E3S Web of Conferences 436, 02011 (2023) https://doi.org/10.1051/e3sconf/202343602011
ICED2023

Use of TEVY index to measure the temperature variability within a year in different climatic zones of Nepal

Bibhuti Ojha[1,*], *Ramesh* Khanal[1], *Theodore* Kalyvas[2], *Nikolaos* Rapsomanikis[2], *Nectaria* Gizani[2], and *Efthimios* Zervas[2]

[1]Nepal Engineering College, Bhaktapur, Nepal
[2] Hellenic Open University, 26332 Patras, Greece

Abstract. TEVY index has been proposed and used to evaluate the temperature variability in 4 stations in Greece. In order to establish the index, more study is necessary; so, this work is aimed to apply TEVY index across 9 stations in Nepal. Daily mean temperature is calculated for each station from the historical data of up to 44 years. Fourier Harmonic analysis is carried out to estimate the daily temperature. Then TEVY index is calculated as the squared of the difference between observed temperature and Fourier series estimated temperature. Correlation analysis carried out to check the level of fit between observed and estimated temperature values. The TEVY index shows the higher variability of temperature in hot climatic zone followed by mild climatic zone and cool climatic zone. Monthly TEVY value shows the higher variation in temperature, that coincides with the precipitation cycle of Nepal, but this statement requires more study to check its validity.

1 Introduction

Climate change is one of the major environmental problems that has preoccupied the scientific community in recent decades [1]. However, many people still disagree about climate change and the need for green technologies [2]. Therefore, it is important to focus on climate change estimation and calculation.

Analysis of meteorological time series data helps to establish precise climate change trend by giving an insight on duration and frequency of weather events [3]. Understanding climatic parameters is a key to understand climate induced disasters. A number of studies has confirmed the climate change in the form of temperature, rainfall patterns, frequency of extreme events, which are also validated through the 27 core climate change indices offered by ETCCDI, that are widely used for weather variability and climate change analysis [3].

Zacharaki et al. [4,5] introduced a new set of indicators for the quantification of climate variability on an annual, monthly and seasonal basis. In addition, Kalyvas [6] has proposed a new index which is based on the deviation between the observed and the estimated temperature calculated through Fourier harmonic analysis. The study further emphasizes on the more study in different climatic zones to establish the TEVY index, Thus, the current study is an application of TEVY index to analyse the trend of temperature in different climate regions of Nepal.

Nepal has a unique geography with elevation ranging from 68 m in the South to 8848m in the North within 193 km span, with this geo-diversity comes the extreme temperature fluctuations that are spatially and temporally varied and distinct. There are considerable relationships between the trends of maximum temperature-related variables and height, implying that higher elevations warm faster and more rapidly. It also demonstrates that the Terai experiences cool days in December and January, although summer months are becoming hot in all regions of the country [7].

2 Data and methods

2.1. Meteorological data

Nepal's physiographical regions vary significantly in terms of altitude, topography and climate. It is essential to choose meteorological stations that will represent all the climatic zones of Nepal. The representative stations are selected from the nine distinct physiographic regions based on elevation: hot climatic zone (up to 300 m), mild climatic zone (300 m to 1500 m) and cool climatic zone (1500 m to 4000 m) and based on region: eastern, central and western region.

* Corresponding author: bibhutio@nec.edu.np

Eastern, central and western division is also important because the east-west progression of the summer monsoon and physiography (mountain ranges) explain patterns in precipitation: short peak, low magnitude regime in the higher mountains of western and central parts, and the (low) extended summer monsoon in the east and moderately high, marked July regime in central Nepal [8].

There are no meteorological stations above 4000 m. For each elevation range, three stations having the maximum number of yearly data were selected for eastern, middle and western Nepal (Fig. 1, Table 1). Daily maximum and minimum temperature data for nine stations were collected from the Department of Hydrology and Meteorology (DHM) which maintains the meteorological station network of Nepal [9].

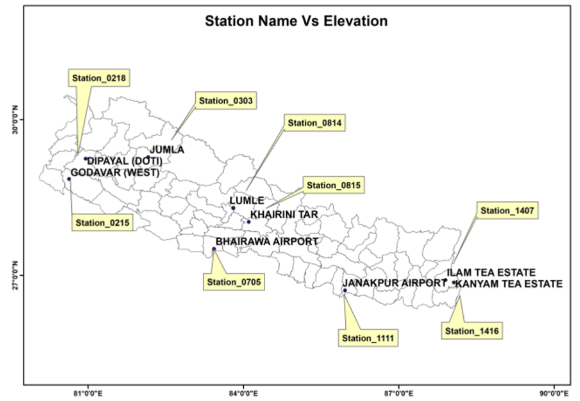

Fig. 1. Nepal Meteorological station location in different physiographical region

The study excludes certain years with missing data over threshold limit, leading to a minimum of 31 years considered for Godawari West station and a maximum of 44 years for Bhairahawa airport station. The threshold limit is set across the stations to ensure that minimum 30 years of data are selected for study (table 1).

Table 1. Station details.

