Environmental Sustainability (2019) 2:43–54
https://doi.org/10.1007/s42398-019-00049-1

ORIGINAL ARTICLE

Assessment of spatio-temporal variability of temperature using geo-statistical techniques: a case study of Upper Teesta River Basin, India

Akhilesh Kumar Mishra[1] · **Suresh Chand Rai**[1]

Received: 5 October 2018 / Revised: 30 January 2019 / Accepted: 4 February 2019 / Published online: 28 February 2019

Abstract

Mountainous regions are conspicuous due to their inimitable natural features. Natural regions are becoming progressively pretentious owing to the temperature variability pattern. Assessing temperature variability is vital to comprehend the physiography of these regions. Upper Teesta basin portrays a unique blend of a sub-tropical climate in the south and tundra type in the north. The Teesta river is considered as the lifeline of Sikkim, lies in the tundra type of climate covering the northern portion, where at least three months (November–January) of a year remain under deep snow and temperature hovering around 0 °C. The upper Teesta river basin covers the whole part of Sikkim scheming the lifestyle and occupation of the people based on the availability of its waters. Atmospheric temperature plays a crucial role in determining stream properties and water volume. Mean monthly temperature data acquired from India Meteorological Department as well as The National Centre for Environmental Prediction (NCEP) have been analysed with the help of kurtosis, skewness, and visualization done through Z-distribution in GIS environment. It provides a strategic outlook towards the proper utilization of the river water despite maintaining harmony with the climate of the region. The result depicts changes in the river itinerary concerning climatic variability pattern that calls for sustainable management of this water resource.

Keywords Global climate change · River basin · Temperature variability · Z-Distribution · Kurtosis · Skewness

Introduction

The consequence of climate on the physical environment has remained of immense trepidation and has extended up to a disquieting rate of retort in current years (Cogălniceanu et al. 2004). Climatic inconsistencies have proved detrimental over time for mountainous environs (Marengo 2004), also have evinced hazardous to humankind instituted in such areas (Mishra and Rai 2014). According to the Intergovernmental Panel on Climate Change (IPCC) Report (2007), the global climate has witnessed alteration rapidly concerning global mean temperature at a rate of 0.7 °C within the past century. The ecosystems of high mountainous area such as the Alps, the Rockies, the Andes and the Himalayas etc. are most susceptible to the spectre of climate change (Beniston 1997; Diaz and Bradley 1997; Wibig and Glowicki 2002; Beniston 2003; Diaz et al. 2003; Villaba et al. 2003; Beniston 2005; Kohler et al. 2011; Zhang et al. 2018). Warming appears to have enhanced and intensified extreme events in these regions (World Meteorological Organization 2003).

River surface temperature is an imperative parameter for understanding the physical setting (Livingstone and Dokulil 2001). The river system is a sensible element of the nature that responds to the global climatic change affecting mountain hydrology and surface-runoff. The large river systems play an important role in functioning of the regional as well as the global climate (Marengo 2004). The streambed has been identified as a critical heat sink for river water (Evans and Petts 1997). Within a basin, the exchange of heat in the atmosphere and the stream water interface is mostly affected by the variation in temperature (Evans and Petts 1997; Brown et al. 2006). Increase in the global temperature creates an adverse impact on the hydrological cycle at a basin scale. Studies done by hydrologists and meteorologists have revealed aberration in the frequency of extreme temperature, which portrays remarkable alteration in agricultural

✉ Akhilesh Kumar Mishra
akhileshdse@gmail.com

[1] Department of Geography, Delhi School of Economics, University of Delhi, New Delhi 110007, India

productivity (Fuhrer et al. 2006; Piao et al. 2010) and also in energy demand (Kapsomenakis et al. 2013) as well as human mortality (Wigley 1985; Díaz et al. 2005). An increase in the surface temperature aggravates the rate of evaporation, which enables the higher amount of transport of water vapours to the atmosphere that leads to accelerating the hydrological cycle (Menzel and Bürger 2002; Hannah et al. 2004). Also, due to global warming, the pattern of circulation of the temperature and precipitation both undergo a wide range of variations, ultimately resulting in the change in the pattern of streamflow (Bhutiyani et al. 2009). Increase in the global air temperature creates an adverse impact on the massive stretch of water existing in the form of ice fields and glaciers, the forested area resulting in the deterioration of health and the socio-economic conditions (Bhutiyani et al. 2007).

The monsoon and winter precipitation control hydrology of many Himalayan rivers and climate-induced alterations may evince to be detrimental to the economic and social well-being of a large population (Bhutiyani et al. 2009). This research delves into the vital role played by the Himalayas in the Indian subcontinent owing to the intervention of polar, tropical and Mediterranean influences which affect the monsoon system over Asian continent (Borgaonkar and Pant 2001; Bhutiyani et al. 2009).

On the other hand, these vicissitudes vary in different regions based on surface albedo, evapotranspiration and carbon cycle (Meissner et al. 2003 and Snyder et al. 2004). Hasanean (2001) had examined trends and periodicity of rainfall while Türkes et al. (2002) analysed the maximum, minimum and average temperatures of Turkey region. Particularly in a mountainous region, there is an anomaly in climatic conditions. Their works have revealed long-term deviations in the warming and cooling periods concerning temperature. The influence of climate change at higher altitudes is conspicuously above the average rates. Assessing the temperature pattern and denoting the variability in higher altitudes is vital as mountains make up 20% of the world's landform cover, provide home to 10% of the human population in the world and contain 50% of the world's freshwater resources (Hussain et al. 2005).

The mountainous expanses are depots of natural resources especially providing the population with valuable minerals and timber, so the preservation of such resource is indispensable at all levels (Bergstrom and Randall 2016). The deprivation rates raise high in such fragile bio-networks of a mountain (Mishra and Rai 2014). They portray remarkable genetic diversity that is a source of food for many people. Although, the mountain ecosystems are always under the threat of climatic uncertainties and suffer from deforestation, forest fires, and overexploitation of natural resources, which makes these regions vulnerable. Such things disturb the soil composition, landform particularly the water ecology in these zones. The life of people in hilly areas is hard when compared to those residing in the plains. In such regions, water proves to be very scarce since most of this life-saving element stays as snow or ice.

The upper Teesta river basin covers the whole part of Sikkim scheming the lifestyle and occupation of the people based on the availability of its waters. Atmospheric temperature plays a crucial role in determining stream properties and water volume. The temperature variability has been shaping the anthropogenic activities for a very long time in the outlet. Therefore, this study has been designed to analyse the spatiotemporal variability in temperature for strategic outlook towards the sustainable management of the river water maintaining harmony with the climate of the region.

