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ARTICLE

A Short Note on Linkage of Climatic Records between Terai and Mid-mountain of Central Nepal

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ABSTRACT

The steep North to South (N-S) gradient and complex topography marks significant variations in the spatial and temporal patterns of climatic variation surrounding within a few distances in the Nepal Himalayas. Hence, to validate climatic linkages between the stations under two distinct topographic conditions, the study examines the observational climatic data from 106m a.s.l. and 1801m a.s.l., as a representative station from a plain and hilly area. Different statistical tools including Pearson correlation analysis and a best-fit regression model were applied to analyze climate data. The analysis of 13129 daily average temperature records and 13147 daily total precipitation records showed that the variation in their sum and average of daily, five days, ten days, and monthly values between the stations in the different elevations marked significantly.Despite these variations, temperature records are measured to be consistent in different altitudes and strongly correlated. The precipitation data showed a comparatively weaker correlation. The coefficients (0.85-1.6) with $R^2>0.50$ in the regression models for the lower elevation and higher elevation station in the mid-mountain region except for the monsoon season. It indicated a similar fluctuation of temperature between these two stations in the respective area. The strong degree of association and the change of climatic parameters in different range and elevations indicate the possibilities of using climatic data from Terai to represent the Mid-mountain region of central Nepal.

1. Introduction

Nepal's steeply geographical variation results in the changing of climatic characteristics like; temperature and precipitation have heavily depended upon seasons. The steep North to South (N-S) gradient and complex topography marks higher variations in the spatial and temporal patterns of climatic variation surrounding a few distances in the Nepal Hi-

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malayas. Consequently, within a span of less than 200 km, the country encounters almost all climates ranging from subtropical to polar and arid environments [1]. The observed contrasting features of climate within a short distance create a microclimate variation that also enhances vegetation variation within the short distance. Therefore, to understand the climate of the complex terrain of Nepal Himalayas, more climatic stations with advanced measurement devices are always desirable. The weather records from high-altitude regions in the central Himalayas are inadequate due to logistical difficulties in inaccessible terrains [2-4]. Understanding the mountain region's climatic characteristics is complicated due to a lack of observational data in spatial and temporal resolution. Furthermore, covering the mountain region's complex terrain by current general circulation climate models (GCMs) is not enough as expected, which hinders our understanding of the climate of complex terrain [5].

Many studies suggest that the mountainous region displayed a more significant and higher warming rate than the global mean air temperature [6-9]. Observational study using long-term observational data of surface air temperature over Nepal showed that the warming trend is more rapid at higher elevations than in the lower elevation region [6,10-14]. While precipitation possesses distinct features; most of the studies found an increase in rainfall with increasing altitude up to a specific elevation and begin to decrease with increasing height [15-21]. Therefore, the Middle Mountain and some high mountain areas receive maximum precipitation with the east-west contrasting pattern [16,19,22-25]. Satellite-based precipitation studies also showed the heterogeneous nature of precipitation over Nepal [20,26,27].

Despite these studies on temperature and precipitation trends, whether it is possible to use the climate data from the rich network site at lower elevation can useful to quantitatively the climate at the poor network site of a high hill or not is a subject out of scientific focus. Very few studies focus on this approach [28,29]. This assessment of the climatic linkage between the stations in the different physiographic region provides the basis for developing a best-fit regression model. This study could also be beneficial for the calibration purpose of paleoclimate studies. This paper aims to determine/quantify the linkages of climatic records along an altitudinal gradient between the stations at Taulihawa (106m a.s.l.) and Khanchikot (1801m a.s.l.). We set up our hypothesis that temporal variations in temperature between the stations have good homogeneity, while precipitation displays substantial spatial heterogeneity.

2. Material and Methods

2.1 The Study Area and Climatology

The study selects the station in the lowland area known asTerai (60-300m a.s.l.) and highland in the hilly region, also called the Middle Mountain (Mid-mountain1, 500-2,700m) as shown in Figure 1 based on the criteria: (1) representative of the different physiographical region of Nepal (2) greater than 1500 m in an altitudinal difference between the stations and (3) Daily meteorological data available for more than three and a half decades.