ID	Station	Elevation (m)	Threshold	Data Years	Region
1416	Kanyam	1678	1%	38	Eastern
1407	Ilam	1300	2%	33	
1111	Janakpur	90	3%	34	
814	Lumle	1740	1%	42	Central
815	Khairini	500	1%	43	
705	Bhirahawa	109	1%	44	
303	Jumla	2300	1%	40	Western
218	Dipayal	617	1%	35	
215	Godawari (West)	288	2%	31	

From the daily maximum and minimum temperature data, the mean daily temperature (observed temperature) was calculated for all the stations. Then yearly mean and yearly standard deviation are calculated for all stations. Daily observed temperature is then used for the Fourier harmonic analysis since a time series with a periodicity can be expanded with a Fourier series expansion in terms of the harmonics which are sinusoidal. Harmonic analysis is a decomposition of time series into a sum of sinusoidal components, the coefficients of which represent the series' discrete Fourier transform and involves estimating the amplitude and phases [10]. The standard formula used to estimate the daily temperature with the Fourier harmonic analysis is:

$$y_n = a_o + \sum_{m=1}^{k} \left[a_m \cos\frac{2\pi mn}{N} + b_m \sin\frac{2\pi mn}{N} \right] \quad (1)$$

Where:
a_o= the arithmetic mean of the daily mean value,
$a_1, a_2, b_1, b_2 \ldots\ldots a_k, b_k$ = the amplitudes,
k = the number of harmonic terms,
n = the number of day of year (0 to 364 or 365 for the leap years),
N = period (365 or 366 days for the leap years).

Only the first harmonic term is taken into account, since it accounts for the greatest amount of the variance. Furthermore, the first harmonic is critical since it has the same period (one year) as the observed data. As the study's major goal is to establish the TEVY index, taking first harmonics gives an added advantage to make the study comparable to the Kalvyas study in 2021 [6]. TEVY value is calculated as the sum of the square of the difference between the observed and estimated values:

$$TEVY = \sum_{m=1}^{k} \left(yi_{obs} - yi_{est} \right)^2 \quad (2)$$

Where, N = 366 for leap years and N = 365 for the other years.

3 Results and discussion

3.1. Mean annual temperature and standard deviation of observed data

The analysis of mean annual temperature was done for nine stations and is presented in Fig. 2. The findings revealed that the highest mean annual temperature was observed in the stations located in the elevation range below 300 m (Janapur, Bhairahawa and Godawari West), followed by the stations in the range 300-1500m (Illam, Khairini and Dipayal). The least mean average temperature is observed in the stations located in the elevation range from 1500 to 4000m (Kanyam, Lumle and Jumla). The least mean annual temperature of the selected stations is found in Jumla and the highest mean annual temperature station is in Godawari West. An anomaly is observed in the case of Godawari West station, because the data from 2003 to 2010 are not included, as the missing data exceed the threshold limit. This period is followed by year 2011 which has the lowest of all average annual temperature.

Fig. 3 shoes the evolution of the standard deviation of the yearly mean temperature values. It is observed that the standard deviation of temperature is increasing for all

https://doi.org/10.1051/e3sconf/202343602011

the stations in the hot climatic zones (Janakpur, Bhairahawa and Godawari West). An anomaly is observed in the Godawari West station in the year 2011 since the fluctuation in the observed temperature is high in this year.

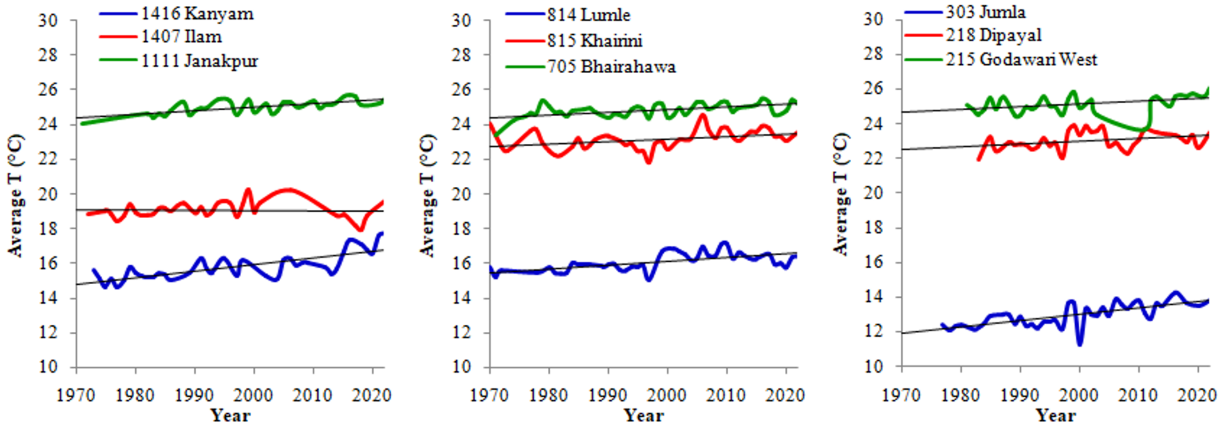

Fig. 2. Mean annual temperature of all stations.