The study area

The Teesta River is reflected as "The Lifeline" of the state of Sikkim carving out of the Himalayas in India. The river originates as Chhombo Chhu from a glacial lake Khanchung Chho at an elevation of 5280 Mt. in the Northeastern corner of the State. Chho Lhamo and Teesta Khangse glacier are the primary sources of water, which are concentrated at the brims of snow-capped ridges and ice fields. The upper Teesta river basin is bounded within the geographic vicinities of 87°59′58.47″ to 88°53′18.07″E and 26°51′34.47″ to 28°7′38.91″N (Fig. 1). This region is spread over a vast area of 8207.48 km^2. Along with its traverse from its foundation until descending to the plains, the river is fed by a number of tributaries on either side of its course. The tributaries in the Eastern flank are shorter in the course, but larger in number despite the tributaries on the Western flank are greatly stretched with larger drainage areas with subsequently providing an enormous amount of discharge to the main Teesta River. Additionally, right bank tributaries drain heavily glaciated areas with massive snowfields. The surface of the basin is underlain primarily by mountains of astounding magnitude, lofty peaks, protuberant ridges and valleys. The hard crystalline gneiss and quartzite schist rocks are dominated in northern, eastern and western portion of the region while the southern portion is composed of phyllites, micaceous schists, shales, slates and alluvial deposits of recent age. Quaternary sediments are very common in the southern part of the area. The northern portion of region renders tundra type of climate and sub-tropical climate in the south with mean annual temperature ranges from 16 °C to 19 °C.

Materials and methods

A time series of Mean- Monthly temperature has been analysed for the study for 30 years (1982–2012). The data was acquired from the Indian Meteorological Department.

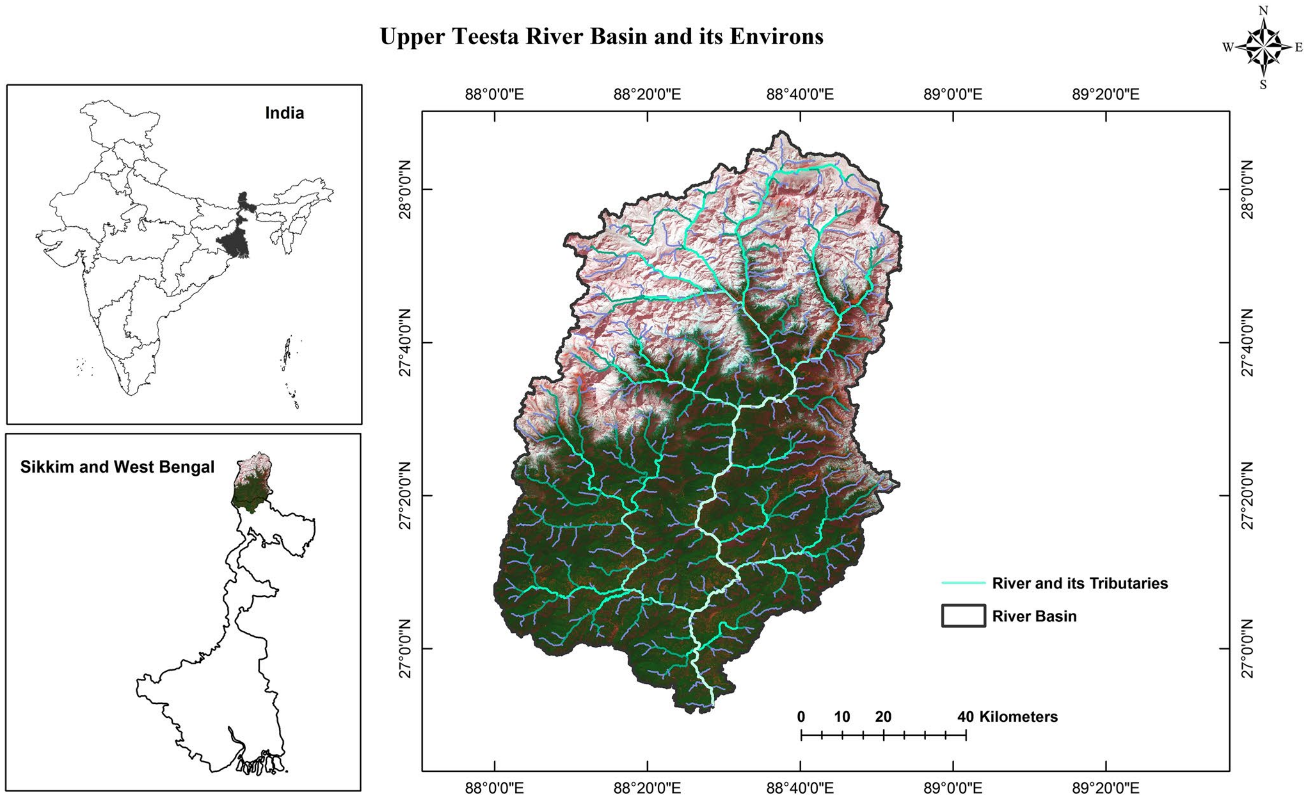

Fig. 1 Location map of the Upper Teesta River Basin

The monthly temperature takes into account both the day's maximum as well as minimum temperature. To elucidate the effect of proper temperature stratification with respect to seasons is necessary. The Z-score has been performed through the specified mathematical Eq. (2) and interpolated through kriging technique (spatial analysis tools) in the ArcGIS 10.4 software for portraying the spatial variability in temperature. Kriging is a spatial interpolation technique for creating a variance surface of unobserved values from the observed value at proximate places (Eq. 1). The variance surface by kriging is more precise than polynomial interpolation (Van Beers 2005). Furthermore, Kurtosis and Skewness (Mitchell et al. 1966) have been utilised to evaluate the temperature for the year of 1982 to 2012 which depicts the recent temperature variability pattern in the upper Teesta river basin (Eqs. 3 and 4).

$$\hat{Z}(S_0) = \sum_{i=1}^{n} \lambda_i Z(S_i) \tag{1}$$

where, $Z(S_i)$ is the measured value at the ith location. λ_i is an anonymous weight for the measured value at the ith location. S_0 is the estimate location, n is the number of measured values.

Z Score signifies the score is alike from mean of 0, determined through the following equation:

$$Z\,Score = \frac{X - \bar{Y}}{S} \tag{2}$$

where, X is the variable, $\bar{Y}$ is the mean, S is the standard deviation.

