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Research Paper

Assessment of heat and cold wave incidences and their link with land surface temperature in Bathinda district of Punjab, India

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ABSTRACT

This study investigates the incidence of heat wave and cold wave condition during 2000 – 2022 in the Bathinda district of South-Western region of Punjab. Notable spikes in heat wave (HW) activity were observed in 2002 and 2022 with 29 and 27 days respectively. Similarly, for severe heat waves (SHW), 2010 and 2022 witnessed the highest frequencies recording 16 and 18 days respectively. Conversely, cold wave (CW) events peaked in 2005 and 2008 with 10 and 11 days respectively. Notably, 2008 also observed the highest frequency of severe cold wave (SCW) days with 15 days. However, results revealed decline in cold wave days towards the latter years, while severe cold wave days also exhibited decreasing frequencies like 2015 and 2016 recorded zero CW and SCW days. One key finding highlights a substantial correlation between land surface temperature (LST) and maximum air temperature during heat wave periods ($R^2 = 0.83$), indicating LST's efficacy as an indicator for monitoring temperature trends during heat wave events.

Key words: Heat wave, Cold wave, Frequency, Land surface temperature, Severe heat wave, Severe cold wave

Heat waves are unusual meteorological occurrences that typically continue for three to seven days and have a high surface air temperature (Rohini *et al.,* 2016). According to the Indian Meteorological Department (IMD), heat wave and cold wave in India are the periods characterized by a significant increase/decrease in maximum/minimum temperatures. India, in particular, is significantly exposed to risks associated with heat waves (HW) and cold waves (CW) (Azhar *et al.,* 2022). Periods of extreme high temperatures can significantly reduce crop yields and cause reproductive failure in many crops (Chaudhury *et al*., 2000; Attri and Rathore 2003; Chakraborty *et al*., 2019, Dash and Mamgain 2011; Siebert *et al*., 2014; Steffen *et al*., 2014). This is due to increased water stress in plants, leading to plant death by halting photosynthesis (Schlenker and Roberts 2009; Steffen *et al*., 2014). Declines in agricultural productivity result in lower food production, subsequently leading to higher food prices. Chakraborty *et al*., (2019) investigated the impact of heat waves on wheat crop production in India, revealing a negative effect. The study found that wheat crop yields decreased by 4.9%, 4.1%, and 3.5% in Punjab, Haryana, and Uttar Pradesh, respectively. Cold waves have an impact on the Rabi crops in the northern regions of India. These crops, cultivated during the winter and harvested in the subsequent spring, are notably affected by the cold spells. The North Indian and Gangetic plain regions, which are vital for rice, wheat, and fruit production systems, rural employment, and national food security, are particularly at high risk from these extreme hot and cold spells (McCarl, 2013). Consequently, HW and CW events are significant socio-ecological concerns (Raymond *et al.,* 2020, Kumar and Singh, 2021).

Land surface temperature (LST) is a crucial metric obtained through remote sensing technologies, measuring ground or soil temperature, pivotal in various fields like meteorology, climatology, agriculture, urban planning, and environmental monitoring. LST indicates Earth's surface temperature, affecting soil and crop canopy temperature impacting plant growth, while measures surrounding air temperature influencing evaporation, transpiration, and photosynthesis rates in plants. Rajesh and Prasad (2024) noted a strong correlation between the near-surface air temperature and land surface temperature in the Samastipur district of Bihar.