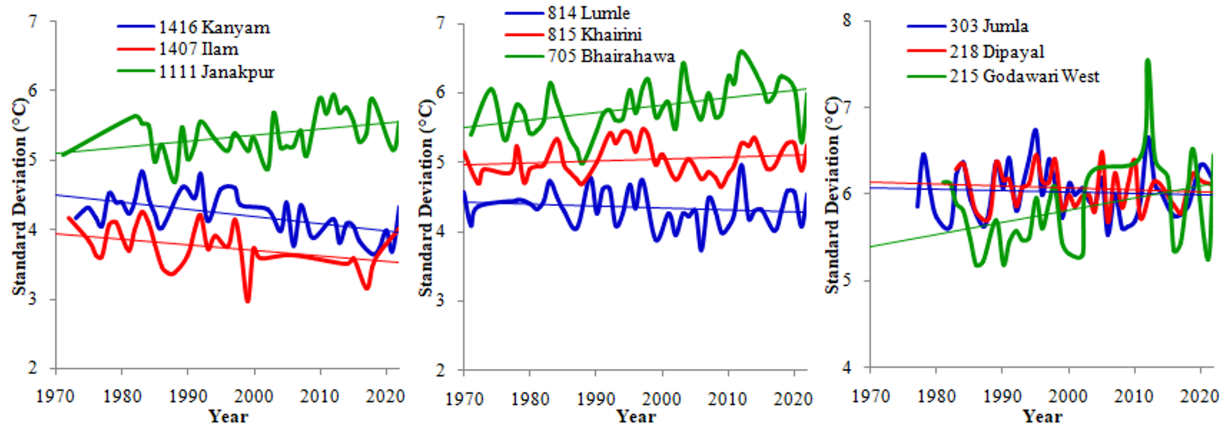

Fig. 3. Standard Deviation of yearly mean temperature.

The trend of standard deviation is not consistent for the stations in the mild climatic zone. Illam shows a decreasing trend, Khairini shows an increasing trend, and Dipayal shows a decreasing trend. All three stations in the cool climatic zone: Kanyam, Lumle and Jumla, show a decreasing standard deviation trend.

Fig. 4, Fig. 5, and Fig. 6 compare the observed values and the value estimated from the Fourier analysis of average temperature data of the nine stations for the year 2018. The year 2018 is selected as it is the most representative year in terms of data availability.

3.2. Fourier harmonic analysis and correlation analysis for single year

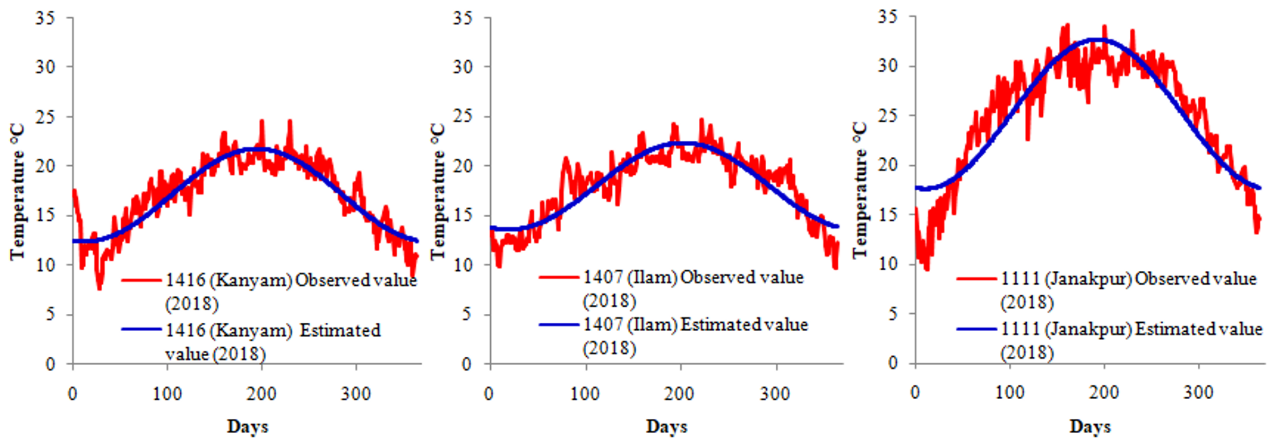

Fig. 4. Observed and estimated temperature of Eastern region.

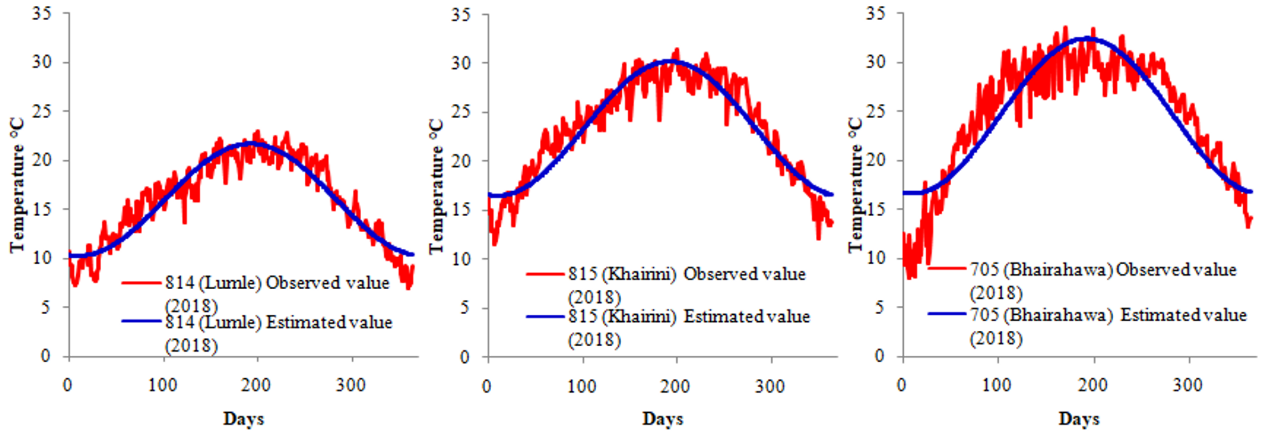

Fig. 5. Observed and estimated temperature for Central region.