Kurtosis portrays the rate of the distribution varying from the average normal condition. Kurtosis has its association with the movement of the mass toward the centre and the tail of the distribution (Kevin et al. 1988). Kurtosis was performed by the following equation:

$$\text{Kurtosis} = \sum_{i=1}^{n} \left(\frac{(Y_i - \bar{Y})^4 / \mathrm{N}}{S^4} \right) \tag{3}$$

here $\bar{Y}$ is the mean, S is the standard deviation, and N is the number of data points.

Skewness discusses the dimension of the data, differing from the normal condition. Based on the standard deviation values Skewness is determined using the following equation:

$$\text{Skewness} = \frac{\sqrt{N(N-1)}}{N-1} \sum_{i=1}^{n} \left(\frac{(Y_i - \bar{Y})^3 / \mathrm{N}}{S^3} \right) \tag{4}$$

where $\bar{Y}$ is the mean, S equals the standard deviation and N is the number of data points.

Results and discussion

The statistical methods (Kurtosis, Skewness and Z-Distribution) were used to evaluate the mean-monthly temperature variability patterns at the inter-annual for the year of 1982 to 2012.

The maps derived from mean monthly temperature depict a pattern where the month of January is observed to have temperatures as low as − 20.73 °C (2012). In such cases, the northern side of the basin is affected with a bout of low temperatures. The temperature pattern is seen to decrease more in the recent past, i.e., from 1982 to 2012. February and March are continuing with the effects of the fading winter experiences temperatures as low as − 16° and raising to a meagre 22 °C. April and May are hot months, but since the most of the study region is a part of the radiant Himalayas, so the temperature only increases up to − 2.28 °C in the northern part of the basin and 25.44 °C in the southern parts of the basin. It is in the southern part of Teesta basin where people reside and therefore, anthropogenic activities take place. There has been a temperature variability pattern from North and South also owing to the year, like June showed a northern temperature of 0.88 °C in 1982 which decreases to − 0.22 °C in 2012.

On the contrary, the highest temperatures of June are seen in the Southern part of the basin for the year 1992, which counts up to 27.96 °C. The temperature for July again goes down to 0.23 °C since the rains wash in and drain the river basin. The highest temperatures are perceived in the Southern part of the basin (26.57 °C, 1992). August podcasts a temperature range between 0.27 °C to as high as 26.86 °C. Nevertheless, if the temperature is considered decade-wise, then it is seen that there has been a decrease in the lowest temperature as we proceed from 1982 to 2012. Also among the four years, the highest temperature is found in the Southern slopes in the year 1992 ranging up to 26.86 °C. In case of October 1982 shows a temperature ranging from -1.76° to 18.20° in 1982, − 1.20° to 22.30 °C in 1992, 2002 experiences a temperature range of − 0.75 °C to 22.79 °C, in 2012 the range varies from a temperature of − 9.45 °C to 21.97 °C. November marks the beginning of the harsh winters wherein the recent year's temperature has reduced much more. As the map portrays that in the year 1982 the lowest temperatures was − 10.98 °C, in 1992 the lowest temperature recorded − 5.68 °C, 2002 experienced − 3.83 °C which had a sudden fall in 2012 to a meagre temperature range of 13.59 to − 8.56 °C. In this month, the highest temperature rises only to an average of 20° (southern slopes). December is attributed as the month recording the lowest temperatures in the northern part of the basin with a range of − 7.49 °C (2002) to − 15.48 °C whereas the highest temperature ranges from 9 to 15 °C only, which is most common in all the years (Fig. 2a and l, Temperature Variability Pattern, January to December 1982, 1992, 2002 and 2012).

To depict the temperature variability pattern more vibrantly statistical analysis has been carried out. Mean has been calculated for the years 1982, 1992, 2002 and 2012. Based on the mean values Standard Deviation has also been calculated. These values have been analysed to calculate Z- Score values for twelve months of the four (above mentioned) years and mapped in the Arc GIS environment.

The range of values has been given between < − 1 to > 0.5 divided into 5 classes of < − 1, − 1.0 to − 0.5, − 0.5 to 0.0, 0.0–0.5 and > 0.5. Since Z-Score represents area based value so the temperature pattern can be discriminated as 0–0.5 representing 19.15% of the total basin area from the mean and the range of 0–0.1 depicting 34.13% area (positive or negative) from mean. Likewise, the maps show the areal differentiation. The variability pattern is studied up to the reference year of 2012, focused on the weather stations. It is done to enhance the visualisation of temperature variability in the basin. The following table shows the Mean, Skewness and Kurtosis for the different weather stations for the reference year (Table 1).

Skewness describes the symmetry of a data set. For symmetry, the data should have Skewness near zero. If Skewness is less than − 1 the data set is highly skewed. The same relates to Skewness greater than + 1. On the other hand, if Skewness comes between − 1 and − 0.5 or + 0.5 and + 1 the distribution is labelled as moderately skewed. Subsequently, the range between − 0.5 and +0.5 is termed as approximately skewed (Bulmer 1979). For the temperature range derived for the year 2012, the Skewness falls approximately between − 0.6 to − 0.09. Therefore, this distribution can be termed as "approximately skewed".

Kurtosis is divided into Mesokurtic (where the normal distribution equals to 3 and excess kurtosis precisely 0), Platykurtic (denotes a distribution < 3 and excess kurtosis < 0), Leptokurtic (where the distribution measure > 3 and excess kurtosis > 0). In the present study the value of kurtosis falls in a range of − 0.7 to − 2.2, therefore, there is an excess kurtosis of − 2.3 to − 0.8 (excess kurtosis < 0) falling under the group of Platykurtic (kurtosis < 3).

The results, therefore, reveal that in recent years the temperature variability has affected the Teesta river basin with a vast difference between the lowest and highest temperatures. Also, the maps reveal that 2002 had the lowest average temperatures.

