Assessing The Impact Of Heatwaves On Wheat Crop Health In Ludhiana District Using Remote Sensing Technologies

ABSTRACT

Climate change is becoming one of the major constraints for agricultural production. Impact on the crop yield due to unseasonal rain, hailstorms, and sudden temperature rise is becoming more frequent. The study assesses the damage done by the heat wave in the Ludhiana district of Punjab in the year 2021-22. Satellite datasets have been used named Sentinel-2 and MODIS datasets. By using the Sentinel-2 Images crop discrimination was performed and wheat crop mask was generated for the year 2018-19 to 2021-22. A comparison of the Normalized Difference Vegetation Index (NDVI) was performed for the study period. MODIS dataset was used to calculate the Temperature Condition Index (TCI) and Temperature Stress Index, which reflects the effect of the heatwave that happened in March 2022. APY (Area, Production, Yield) and data on the procurement of wheat for the year 2021-22 and normal years were compared to visualize the impact of heat wave on the various market dynamics such as production, productivity, etc.

Keywords – Climate, Heat Wave, Remote sensing, Satellite, APY, Wheat Crop Health

INTRODUCTION

Agriculture is the backbone of India, around 52% of Indians directly or indirectly depend on agriculture for employment(Department of Agriculture & Cooperation and Farmers Welfare, 2021). Almost all major cereals are produced in India, and 13.53% of the wheat is produced in India from the total production of the world (Ministry of Commerce & Industry, 2021).India is the second largest producer of wheat and major producing states are Utter Pradesh, Madhya Pradesh and Punjab[21-24]. These three states combined produce around 72% of the total wheat in India (Economic Survey of India,2023).The major chunk of the produce of wheat goes for domestic consumption, which makes wheat India's one of the most important staple foods.

Table 1: Top Five Wheat Producing States

State	Area ('000 ha)	Production('000 Tonnes)	Yield (kg/ha)
Uttar Pradesh	9683.6	33578.44	3468
Madhya Pradesh	5994	18639.78	3110
Punjab	3521.68	17151.03	4870
Haryana	2479.14	11611.46	4684

Rajasthan	2878	10299.69	3579

(Source – Directorate of economics and statistics)

Climate change is a major concern for crops,and various studies have beenconducted to assess the long-term impact of climate change in the agriculture sector. It is estimated that in the long run due to climate change crop production could be reduced severely(Guiteras, 2009), due to sudden impacts on the crop like unseasonal rain or hailstorms which affect the market because of sudden supply cuts prices of the commodities get higher.

Wheat crop is mostly grown in the rabi season in India and the key stages of the wheat crop are: Seedling emergence, Tiller initiation, Node stage, Boot Stage, Emergence of earhead, Milk stage, Dough stage, and Maturity (Pandey *et al.*, 2010).Each stage has specificrequirementsfor certain weather conditions. Many studies have been done which found under heat stress duration of the grain filling gets reduced and the supply of photoassimilates gets reduced ultimately hindering the proper grain filling in the wheat (Calderini*et al.*, 2006; Dias and Lidon, 2009; Yin *et al.*, 2009).

The widespread availability of high-resolution satellite imagery, coupled with its increasing affordability and accessibility, has revolutionized crop monitoring. Compared to traditional, labor-intensive field-based methods, satellite data enables cost-effective and large-scale crop health assessments, growth patterns, and even potential disease outbreaks (Defourny*et al.*, 2019). Furthermore, developing advanced algorithms for analyzing satellite imagery allows for even deeper insights, facilitating yield prediction, irrigation management, and precision agriculture practices (Defourny*et al.*, 2019).

MATERIALS AND METHODS

Study Area

The area selected was purposively chosen as one of the prime wheat-growing regions, specifically the Ludhiana district in Punjab and it was one of the impacted regions during the heatwave in 2021-22.The Ludhiana districtis located in the central part of Punjab, India. Ludhiana is well-known for its lush terrain and thriving agricultural industry. Comprehending the intricate relationships among diverse elements such as terrain, soil, climate, and additional crop-related concerns is essential to valuing the agricultural achievements of the area. Ludhiana's 3767 sq. km of total land area is split between the upland plain region and the Sutlej flood lowlands. The district on average receives 551mm of rain(Source – ICAR-CRIDA).