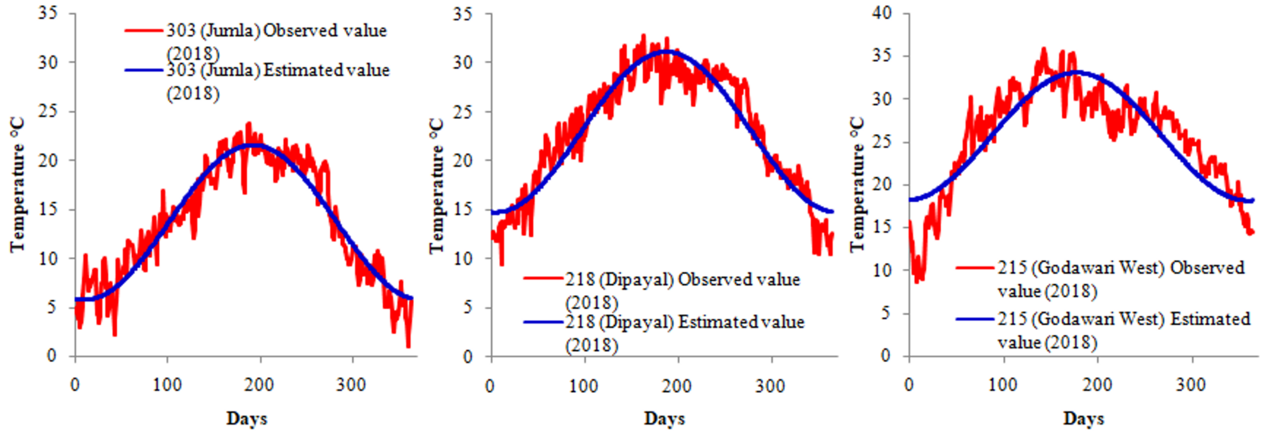

Fig. 6. Observed and estimated temperature for Western region.

The stations at the hot climatic zone show more temperature fluctuations between observed and estimated data and the variation is more striking during the late December and January. The observed temperature values in the mild climatic station have a quite good agreement with the estimated temperature curve and the variation is also similar to the stations of the hot climatic zones i.e. during late December and January. The highest altitude stations, however, have the best agreement with the estimated temperature curve.

Fig. 7, Fig. 8 and Fig. 9 show the scatter plot between the observed and estimated daily values for the nine stations for the year 2018. The r^2 value for all three stations in the warmer climatic zone is lower than that of stations in the mild and cool region. The two stations in the cool climatic zones - Kanyam and Jumla - have higher correlation coefficient than the two stations of mild climatic zone - Illam and Dipayal. The trend is different for the central Nepal as the station in the cool climatic zone - Lumle and Khairinitar have the same r^2 value.

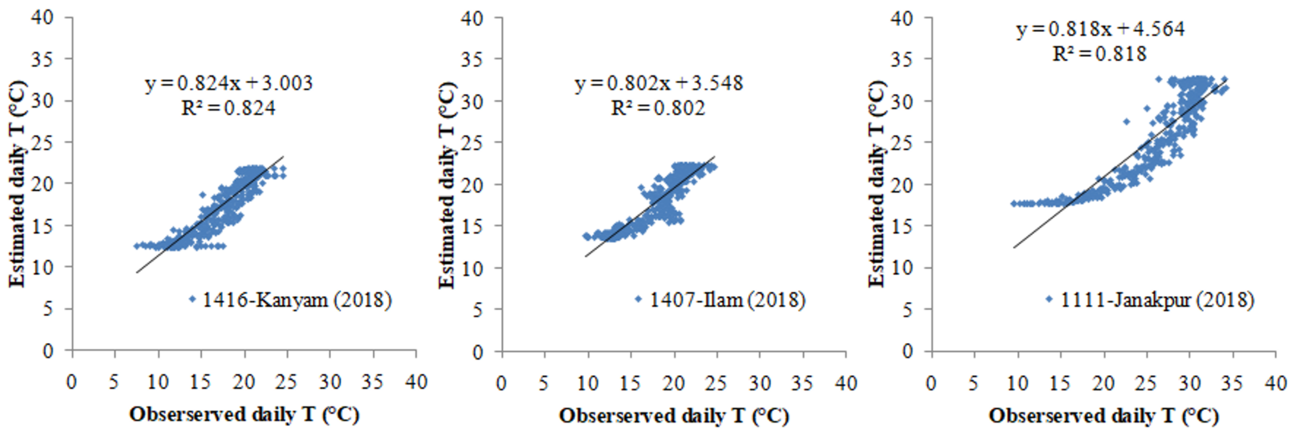

Fig. 7. Observed and estimated temperature scatter plot for Eastern region.