The Teesta river basin is impacted by a highly periodic rainfall regime determining the fluvio-geomorphic systems. The sensitivity of surface runoff in changing stratigraphy

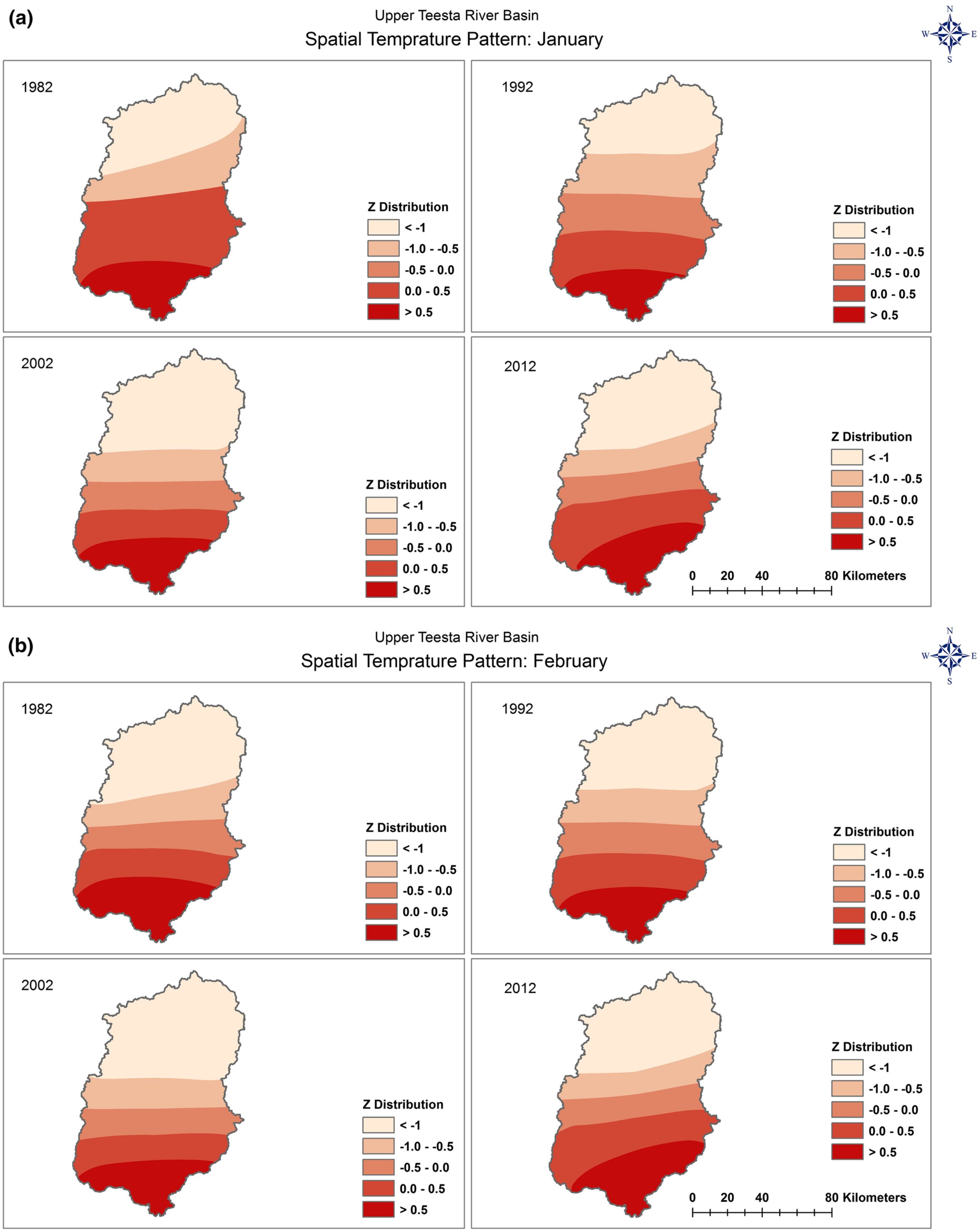

Fig. 2 **a–l** Visualization of Temperature anomaly through Z-distribution over the Upper Teesta River Basin for the year 1982, 1992, 2002 and 2012

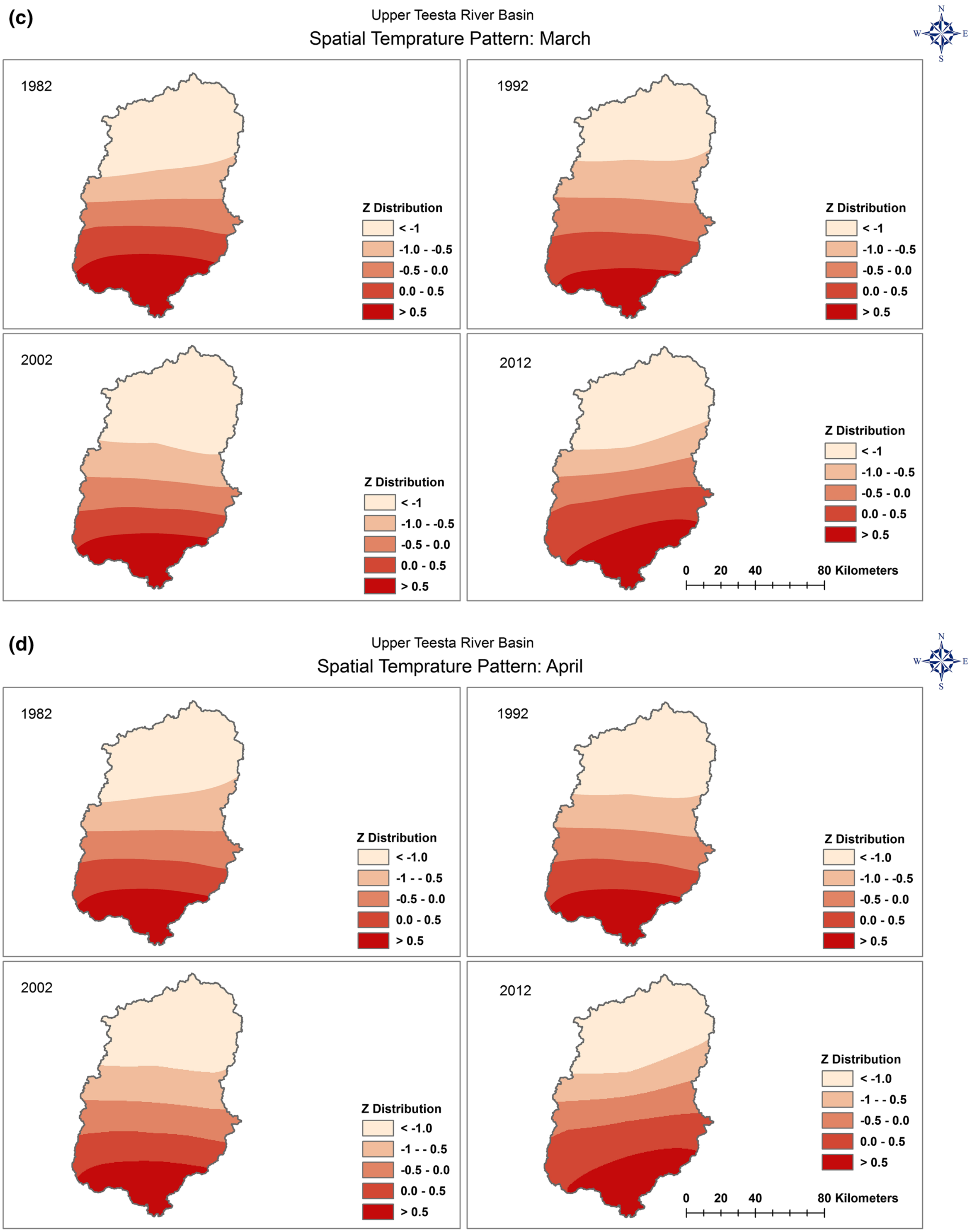

Fig. 2 (continued)