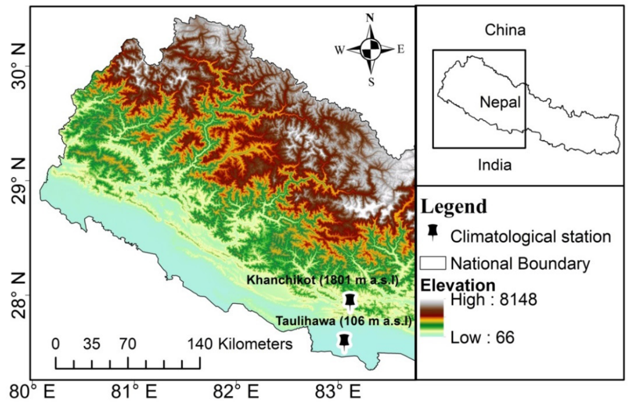

Figure 1. Location of climatological stations under study

Seasonal variation is one of the influencing factors of the climate of Nepal; hence this study is one of the alternative options to set a remarkable benchmark. The season of Nepal is divided into four groups based on the temperature and precipitation; (1) winter, (2) pre-monsoon, (3) monsoon, and (4) post-monsoon. The previous year's December, January, and February of the current year fall in the winter season, March to May in pre-monsoon, Jun to September in monsoon, and October, November in post monsoon season, respectively. Monthly variations of temperature and precipitation based on the long-term averages showed that June is the month with the highest temperature, and January is the coldest month for both stations. In the same way, July and November are the months with the highest and lowest precipitation. Lower elevation station receives 87.5% of the total rainfall (1482mm) only during the summer season. In contrast, the Middle Mountain station receives 81% of the total precipitation (1810mm) in the same season. The mid-mountain station receives a higher percentage of rainfall (10%) in the pre-monsoon season than the Terai region (6.5%). The climatology of Taulihawa (27.571°N, 83.067°E, 106m a.s.l.) and Kanchikot (27.922°N, 83.129°E, 1801m a.s.l.) is shown in Figure 2.

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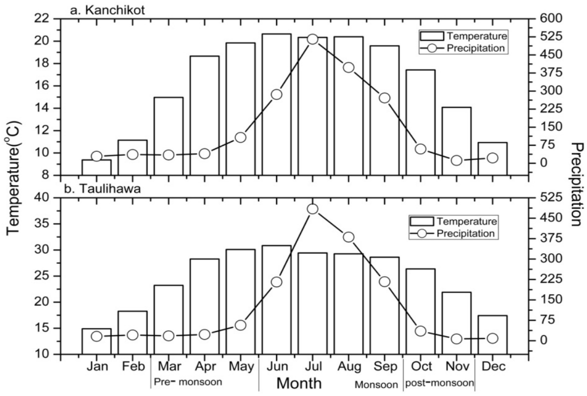

Figure 2. Monthly climatology of (a) Khanchikot station and (b) Taulihawa station

2.2 Data and Methodology

The climate data for Taulihawa and Khanchikot from January 1980 to December 2016 was collected from the Department of Hydrology and Meteorology (DHM), Government of Nepal. Altogether, 13129 daily temperature and 13147 precipitation records were used for the study analysis. In these data, daily, five days, ten days, and monthly looped climatic records were analyzed to measure mean temperature and sum of precipitation for a lower and higher altitude station, and these were compared to each other for 36 years. The parameters like mean and standard deviation were observed by the time series analysis and were checked by t-statistics (paired sample t-tests) and/or two-sample Kolmogorov-Smirnov tests. Moreover, Pearson's correlation was used to measure the degree of association among the temperature and precipitation records.

Similarly,the line of best fit to quantify the associations of climatic records between low and high elevation were done via regression model. It measures the trend of the association based on daily mean temperature and daily precipitation according to months. The Intercept, slope, and R^2−values are used to assess the physical parameters and quality of the regression models, as shown by [28,29]. The study used a regression model based on five days, ten days, and monthly mean temperature and total precipitation to confirm the daily data pattern. To catch the discrepancy and understand the magnitude of seasonal co-variation, the study pooled data from the 5-day mean, sum of temperature, and precipitation for the individual season.

3. Result and Discussion

3.1 Difference between Climate Records at Lower and Higher Altitude Station

Both the temperature and precipitation records at the higher and lower elevations stations show quite different interms of means and normality of data distribution. Based on the paired t-test, the daily and their looped for five days, ten days, and a monthly average of temperature and sum of precipitation for the study period are significantly different between Taulihawa and Khanchikot. Kolmogorov-Smirnov two-sample test (K-S test) of all the temperature data sets also shows a significant difference in their continuous distribution.

