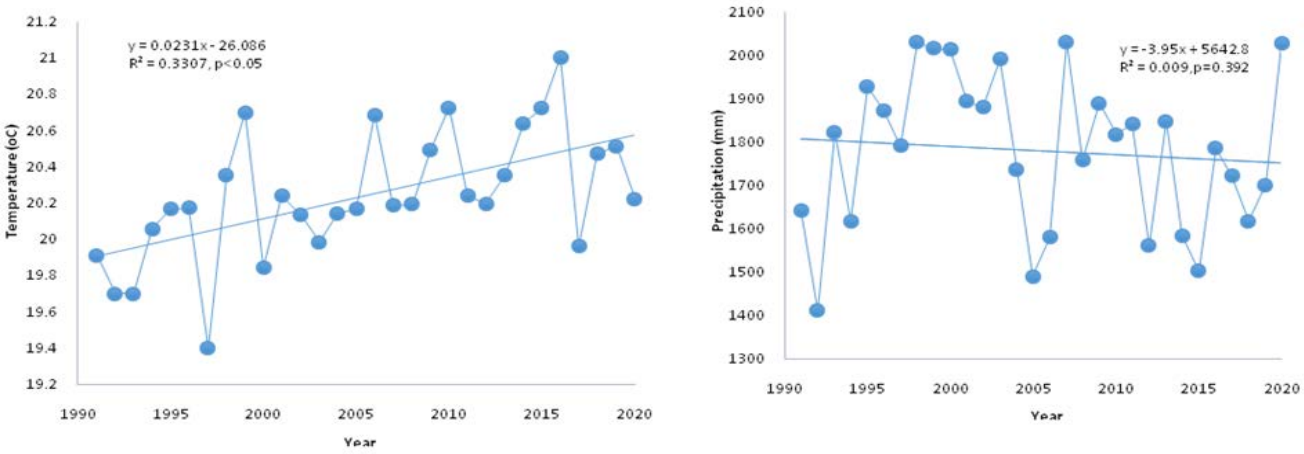

Figure 2. Sen's slope and MK test (*p* value/trends) of Temperature from 66 stations (a) and precipitation from 228 meteorological stations (b) during 1990- 2020 in Nepal

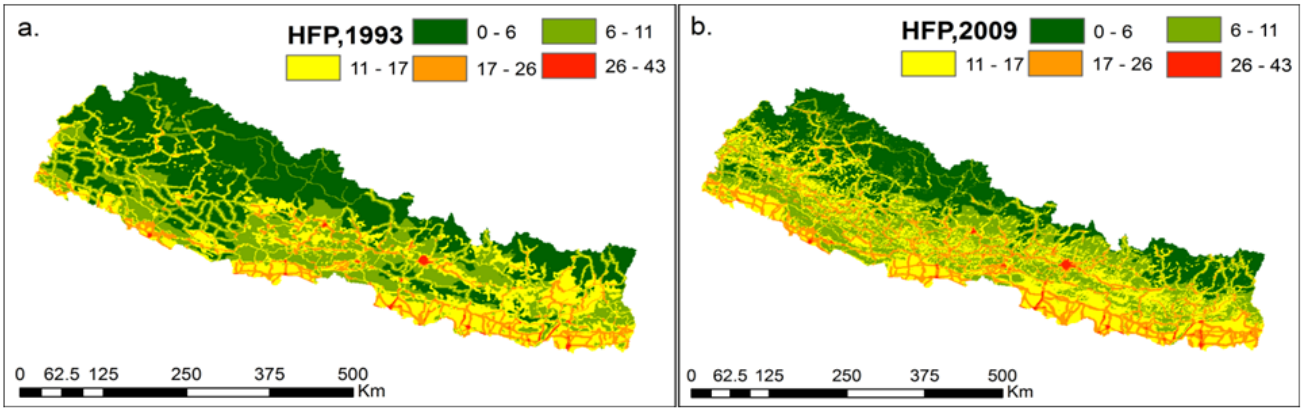

Figure 3. 1 km gridded Human footprint pressure in natural system in Nepal; a. Human footprint pressure, 1993; b. Human footprint pressure, 2009 in Nepal

The increased human footprint pressure also corresponded to the population growth rate. In which, the total population in Nepal was 26,494,504 with annual growth rate of 1.35%, while the average and maximum population density was 260 and 15355 people/km^2, respectively [31]. According to the Census Report 2021, the population of Nepal has reached 29,192,480, which is an increase of 2,697,976 compared to a population of 26,494,504 ten years ago in 2011 [32]. The HFP of Nepal was retrieved from global gridded data sets which was developed using following pressure components which are 1) extent of built environments; (2) crop land; (3) pasture land; (4) human population density; (5) night-time lights; (6) railways; (7) roads; and (8) navigable waterways. These pressures were weighted according to estimates of their relative levels of human pressure following Sanderson et al. 2002, and then summed together to create the standardized human footprint for all non-Antarctic land areas. Moreover, human pressure in Nepal is perversely intense, widespread and rapidly intensifying in places with high biodiversity, forest, wetlands, natural/cultural hotspot and ecosystem rich areas**.**