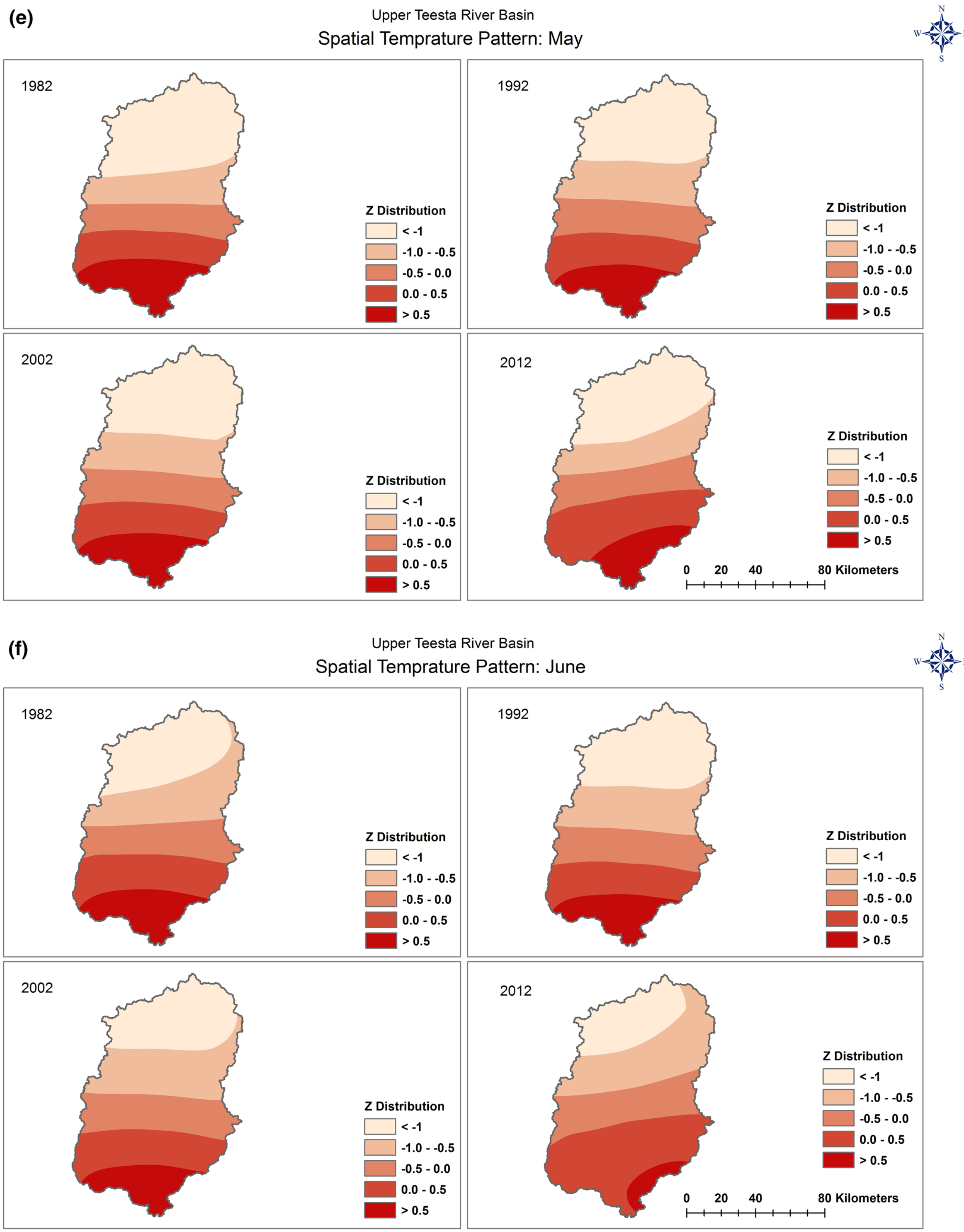

Fig. 2 (continued)