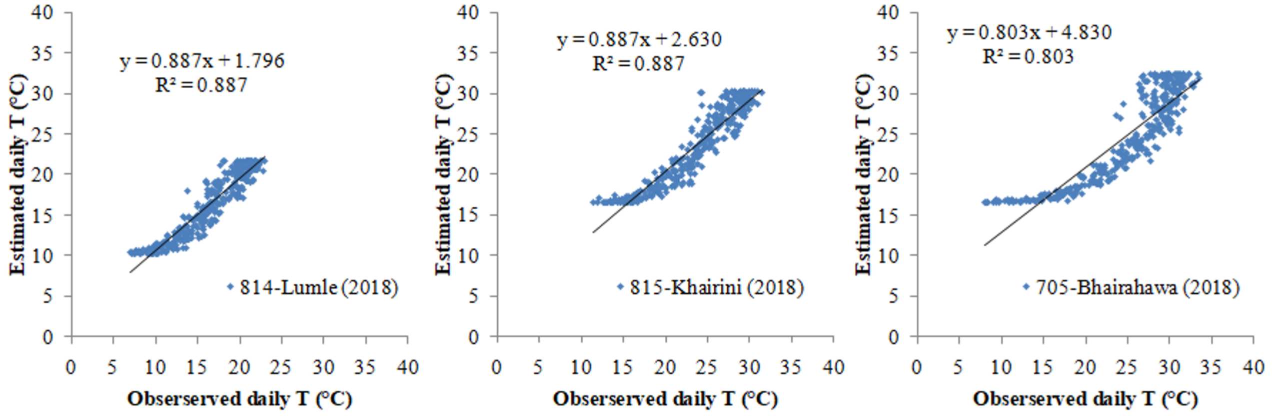

Fig. 8. Observed and estimated temperature scatter plot for Central region.

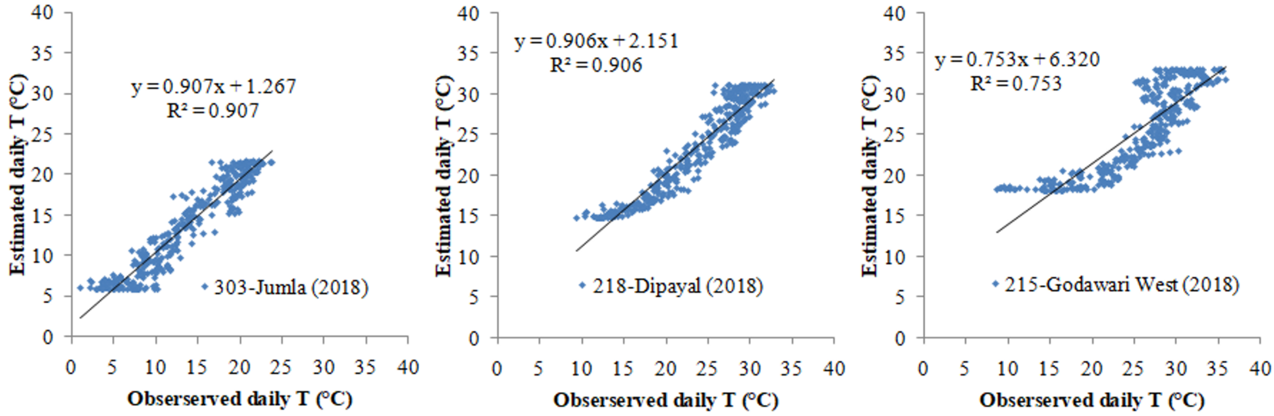

Fig. 9. Observed and estimated temperature scatter plot for Western region.

3.3 Correlation analysis for observed and estimated temperature for all year

In this section, a correlation analysis of observed temperature and expected temperature is performed. The correlation is carried out for every year of nine stations. Fig. 10, Fig. 11, and Fig. 12 below illustrate the trend of the r^2 and the linear trendline coefficients a and b for all stations. In the hypothetically ideally-case scenario, where the estimated values exactly match the observed values, a value of 1, b value of 0, and r^2 value of 1.0 are required for the best fit of line $y = ax + b$.

Fig. 10 shows that the cool climatic zones stations such as Jumla has an average r^2 value of 0.91 with quite low fluctuations, Lumle has an average r^2 value of 0.846 with some fluctuations, and Kanyam has an average r^2 value of 0.817, with many fluctuations. Since all these stations have r^2 greater than 0.8, we can assume that a quite good correlation exists between observed values and those estimated from the proposed methodology.

For the stations in the mild climatic zones, the r^2 value for Dipayal, Khairini and Illam are respectively 0.88 with some fluctuations, 0.869 with some fluctuations and 0.762 with noticeable fluctuations. Overall, r^2 value is close to 0.8 and this correlation can also be considered to be relatively good.