MATERIAL AND METHODS

The study was conducted in the south-western region of

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Table 1: Criteria used in this study for defining heat and cold waves

Heat wave criteria based on maximum temperature (Tmax)	Cold wave criteria based on minimum temperature (Tmin)
Severity criteria for heat wave: For normal Tmax ≤ 40 °C: a) If (Actual Tmax- Normal Tmax) = 5- 6 °C (HW) b) If (Actual Tmax- Normal Tmax) = ≥ 7 °C (SHW)	Severity criteria for cold wave: For normal Tmin ≥ 10 °C: a) If (Actual Tmin- Normal Tmin) = −5 to −6 °C (CW) b) If (Actual Tmin- Normal Tmin) = ≥ −7 °C (SCW)
For normal Tmax> 40 °C: a) If (Actual Tmax- Normal Tmax) = 4–5 °C (HW) b) If (Actual Tmax- Normal Tmax) = ≥ 6 °C (SHW)	For normal Tmin< 10 °C: a) If (Actual Tmin- Normal Tmin) = −4 to −5 °C (CW) b) If (Actual Tmin- Normal Tmin) = ≥ −6 °C (SCW)

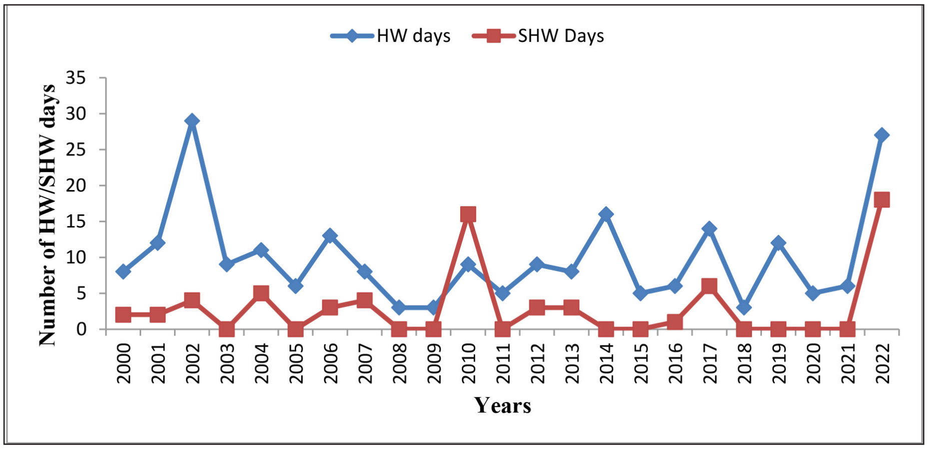

Fig. 1: Frequency and trend of heat and severe heat wave days during 2000 to 2022

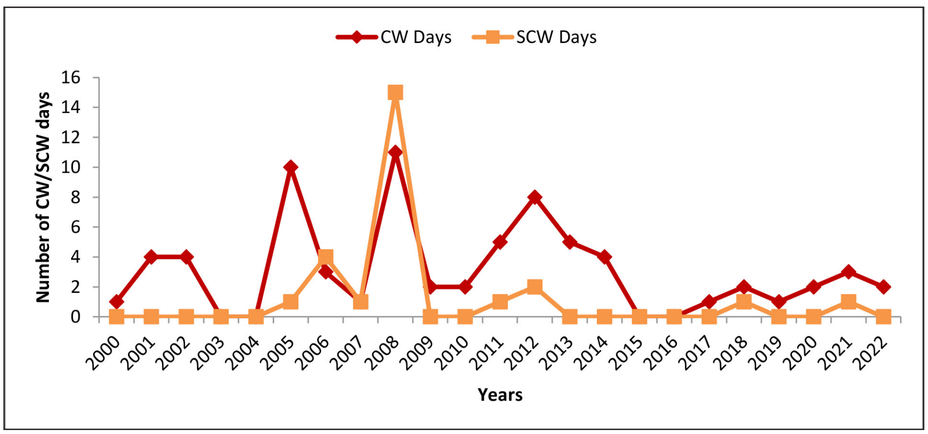

Fig. 2: Frequency and trend of cold and severe cold wave days during 2000 to 2022

Punjab, focusing on Bathinda, which is geographically situated at latitude of 30.58°N and a longitude of 74.18°E, with an altitude of 211 meters above sea level. The climate in this region is characterized by an annual average rainfall of approximately 450 mm, with 80% of this precipitation occurring during the southwest monsoon season, spanning from July to mid-September, and the remaining 20% in the winter months. The area experiences extreme weather conditions, including dust storms in summers, with temperatures occasionally exceeding 47.0°C in May and June, and frigid winters, notably in December and January, with minimum temperatures dropping to around 0.0°C. These seasonal variations in temperature and rainfall are significant drivers for the study. To conduct the analysis, the maximum temperature (Tmax °C) and minimum temperature (Tmin °C) for 23-year period from 2000 to 2022 was acquired from the Agrometeorological Observatory located at the PAU Regional Research Station in Bathinda.