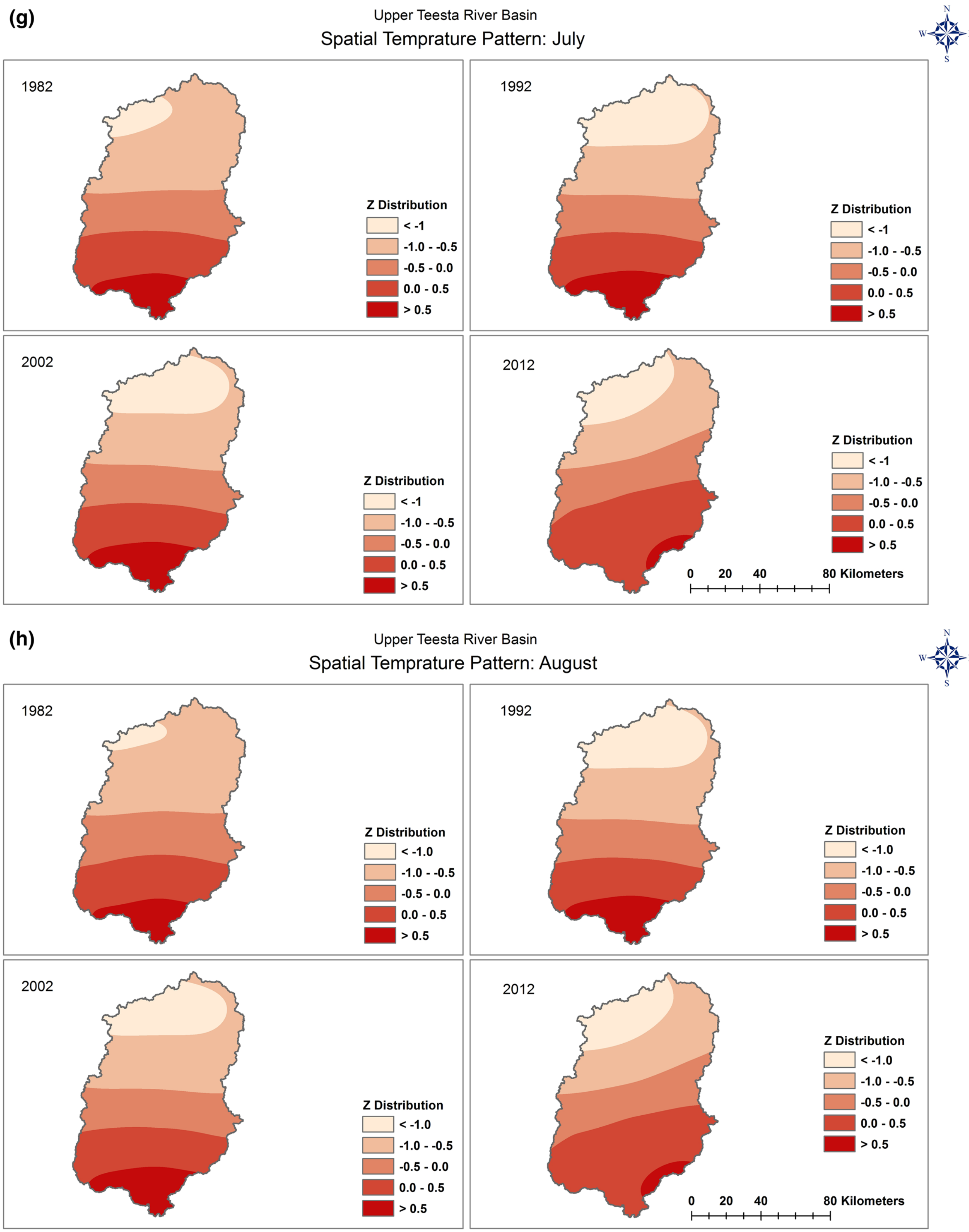

Fig. 2 (continued)

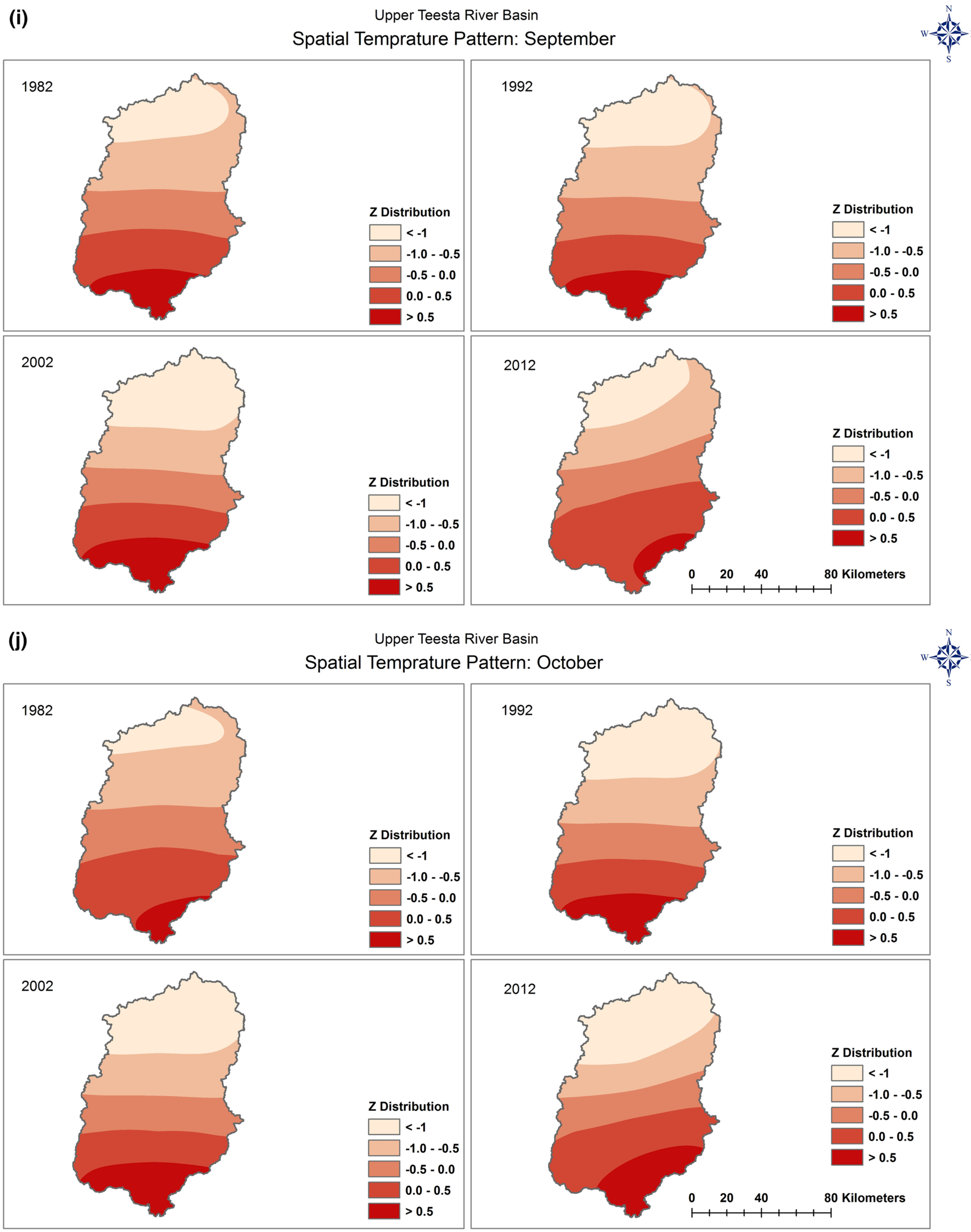

Fig. 2 (continued)