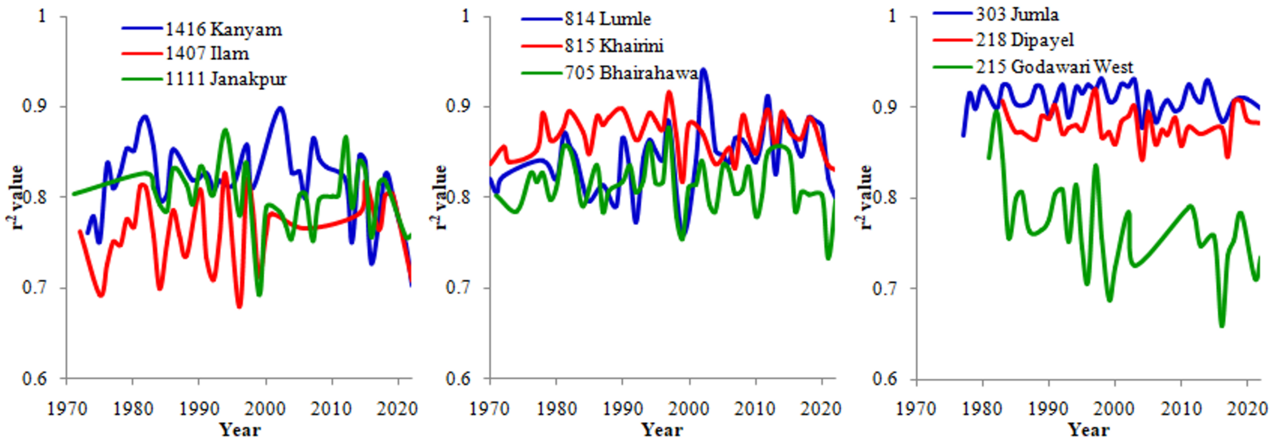

Fig. 10. Trend of r^2 for all 9 stations.

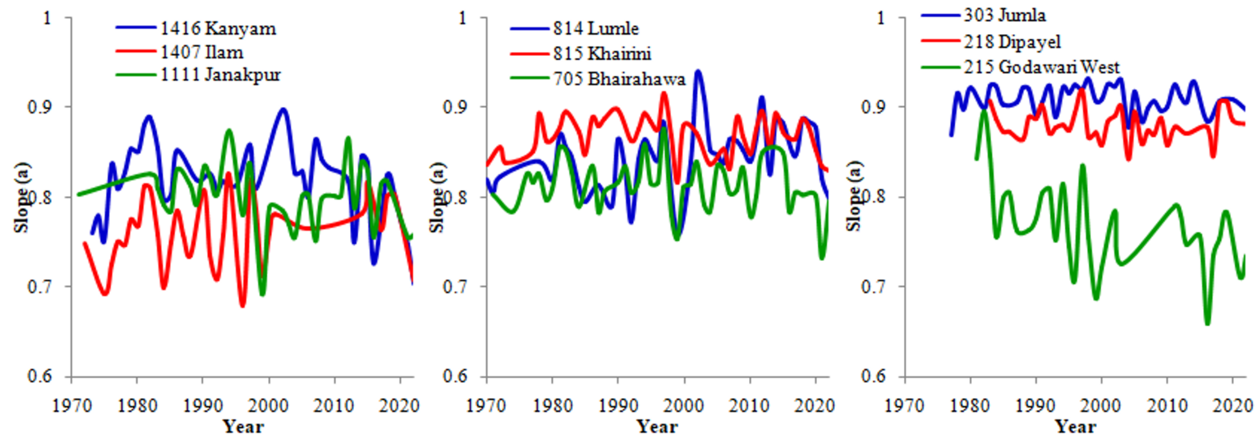

Fig. 11. Trend of slope (*a*) for all 9 stations.

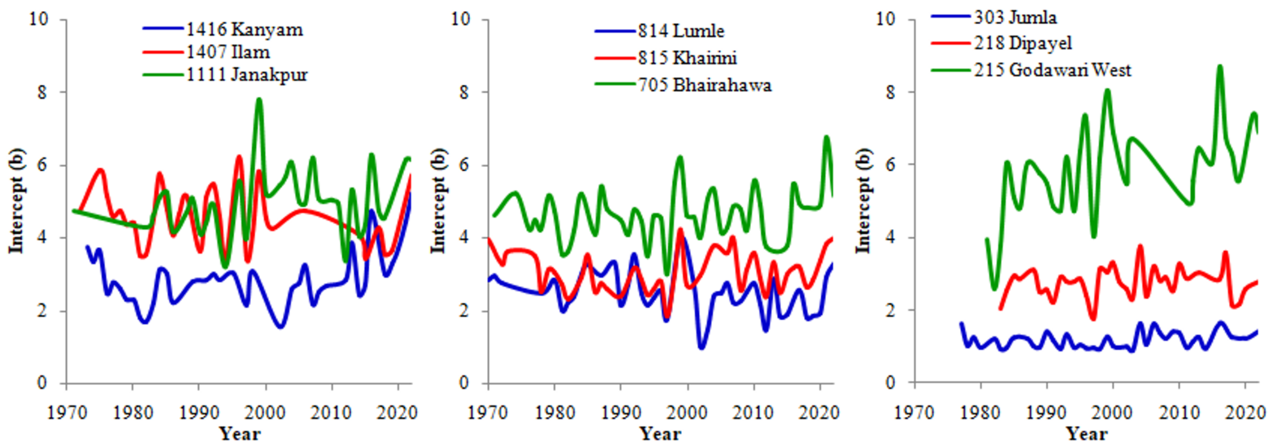

Fig. 12. Trend of intercept (*b*) for all 9 stations.