Heat waves (HW) and cold waves (CW) criteria

The criteria used to define and identify heat waves (HW) and cold waves (CW) are detailed in Table 1 (Anonymous, 2022). These criteria are based on the deviation of daily maximum and minimum temperatures at the study station from specific threshold values in comparison to a climatological benchmark. For the computation of climatological values, a reference period spanning from 1969 to 1999 obtained from IMD was utilized. Usually when there is consecutive deviation of maximum temperature from

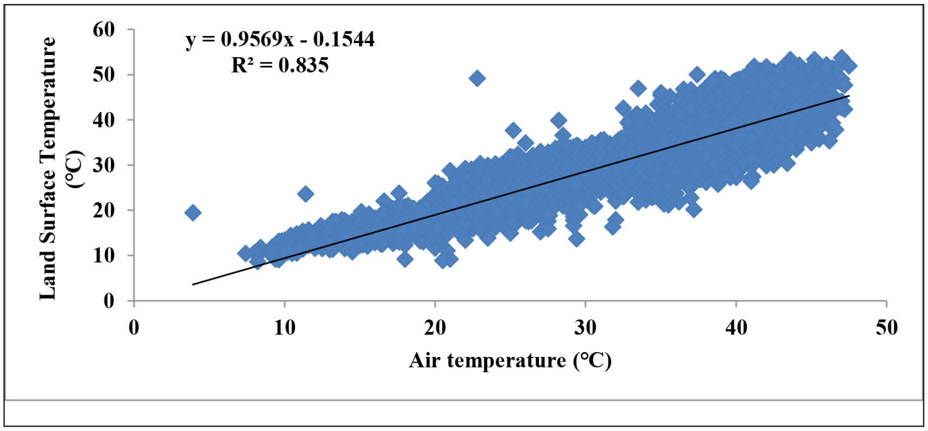

Fig. 3: Relationship between land surface temperature and air temperature

normal maximum temperature and negative deviation of minimum temperature from normal minimum temperature for two to three days then it is considered as heat and cold wave respectively as shown in Table 1. But present study each individual day was taken into consideration with deviations from historical normal maximum/minimum temperatures as potential heat/cold wave days for a more comprehensive analysis. It's noteworthy that instances of particularly severe heat waves (SHW) or severe cold waves (SCW) with higher levels of intensity were categorized separately.

Land surface temperature (LST) retrieval

Freely available daily MODIS (terra)-LST data was downloaded from the MOD11A1 version 0.061 sensor with 1 km spatial resolution, which further pre-processed and extracted for Bathinda district (30.21° N, 74.95° E) of Punjab using study area shape file in ArcMap 10.8 software for the span of 22 years (2000 to 2022). The LST data was then analyzed to establish its relationship with air temperature.

RESULTS AND DISCUSSION

Frequency of heat and severe heat wave days

The data presented in Fig. 1 illustrates the annual distribution of heat wave (HW) days and severe heat wave (SHW) days over the span of 23 years from 2000 to 2022. Notably, the years 2002 and 2022 stand out with the highest number of HW days, recording 29 and 27 days respectively. Moreover, the years 2006 and 2017 also experienced considerable HW days with 12 and 14 days respectively, which might signify specific periods of heightened heat stress on the environment. The prevalence of SHW days, characterized by even higher temperatures, is evident in the years 2010, 2017 and 2022, recording 16, 6 and 18 days respectively.