Figure 3 (a) and (b) show the monthly differences of precipitation and temperature between two stations at a distinct elevation range. The peak differences of rainfall are found during the early and late summer. The annual mean temperature at Khanchikot was recorded 8.4± 0.64℃ lower than at the lower elevation due to the elevation-dependent temperature [10,29]. These results clearly show that the high elevation region received more precipitation than the lowland region throughout the 36 years of duration. This result demonstrated that the annual rainfall increased with altitude for elevations below 2000m, and results are more consistent with most of the earlier studies [15-19,21,30]. Annual and monsoon season (June-September) precipitation at Khanchikot was 328.8±368mm and 174±321.4mm higher than on Taulihawa. Comparing the daily mean temperature by months (Figure 2) shows that the temperature at a higher elevation is 5.4°C to 10.3°C lower than the station in lower elevation. The differences

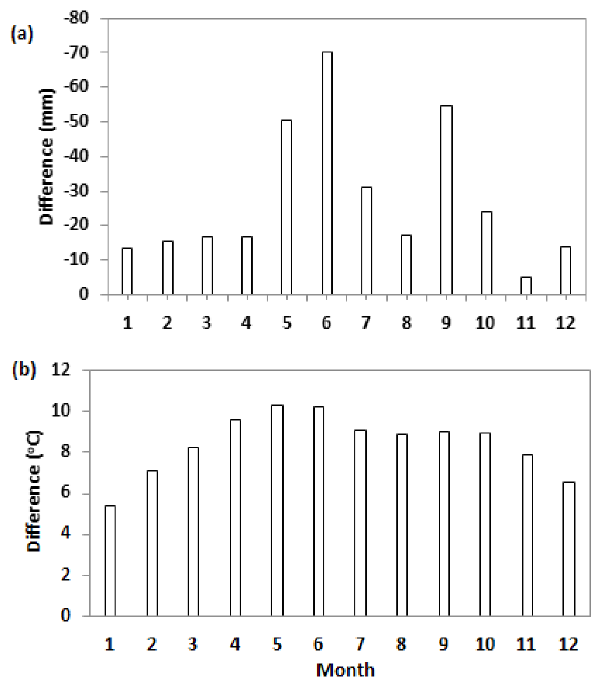

Figure 3. Mean monthly differences between Khanchikot (high elevation) and low elevation station Taulihawa daily precipitation (a) and daily mean temperatures (b)

are higher from April through October (≥9°C) with smaller during winter months. While Analyzing the temperature trends between those two climatic stations, a higher increasing trend (0.039°C/year) was found at a high elevation mountain station than that at a low elevation station (0.0006 °C/year). Generally, cloud cover, water vapor (atmospheric moisture), other aerosols, and soil moisture could be the potential drivers of this elevation-dependent warming [6-9].

3.2 Association of Temperature and Precipitation Records between the Highland Station and Lowland Station

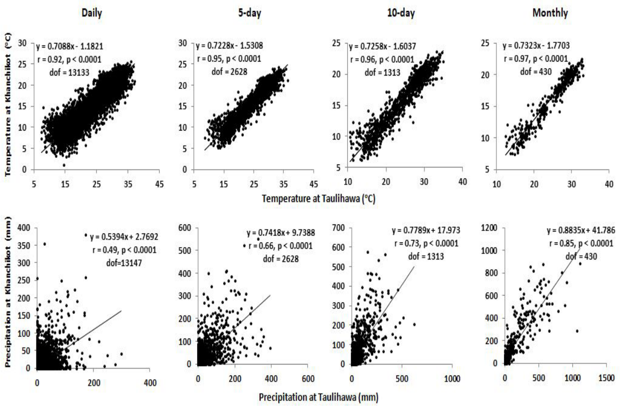

Figure 4. A scatter plot for the daily, 5-day, 10-day, and the monthly sum of precipitation and mean temperature at the Khanchikot and Taulihawa from January 1, 1980, to December 31, 2015.

The coefficient of variation (CV)measured from Table 1 shows that the mean daily temperature records between the Khanchikot and Taulihawa were found to be more consistent with CV less than 30%. The standard deviation (σ) for daily, five days, ten days, and the monthly temperature seems identical. As the length of time interval increases, the standard deviation of precipitation also increases and vice-versa in temperature. The significant correlations of daily, 5-days, 10-days, and monthly temperatures between the Khanchikot and Taulihawa (Table 1, Figure 4) were up to 0.92 for 13129 degrees of freedom (df) of the daily mean temperature series and 0.97 for the monthly means (df = 430). Similarly, for the precipitation, the correlations increased with increasing lengths of the time intervals, from 0.49 for the daily sum to 0.85 for the monthly sum, all were statistically significant for a p-value less than 0.0001 (Figure 3). Increasing the correlation with increasing time-windows for data sum suggested that low values of precipitation in both sites were complicated to model by linear regression [28,29].