4.3. Nexus between Climate, HFP and SDGs in Nepal

Nepal has made commendable efforts for the implementation of the SDGs since its adoption. However, different climatic events and large human pressure has made beyond its control. Nepal proposes to reduce extreme poverty to less than five percent and raise per capita income to US$ 2,500 in 2030 from US$ 766 in 2015 [33]. At the same time, reduce hunger, food security and improved nutrition goals will have negatively suffered from climate change phenomena. Good health, clean water and sanitation are another goals adopted in Nepal which are very challenging during negative footprint and climatic extremes. Climate change may have both positive and negative nexuses with SDGs for example, increased temperature encourage people to adopt clean and renewable energy, low carbon emission industry and green infrastructures. Economic growth of Nepal was also affected by pandemic, high amount consumption of natural resources, high investment on climate induced disaster control and mitigation may hamper national GDP and economic growth, so that it could not get achieved 2030 target of economic growth. Climate change and increased human foot print pressure have closely related on goal 11 (Sustainable cities and communities), goal 13 (climate action), goal 14 (life below water) and goal 15 (life on land). High temperature increased urban heat stress and low precipitation increased drought and water scarcity in cities. Climate action on mitigation and adaptation should get high priority and investment on this fluctuated scenario. Negative impacts of climate change and human foot print pressure are found on ecosystem

changes, so that life on land and water are severely affected. The possible negative and positive effects on SDGs in Nepal are listed (Table 2). Climate change and human pressure on natural systems also bring opportunities to promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels in national and international groups and nations (SDG 16). At the same time, climate change issues help to strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development. Thus, climate change problem and excessive exploitation of natural resources effects on SDGs aim i.e. to end poverty, protect the planet and ensure peace and prosperity by 2030, on balancing the three dimension of sustainable development i.e. the social, economic and environment.

Table 2. Nexus Between Temperature, Precipitation and Human Pressure on SDGs in Nepal

S. N.	Agenda/SDGs	Impacts of Climate and Human Pressure change on SDGs in Nepal		
		Increased Temp (°C)	Decreased Ppt (mm)	Increased HFP
1	No poverty	Negative	Negative	Negative
2	Zero hunger	Negative	Negative	Negative
3	Good health and well being	Negative	Negative	Negative
4	Quality education	Not relevant	Not relevant	Not relevant
5	Gender equality	Not relevant	Not relevant	Not relevant
6	Clean water and sanitation	Negative	Negative	Negative
7	Affordable and clean energy	Positive	Negative	Positive
8	Decent work and economic growth	Negative	Negative	Negative
9	Industry, innovation and infrastructure	Positive	Positive	Negative
10	Reduce inequalities	Not relevant	Not relevant	Not relevant
11	Sustainable cities and communities	Negative	Negative	Negative
12	Responsive consumption and production	Not relevant	Not relevant	Negative
13	Climate action	Negative	Negative	Negative
14	Life below water	Negative	Negative	Negative
15	Life on Land	Negative	Negative	Negative
16	Peace, Justice and Strong Institution	Positive	Positive	Positive
17	Partnership for the goals	Positive	Positive	Positive

5. Conclusion

This study has investigated temperature and precipitation changes during last 30 years in Nepal and all ecological regions. Identifying how human foot print pressure has increased to natural system in Nepal is also the part of this research. These climatic factors and changes in human pressure has close nexus with SDGs, adopted by Nepal which has been evaluated in this study. The temperature was found increased by 0.02°C yr^{-1} in Nepal including 0.004 °C yr^{-1}, 0.020 °C yr^{-1} and 0.08°Cyr^{-1} in Terai, Hills and Mountain regions respectively. In the contrary, precipitation was found decreased. Human foot print pressure also has increased in 2009 with maximum value reaching 43, in the major cities in compared to 1993. This increased human pressure has been supported by increased population density in Nepal. The environmental changes in mountainous country like Nepal has mainly negative influences and pose challenges to attain SDGs except some positive effects on encouraging strong institution, partnership, uses of clean energy and green infrastructure development. This study helps to know the climate and human pressure change in mountain environment and its chain of connection with SDGs adopted by Nepal. The finding could be useful for decision makers and new researchers for further study in climate change and SDGs in Nepal.

Acknowledgements

The authors would like to thanks Department of Hydrology and Meteorology, Nepal for temperature and precipitation data. We are thankful to Singhania University. We acknowledge NASA team for making available HFP gridded data for Nepal.

Declaration of Authors

The authors declare no competing interests.

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