Pai *et al*., (2013) observed a noticeable uptick in HW and SHW days was across the India in the recent decade of 2001-2010 as compared to the preceding four decades. The investigation further identified significant long-term increasing trends in HW days over India throughout the analysis period. Panda *et al*., (2017) also noted that during the post-1980, there was a significant rise in the number, frequency, and severity of daytime heat waves. The years 2002 and 2010 also revealed a hotter-than-normal climate in India from 1998 to 2013. Kaur *et al*., (2022) noted a decline in the duration of extreme heat waves from 1971 to 2019. However, they observed an increase in both the frequency of heat wave events and their intensity during the same period at Jalandhar district of Punjab, India.

Frequency of cold and severe cold wave

The Fig. 2 illustrates the occurrences of cold wave (CW) days and severe cold wave (SCW) days spanning from 2000 to 2022. Over this period, the data showcases fluctuations in extreme cold events. Notable years include 2005 and 2008, which had the highest CW days, with 10 and 11 days respectively, while 2008 also experienced the most SCW days at 15. Conversely, some years, like 2015 and 2016, recorded zero CW and SCW days, indicating milder conditions. Smitha *et al*., (2016) conducted an investigation into the extended patterns of maximum duration for cold weather (CW) days within the cold weather season (DJF) spanning the years 1971 to 2020. Their findings demonstrated a discernible pattern of decreasing trends in the aforementioned maximum duration. This observation serves as a significant contribution to understanding of long-term climate trends. Kaur *et al*., (2022) observed rise the amplitude of cold waves exhibited a declining trend at Jalandhar district of Punjab, India.

Relationship between LST and air temperature

Relationship between land surface temperature (LST) and maximum air temperature from 2000 to 2022 reveals a compelling association. The high R^2 value of 0.83 demonstrates a substantial correlation between land surface temperature and maximum temperature (Fig. 3). This indicates that increases in maximum air temperature correspond to elevated land surface temperature, indicating a consistent temperature rise during heat wave occurrences. This substantial coefficient of determination underscores the utility of LST as a reliable indicator of temperature trends. It reviles the potential utility of satellite-derived LST data for monitoring and assessing heat wave conditions. Albright *et al*., (2011) observed good correlation of MODIS LST data and air temperatures and were generally more sensitive to summer-long heat waves. These results demonstrate the value of MODIS LST data for measuring ecologically-relevant heat waves across large regions. Mutiibwa *et al*., (2015) established a robust correlation between land surface temperature (LST) and near-surface air temperature (T_{air}). It is noteworthy that these two temperature parameters possess distinct physical meanings and exhibit diverse responses to atmospheric conditions. Also Lin *et al*., (2016) highlighted the pivotal roles of ground-level air temperature (Ta) and land surface temperature (LST) in various research areas, especially in complex mountainous settings. They examined Taiwan's regional monthly mean Ta alongside MODIS monthly mean LST data, unveiling robust correlation (0.91-0.96) and slight differences (1.25-1.77°C standard deviation). These insights hold significance for climate and ecology studies within challenging landscapes.

CONCLUSION

Investigation of temperature trends from 2000 to 2022 has yielded important information about the incidence and occurrence of heat waves (HW) and cold waves (CW) days in the Bathinda district, Punjab. The analysis turned out certain noteworthy years, such 2000, 2010, and 2022, that were marked by high heat frequencies and days with extreme heat wave days. On the other hand, there were notable instances of extreme cold wave days in a few different years, such as 2005, 2008, and 2012. Important insights were obtained from the link between land surface temperature (LST) and air temperature. The strong correlation between LST and air temperature ($R^2 = 0.83$) emphasized the utility of LST as a reliable indicator of temperature trends. In practical terms, the high connection between air temperature and LST indicates the potential value of LST data obtained from satellites for tracking and evaluating temperature conditions during severe occurrences. Ultimately, this study provides valuable insights into the temporal patterns of heat and cold wave occurrences in the south-western region (Bathinda) of Punjab and their connection to land surface temperature.

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