For the stations in the hot climatic zones, the r^2 value for Godawari West, Bhairahawa and Janakpur is, respectively, 0.769 with noticeable fluctuations, 0.813 with some fluctuations and 0.799 with some fluctuations. Overall, the r^2 value is close to 0.8 and this correlation can be considered to be relatively good.

Fig. 11 shows that for the stations in cool climatic zones: Jumla, Lumle and Kanyam, mean *a* value is, respectively, 0.909 with mild fluctuation, 0.846 with noticeable fluctuation and 0.817 with noticeable fluctuation. Since all these stations shows an *a* value greater than 0.8, this correlation can be considered as a good one.

The mean value of the slope *a* for the stations in the mild climatic zones: Dipayal, Khairini and Illam, is, respectively, 0.881 with some fluctuation, 0.869 with noticeable fluctuation and 0.761 with noticeable fluctuation. Since all these stations shows *a* value close to or greater than 0.8, this correlation can be considered as a good one.

The mean value of the slope *a* for the stations in the hot climatic zones: Godawari West, Bhairahawa and Janakpur is, respectively, 0.769 with high fluctuation, 0.813 with noticeable fluctuation and 0.799 with noticeable fluctuation. Since all these stations shows a value close to and greater than 0.8, this correlation can be considered as a good one.

The analysis of the intercept value (*b*) is shown in Fig. 12. A closer proximity to zero for *b* indicates a stronger correlation. All three stations of the cool climatic zone Kanyam, Lumle and Jumla have the least *b* value and that for all the stations from mild to cool climatic zones in eastern, central and western region are in increasing trend.

Based on the regression analysis, it can be said that there is a quite good correlation between observed and calculated data.

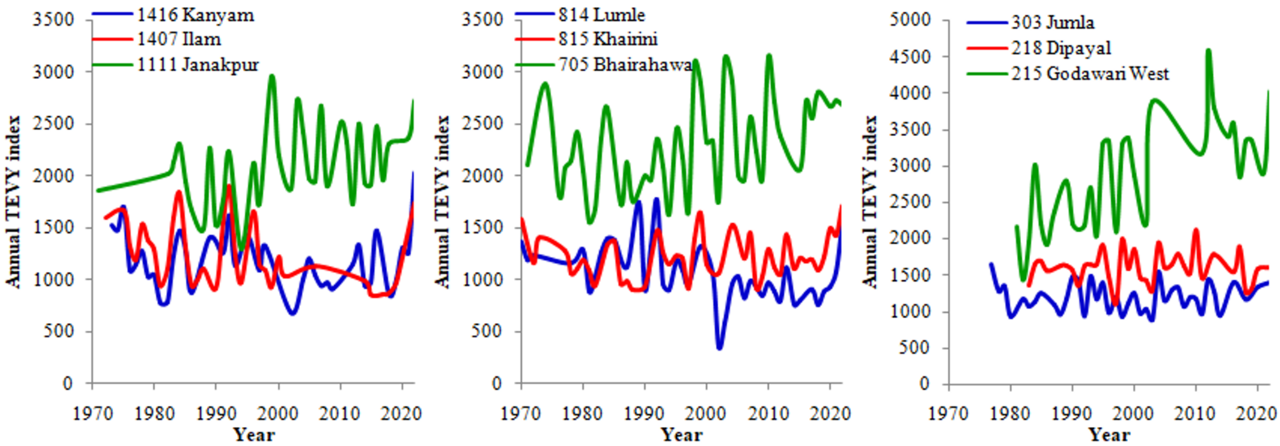

Fig. 13. Annual TEVY value for 9 stations.

In central and eastern Nepal, no such clear distinction of TEVY trend line is observed for the stations located in mild and cool zone. Though TEVY value is high for all the stations of hot climatic zone (Bhairahawa and Janakpur), TEVY trend lines of mild and cooler stations in central and eastern Nepal are intersecting. To better analyze, the mean value of TEVY is calculated. In the central region, although graphically appearing very similar and not distinct cool climatic zone (Lumle) has lower mean annual TEVY value of 1058.08 and where as mild climatic zone (Khairini) has higher mean annual TEVY value of 1218.63, however, variation is more for Lumle when compared with Khairini.

Similar pattern is observed for the eastern region as well. Hot climatic zone (Janakpur) has higher and more fluctuating TEVY value where as mild climatic zone (Ilam) and cool climatic zone (Kanyam) has lower, less fluctuating and intersecting graph. Between later two stations, mean of annual TEVY value is more for Ilam (1237.21) than for Kanyam (1184.63).

Overall, it can be said that TEVY is decreasing as we move from mild to cool zone for eastern, central and western Nepal.

3.4 TEVY index application

3.4.1 Yearly Variation of TEVY value

In this section annual TEVY value is calculated and its trend over the year is analysed for each station.

From Fig. 13, it is observed that annual TEVY value is higher and more fluctuating for the stations in the hot climatic zones (Janakpur, Bhairahawa and Godawari West). The TEVY value gets lower and less fluctuating as we go from mild to cool climatic zone region.