Table 1. Standard deviation (σ), coefficient of variation (CV) of temperature and precipitation records on the Taulihawa / at Khanchikot stations with their Pearson correlation coefficients (ρ)for (p-value < 0.001 for all correlations) and the degree of freedom (df) from January 1, 1980, to December 31, 2015

Parameter	σ	CV	ρ/df
	Taulihawa/ Khanchikot	Taulihawa/ Khanchikot	
Daily precipitation	14.94/16.31mm	3.68/3.29	0.49/13147
Daily maximum temperature	5.67/4.31 °C	0.18/0.21	0.83/13133
Daily average temperature	5.74/4.41 °C	0.23/0.27	0.92/13129
Daily minimum temperature	6.64/4.76 °C	0.35/0.38	0.91/13136
5-days precipitation	45.5/50.96mm	2.24/2.06	0.66/2628
5-days maximum temperature	5.47/4.11 °C	0.18/0.2	0.87/2628
5-days average temperature	5.64/4.31 °C	0.23/0.26	0.95/2628
5-days minimum temperature	6.51/4.65 °C	0.35/0.37	0.94/2628
10-days precipitation	76.62/82.35mm	1.89/1.66	0.73/1313
10-days maximum temperature	5.36/4.01 °C	0.17/0.2	0.88/1313
10-days average temperature	5.59/4.24 °C	0.22/0.26	0.96/1313
10-days minimum temperature	6.46/4.59 °C	0.34/0.36	0.95/1313
Monthly precipitation	189.11/196.08mm	1.53/1.3	0.85/430
Monthly maximum temperature	5.12/3.86 °C	0.17/0.19	0.90/430
Monthly average temperature	5.45/4.12 °C	0.22/0.25	0.97/430
Monthly minimum temperature	6.32/4.47 °C	0.34/0.36	0.96/430

3.2.1 Using Taulihawa Low Elevation Climate Station Temperature to Represent the High Elevation (Khanchikot)

Using the elevation difference of 1695 m (1801-106m), the mean lapse rate was calculated as −0.51°C/100m with increasing altitude for all daily values, while those for different time intervals and seasons were slightly different. However, their standard deviation decreased with the increasing lengths of the time intervals, changing from ±0.144 °C/100m for the daily data to ±0.10 °C/ 100m for the monthly means. The mean lapse rate is close to the average temperature lapse rate of −0.54

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°C/100m reported by [6,11,12].

The regression analysis of daily and five-day data pooled is presented in Figure 5 with the intercepts, slopes, and R-square values of the highland station against the lowland. Such results fully supported our hypothesis that the variations of the daily and 5-day looped mean temperatures in the low elevation are excellent representatives for the upper elevation station in Arghakhanchi district. It is clear that from Figures 5c and 5d, the regression parameters possess distinct seasonal characteristics. Each regression parameters have their physical meaning and importance for the climatic information. In the case of the temperature, the intercepts of the regression models may not be very useful, which indicates a hypothetical 'base temperature' at Khanchikot for the corresponding 0°C temperature at the Taulihawa. The most useful parameter of the regression model is the slope. The slope of the model represents the degree of temperature changes at the Khanchikot per °C measured at the lower elevation station at Taulihawa.

During the monsoon season (June-September) observed interesting features of temperature change of high elevation Khanchikot corresponding to the Taulihawa; for every 1°C temperature change on the lowland, the highland temperatures changed only by 0.35 to 0.49°C, it may be caused by the natural dependency of temperature on precipitation. The Middle mountains are the first obstacles for summer monsoon in Nepal that often onsets mid-June [30]. Thus, the onset of monsoon and associated cloudiness in the Middle Mountain and comparatively dry and fair weather in the plain area might be the reasons for the large variation of temperature during the monsoon season (June-September). However, with the end of winter to the pre-monsoon (February-May) and the end of summer monsoon to the post-monsoon (September-November), the model's high slope possessed a strong association of temperature between lower and higher-elevation at Taulihawa and Khanchikot, respectively. After the retreat of monsoon, the post monsoon season begins and after winter, pre monsoon seasons, which are characterized by sunny days, clear sky and gradually decreasing / increasing in temperature throughout the country. Therefore, there is a strong association of temperature between the stations during these seasons. Similar results were obtained in the other similar study [21]. Both the daily and 5-day mean temperatures, the regression parameters have similar patterns with slight variation in magnitudes. These results clearly showed that temperature dependency high elevation increasing with an increase in the time interval.