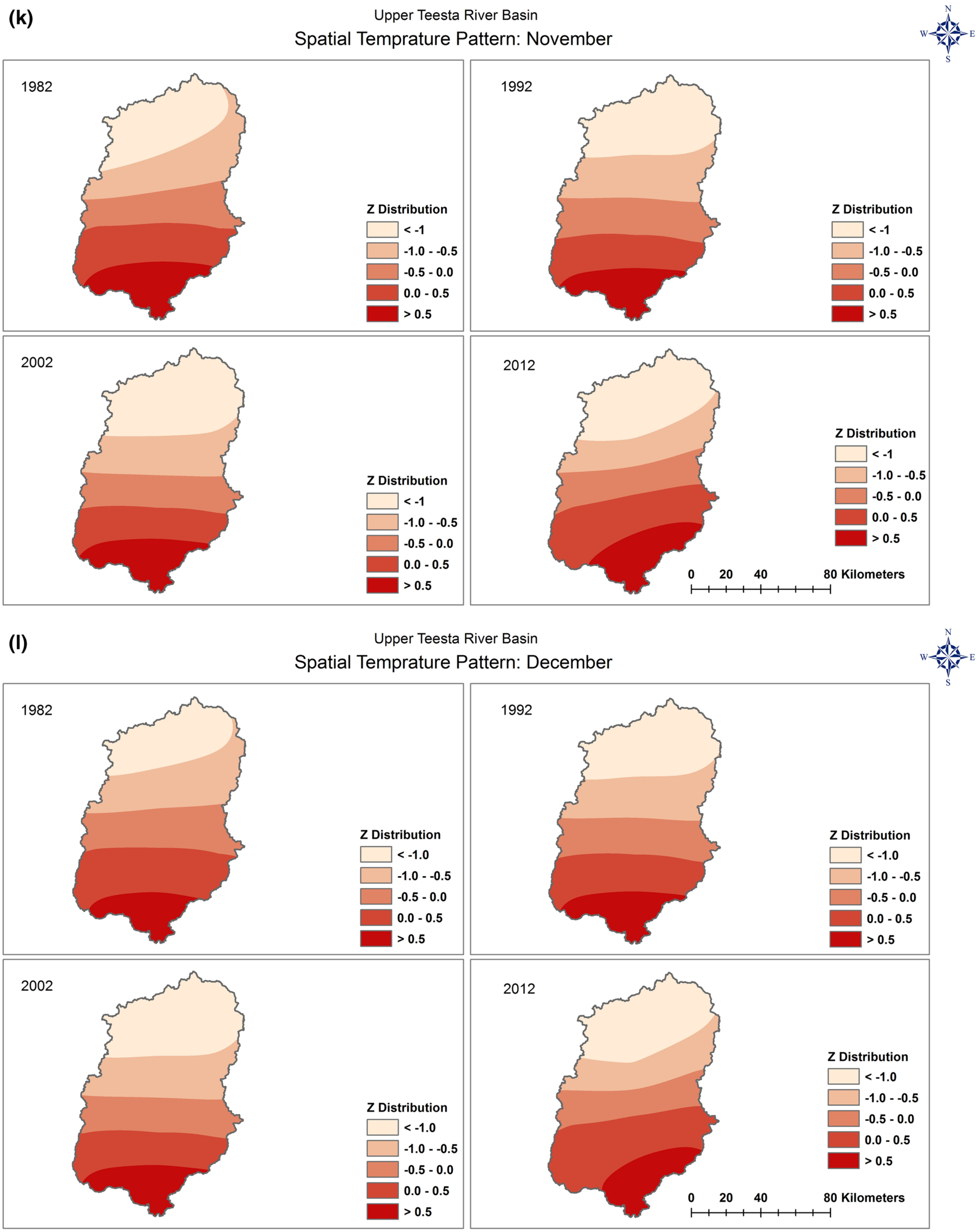

Fig. 2 (continued)

Table 1 Results of Temperature variability over the Upper Teesta River Basin for selected stations

Longitude	Latitude	Mean	Variance	Kurtosis	Skewness
88.13	26.70	22.92	20.344	−0.900	−0.617
88.44	26.70	23.56	19.561	−0.875	−0.650
88.75	26.70	25.02	20.424	−0.840	−0.641
88.13	27.01	16.67	19.064	−0.808	−0.724
88.44	27.01	19.46	19.874	−0.757	−0.769
88.75	27.01	22.15	19.649	−0.598	−0.786
88.13	27.32	11.00	23.414	−1.291	−0.394
88.44	27.32	13.34	24.976	−1.216	−0.416
88.75	27.32	14.79	23.588	−1.027	−0.464
88.13	27.63	−1.45	38.200	−1.154	−0.297
88.44	27.63	−0.93	45.846	−2.444	−0.148
88.75	27.63	3.33	43.701	−1.176	−0.288
88.13	27.94	−9.49	53.071	−1.674	0.097
88.44	27.94	−9.21	61.069	−1.594	0.024
88.75	27.94	−5.45	67.183	−1.426	−0.123

of the river bank is very complicated. The upper portion of river bed is imbricated with cobble and gravel while downstream is with silt and debris forms channel bar, fan lobes and terrace. Stratigraphy of river bank i.e., lithofacies characters of alluvial deposits (Monecke et al. 2001), temporal fluke of sedimentation, aggradation and incision stages in streams (Goodbred 2003) play a vigorous role on climatic changes. Owing to slope gradient and high runoff, the vertical corrosion is high, resulting in a enhanced snow melting process, and consequent voluminous sediment loads (Vandenberghe et al. 1994). The hydrologic regime coupled with anthropogenic activities have a plethora of impact on the fluvial system, and the incident climatic variability is associated with the greenhouse effect and global warming (Goudie 2006).

Conclusion

In this paper, an attempt has been made to evaluate and visualize the Spatio-temporal variability of temperature during the period of 1982–2012 for the upper Teesta river basin. In the regional context, climate change attributes to a mainly unpredicted shift in temperature, unsolicited changes in the agricultural pattern (shift in cropping and growing season). In a region where temperature pattern is the critical ingredient deciding the anthropogenic activities, it is of immense importance to study the variability pattern in it. This study had revealed that there had been a significant change in the temperature patterns as we travel from south to northward. The same temperature anomaly is attributed across the mountainous region of the upper Teesta river basin owing to the relationships between temperature and topographic physiognomies. Also, variation has been observed along the ranges during summer and winter seasons, subsequently, affecting the nature of the terrain and the river water may portray changes depending on the type and intensity of influence. Such alteration in temperature will inevitably lead to a reduction in runoff generation; therefore, meteorological and climatic conditions (evapotranspiration, wind, relative humidity) will be affected in the upper Teesta river basin.

The results divulge that there is a significant variability in temperature pattern during the period of 2002–2012. Also, temperature anomaly has been observed on a yearly basis. According to Z-distribution results, the annual mean temperature has shown strong anomaly continuity in the upper Teesta river basin, signifying that the future trend will be approximately consistent with that of the past.

Acknowledgements We express our sincere thanks to University Grants Commission (UGC), Government of India for the financial support to carry out this work. The authors are also grateful to anonymous reviewers and editors for their constructive comments.