In western region, TEVY value is more for hot climatic zone (Godawari West) followed by mild (Dipayal) and cooler climatic zone (Jumla). The coolest of the selected stations, Jumla, has lower and more consistent TEVY over the period.

3.4.2 Monthly variation of TEVY value

In this section, average daily TEVY value for each month for all nine stations was calculated and the trend is analyzed.

From Fig. 14, it is clear that monthly TEVY value is higher in hot climatic zone (Janakpur, Bhairahawa and Godawari) than compared with the mild and cool zones. For all the climatic zones, TEVY has four peaks.

These four peaks can be compared with the monthly distribution of precipitation in Nepal. A study [11] on precipitation data from 2000-2018 shows that the distribution of precipitation in Nepal is under four classification summer season (June to September), pre-monsoon season (March to May), post-monsoon season (October to November), and the winter season (December to February), accounts for 80%, 13%, 4% and 3% of the year precipitation respectively. The four peaks of monthly TEVY matches with the precipitation pattern of Nepal.

Furthermore, Lumle has the least value of TEVY of all the nine stations under study. Precipitation pattern in

Nepal is highly affected by topographic effect due to high mountains. Lumle is toward windward side of massive Annapurna and has an annual precipitation greater than 5000 mm while the annual precipitation of Nepal is 1600mm. [12].

The study does not cover the effect of precipitation to the fluctuation of temperature. Identifying relation between temperature variation and rainfall pattern needs further study.

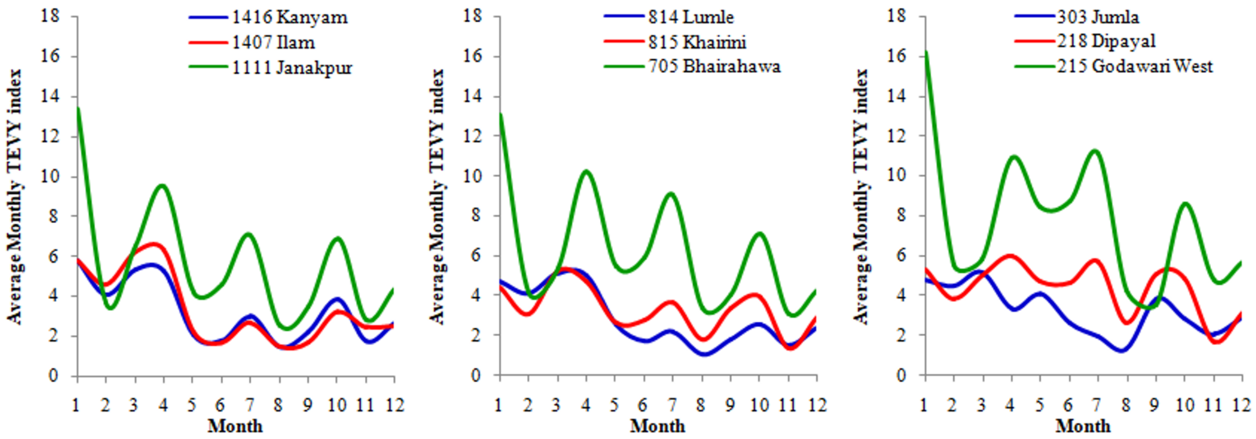

Fig. 14. Average daily TEVY value for each month.

4 Conclusions

For the purpose of assessing the temperature variability within a year, a new index, TEVY index, has been proposed and applied in 4 meteorological stations in Greece. This work applies this index in 9 meteorological stations of Nepal. As a temperature variability indicator index, it is observed that in different climatic zone the result of TEVY is unique, in case of Nepal, TEVY is decreasing as we move from hot climatic zone to cool while it was just the reverse in the pilot study conducted in Greece.

References

1. T. Kalyvas, E. Zervas, Low Carbon Energy Technologies in Sustainable Energy Systems, 287-307 (2021)
2. Z. Gareiou, E. Drimili, E. Zervas, *Low Carbon Energy Technologies in Sustainable Energy Systems*, 309-327 (2021)
3. CLIVAR, *Climate Change and Ocean – Variability, Predictability and Change* [Online] (2009)
4. K. Zacharaki, A. Tseliou, N. Rapsomanikis, E. Zervas, IOP Conf. Ser. Earth Environ. Sci. **1123**, 012017 (2022)
5. K. Zacharaki, A. Tseliou, N. Rapsomanikis, E. Zervas, IOP Conf. Ser. Earth Environ. Sci. **1123**, 012018 (2022)
6. T. Kalyvas, S. Manika, E. Zervas, IOP Conf. Ser. Earth Environ. **899**, (2023)
7. A. Poudel, L. Cuo, J. Ding, A.R. Gyawali, Int. J. Climatol. **40**, 4956-4977 (2020)
8. S.R. Kansakar, D.M. Hannah, J. Gerrard, G. Rees, Int. J. Climatol. **24**, 1645-1659 (2004)
9. Department of Hydrology and Meteorology, [Online] (2023)
10. P. Bloomfield, *Fourier analysis of time series* (John Wiley & Sons, USA, 2000)
11. K. Hamal et.al., Hydrology **4**, 1645-1659 (2020)
12. M. Maharjan et. al., Earth & Space Sci. **10**, (2023)