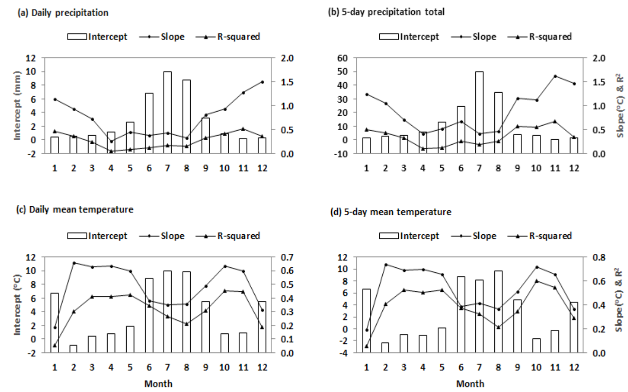

Figure 5. Theregression models by months with the Khanchikot temperature/ precipitation as the dependent variable and the Taulihawa as independent variables. Regression models using the daily (a) and 5-day (b) mean temperature data, and daily (c) and 5-day (d) total precipitation data

3.2.2 Using Taulihawa Low Elevation Climate Station Precipitation to Represent the High Elevation (Khanchikot)

Precipitation of any place depends upon the numerous factors such as topography, prevailing winds, orientation, land distribution patterns, etc. Therefore, it is not easy to use low elevation precipitation data representing high elevation stations in high-resolution temporal records in different elevation gradient of Nepal. The regression model results also satisfy our hypothesis in case of the precipitation records between two different elevation stations. The Figure 4 shows the statistically significant correlation of precipitation records between Taulihawa and Khanchikot. It is clear that the correlation only is improved with the increasing length of the time intervals. Thus, we must be careful when using the low elevation climatic data to represent the upper elevation station.

The intercepts of the regression models for precipitation have actual physical meanings. They represent the amount of rainfall at high elevation Khanchikot station for zero or no rain at Taulihawa. The model output results indicate that the monthly mean precipitation on the Khanchikot is approximately 42mm when there is zero precipitation at Taulihawa.

The regression analysis of the daily and five-day precipitation totals through month-wise grouping is depicted in Figures 5a and 5b. It shows that the intercept values were generally higher from April to September (summer precipitation). The relevancy of rainfall at the high elevation based on the low elevation seems to be increased up to 50mm at Khanchikot for zero or no rain at Taulihawa for 5-day looped total precipitation during July, a significant R^2 value of 0.20. It resembles that the high elevation Khanchikot station received higher frequencies of light rainfall than at the Taulihawa. On the other hand, the slopes were higher than 0.6 from late summer and early pre-monsoon season (September - March) with peak values of about 1.5 during December (Figure 5a). The variation of R^2-values shows that the values sharply declined after the winter months and increased with the late summer monsoon season (September). Throughout the summer months, the R^2 values were much lower. Similar patterns are observed for the 5-day data (Figure 5b). These results are consistent with other similar studies in the region [20].

4. Conclusion

This study used time-series data to examine the association of climatic linkage between the stations in diverse topographic conditions at the Mid-mountain and the Terai region of central Nepal. The daily precipitation and temperature data were analyzed and compared for 36 years from 1980 to 2016. The measure of daily, five days, ten days, and monthly data observed the magnitude of the discrepancy of temperature and precipitation parameters with time and geography. It varied significantly between the stations. Despite the discrepancy, the measure of the variation of temperature and precipitation between the mid-mountain and the Terai region is found to be consistent, and their agreement increases with an increasing time interval (r=0.92, p<0.0001, n=13129 for daily to r=0.97, p<0.0001, n=432, for monthly temperature and r=0.49, p<0.0001 for daily to r=0.85, p<0.0001, n=432 for monthly precipitation). It represents the strong degree of association of temperature between the stations. The regression coefficient near the unity (~1) with R^2 >0.50 indicates a similar change in temperature except in the monsoon season. Due to the heterogeneous topographical features and sharp elevation contrast, the precipitation association was not as strong as in temperatures, supporting our hypothesis. The study found that it is possible to use temperature data of the Terai region to assess the climate at the mid-hill quantitatively. However, corrections are necessary when the absolute values of climate are considered. The diversified geographical features of Nepal provided the unique opportunity to study the climatic linkage along the altitudinal gradient. However, the relation established by considering that a single station should not be over-interpreted. Still, this study represents a further step towards understating the connection between climatic records in different geographic settings. A forthcoming study will extend the data in spatial range over Nepal, enabling the climatic link throughout the physiographic regions of Nepal.

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