References

Beniston M (1997) Variations of snow depth and duration in the Swiss Alps over the last 50 Years: links to changes in large-scale climatic forcing. Clim Change 36:281–300

Beniston M (2003) Climatic change in mountainous regions: a review of possible impacts. Clim Change 59:5–31

Beniston M (2005) The risks associated with climatic change in mountain regions. Global change and mountain regions. Springer, Dordrecht, pp 511–519

Bergstrom JC, Randall A (2016) Resource economics: an economic approach to natural resource and environmental policy. Edward Elgar Publishing, Cheltenham

Bhutiyani MR, Kale VS, Pawar NJ (2007) Long-term trends in maximum, minimum and mean annual air temperatures across the northwestern Himalaya during the 20th century. Clim Change 85:159–177

Bhutiyani MR, Kale VS, Pawar NJ (2009) Climate change and the precipitation variations in the northwestern Himalaya: 1866–2006. Int J Climatol J Royal Meteorol Soc 30(4):535–548

Borgaonkar HP, Pant GB (2001) Long-term climate variability over monsoon Asia as revealed by some proxy sources. Mausam 52:9–22

Brown LE, Hannah DM, Milner AM (2006) Hydroclimatological influences upon water column and streambed thermal dynamics in an alpine river system. J Hydrol 325:1–20

Bulmer MG (1979) Principles of statistics. Dover Publications

Cogălniceanu D, Vâlcu CM, Vâlcu M, Găldean N, Staicu G (2004) Seasonal variability of temperature in alpine lakes from the Retezat National Park, Romania, Studii şi Cercetări. Biologie 9:152–157 **(Universitatea din Bacău)**

Diaz HF, Bradley RS (1997) Temperature variations during the last century at high elevation sites. Clim Change 36:253–279

Diaz HF, Grosjean M, Graumlich L (2003) Climate variability and change in high elevation regions: past, present and future. Clim Change 59:1–4

Díaz J, García R, López C, Linares C, Tobías A, Prieto L (2005) Mortality impact of extreme winter temperatures. Int J Biometeorol 49(3):179–183

Evans EC, Petts GE (1997) Hyporheic temperature patterns within riffles. Hydrol Sci J (Journal Des Sciences Hydrologiques) 42:199–213

Fuhrer J, Beniston M, Fischlin A, Frei C, Goyette S, Jasper K, Pfister C (2006) Climate risks and their impact on agriculture and forests in Switzerland. In: Climate variability, predictability and climate risks. Springer, Dordrecht, pp 79–102

Goodbred SL Jr (2003) Response of the Ganges dispersal system to climate change: a source-to-sink view since the last interstade. Sed Geol 162(1–2):83–104

Goudie AS (2006) Global warming and fluvial geomorphology. Geomorphology 79(3–4):384–394

Hannah DM, Malcolm IA, Soulsby C, Youngson AF (2004) Heat exchanges and temperatures within a salmon spawning stream in the Cairngorms, Scotland: seasonal and sub-seasonal dynamics. River Res Appl 20:635–652

Hasanean HM (2001) Fluctuations of surface air temperature in the east Mediterranean. Theoret Appl Climatol 68(1–2):75–87

Hussain SS, Mudasser M, Sheikh MM, Manzoor N (2005) Climate change and variability in mountain regions of Pakistan implications for water and agriculture. Pak J Meteorol 2(4):75–90

IPCC (2007) Climate change and world food security: a new assessment. Glob Environ Change 9:S51–S67

Kapsomenakis J, Kolokotsa D, Nikolaou T, Santamouris M, Zerefos S (2013) Forty years increase of the air ambient temperature in Greece: the impact on buildings. Energy Convers Manage 74:353–365

Balanda KP, Mac Gillivray HL (1988) Kurtosis: a critical review. Am Stat 42(2):111–119

Kohler T, Maselli D, Neu U (2011) Mountains and climate change: a global concern. Alpine J 115(359):231–239

Livingstone DM, Dokulil MT (2001) Eighty years of spatially coherent Austrian lake surface temperatures and their relationship to regional air temperature and the North Atlantic Oscillation. Limnol Oceanogr 46(5):1220–1227

Marengo JA (2004) Characteristics and spatio-temporal variability of the Amazon River basin water budget. Clim Dyn 24(1):11–22

Meissner KJ, Weaver AJ, Matthews HD, Cox PM (2003) The role of land surface dynamics in glacial inception: a study with the UVic Earth System Model. Clim Dyn 21(7–8):515–537

Menzel L, Bürger G (2002) Climate change scenarios and runoff response in the Mulde catchment (Southern Elbe, Germany). J Hydrol 267(1–2):53–64

Mishra PK, Rai SC (2014) A cost–benefit analysis of indigenous soil and water conservation measures in Sikkim Himalaya, India. Mt Res Dev 34(1):27–35

Mitchell JM (Jr), Dzerdzeevskii B, Flohn H, Hofmeyr WL, Lamb HH, Rao KN, Wallen CC (1966) WMO Technical Note No. 79, World Meteorological Organization, Geneva

Monecke K, Winsemann J, Hanisch J (2001) Climatic response of Quaternary alluvial deposits in the upper Kali Gandaki valley (West Nepal). Glob Planet Change 28(1–4):293–302

Piao S, Ciais P, Huang Y, Shen Z, Peng S, Li J, Zhou L, Liu H, Ma Y, Ding Y, Friedlingstein P (2010) The impacts of climate change on water resources and agriculture in China. Nature 467(7311):43–51

Snyder PK, Delire C, Foley JA (2004) Evaluating the influence of different vegetation biomes on the global climate. Climatol Dyn 23:279–302

Türkeş M, Sümer UM, Demïr İ (2002) Re-evaluation of trends and changes in mean, maximum and minimum temperatures of Turkey for the period 1929–1999. Int J Climatol 22(8):947–977

Van Beers W (2005) Kriging metamodeling in discrete-event simulation: an overview. In: Proceedings of the 37th conference on Winter simulation. Winter Simulation Conference, pp 202–208

Vandenberghe J, Kasse C, Bohncke S, Kozarski S (1994) Climate-related river activity at the Weichselian-Holocene transition: a comparative study of the Warta and Maas rivers. Terra Nova 6(5):476–485

Villaba R, Lara A, Boninsegna JA, Masiokas M, Delgado S, Aravena JC, Roig FA, Schmelter A, Wolodarsky A, Ripalta A (2003) Largescale temporal changes across the southern Andes: 20th century variations in the context of the past 400 years. Clim Change 59:177–232

Wibig J, Glowicki B (2002) Trends in minimum and maximum temperature in Poland. Clim Res 20:123–133

Wigley TM (1985) Climatology: impact of extreme events. Nature 316:106–107

World Meteorological Organization (2003) Statement on the status of global climate in 2003. WMO, Geneva, Switzerland. Publication No. 966

Zhang X, Sheng W, Qi S (2018) Hazards and reflection on Fangshan District extreme rainstorm of July 21, 2012, the urban mountainous region of Beijing, North China. Nat Hazards 94(3):1459–1461

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.