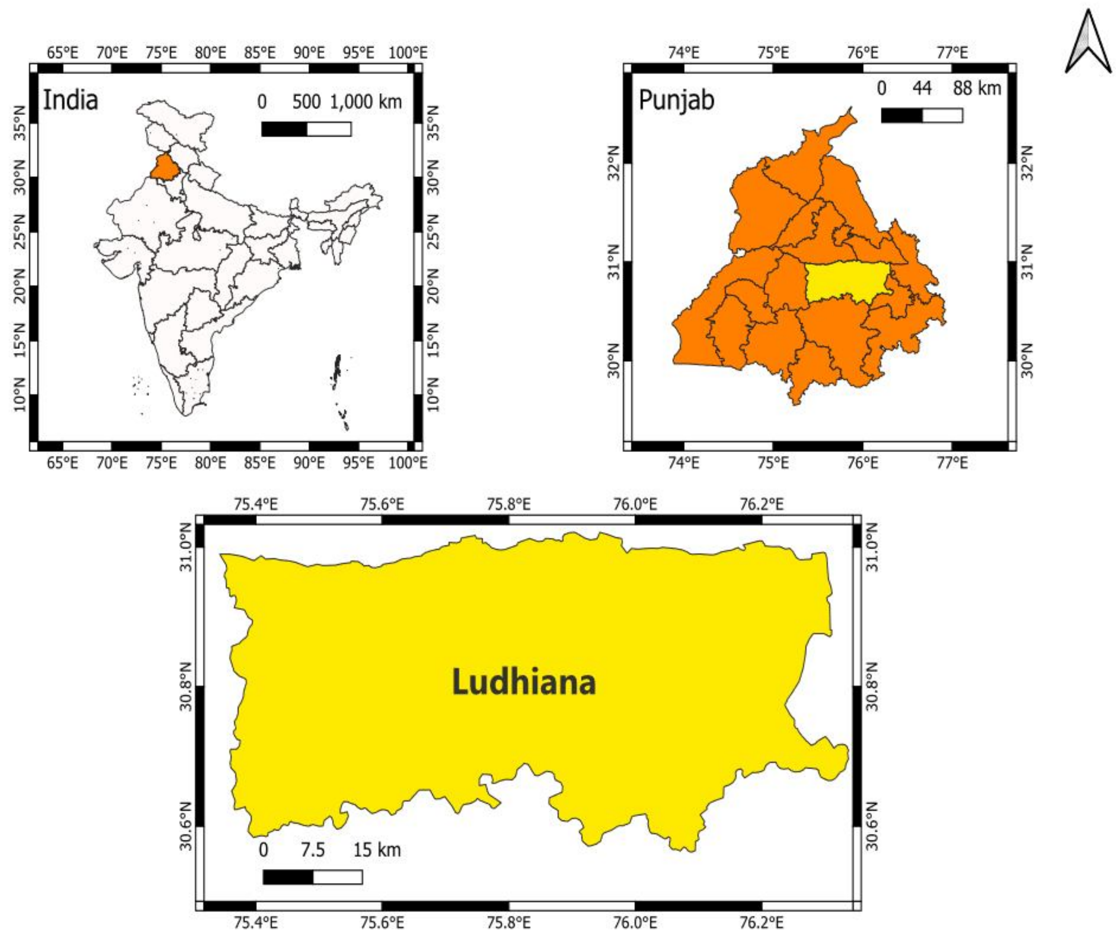


Fig. 1: Study Area

Image Acquisition

GEE is a free cloud platform that hosts petabyte scales of remotely sensed data from the years, including Landsat, MODIS, National Oceanographic and Atmospheric Administration Advanced Very High-Resolution Radiometer (NOAA AVHRR), Sentinel 1, 2, 3 and 5-P data, and Advanced Land Observing Satellite (ALOS) data (Vora *et.al.*, 2023).

In this study, Sentinel-2 images were acquired from the Google Earth Engine (GEE) for the study period of the rabi season. Images from the Sentinel-2 dataset were used in the study.

Sentinel-2 images have in total 13 bands from which 5 bands were used in the study, which are B2, B3, B4, B8, and B11. QGIS was used for crop classification by utilizing separated image stack of each year.

Crop Classification

Crop classification in this study employed a pixel-based approach (Avci *et al.*, 2011). Initially, unsupervised machine learning was utilized for classification, followed by expert validation and consideration of local cropping patterns (Wang et al., 2019). The Iterative Self Organizing Data Analysis Technique (ISODATA) was employed consistently across all years, resulting in the generation of 250 classes over 15 iterations (Avci *et al.,* 2011). Each class was labelled based on the phenological profiles of the crop, following the creation of wheat masks for each year.

NDVI (Normalized Difference Vegetation Index)

The NDVI is calculated from these individual measurements as follows:

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}$$

where Red and NIR stand for the spectral reflectance measurements acquired in the red (visible) and near-infrared regions, respectively. This spectral reflectance are themselves ratios of the reflected radiation to the incoming radiation in each spectral band individually, hence they take on values between 0 and 1. By design, the NDVI itself thus varies between -1 and +1. NDVI is functionally, but not linearly, equivalent to the simple infrared/red ratio (NIR/VIS)(Crippen, 1990).

Temperature Condition Index

TCI was developed by Kogan, 1995.TCI is calculated based on the below-mentioned equation. MOD11A2 dataset version 6 of the 8-day composite was used for the calculation. In total past 10 years data were used of the same date and same pixels of selected timespan to drive maximum and minimum temperature for each pixel.

$$\text{Temperature Condition Index} = \frac{T_{max} - T_i}{T_{max} - T_{min}} * 100$$

Temperature Stress Calculation

MOD11A2 dataset version 6 which providesan 8-day composite image was downloaded for the study period to analyse the effect of the heatwave.

Temperature stress was formulated by Raich,1992.

$$\textit{Temperature Stress Index} = \frac{(T - T_{min})(T - T_{max})}{[(T - T_{min})(T - T_{max})] - (T - T_{opt})^2}$$

Whereas,

T = Temperature,

T_{min} = Minimum Temperature

T_{max} = Maximum Temperature

T_{opt}= Optimum Temperature

For the calculation of temperature stress in which T_{min}, T_{max}, and T_{opt} are 5°C, 35°C, and 25°C respectively (Porter and Gawith, 1999).

RESULT AND DISCUSSION

At first crop discrimination was performed to get the wheat crop mask for each year, after that NDVI, TCI, Temperature Stress was calculated for each year to visualize the impact of the heatwave. At last, APY data was used from various sources to analyze impact on the market dynamics.

For the crop classification,a total of 250 classes, 0.950 convergence, and 15 interactions were performed to run ISODATA algorithm. Each class waslabelled and the wheat crop was identified.

NDVI Comparison of Heat Wave Year to Normal Years

To calculate the NDVI, Sentinel-2 dataset was used. Below Fig. 2 indicates there is no significant effect visible in the year 2021-22, when the heat wave damaged the crop. In the year 2021-22, the line is almost the same as the past two years which were normal and it also indicates the growth and senescence of the crop.

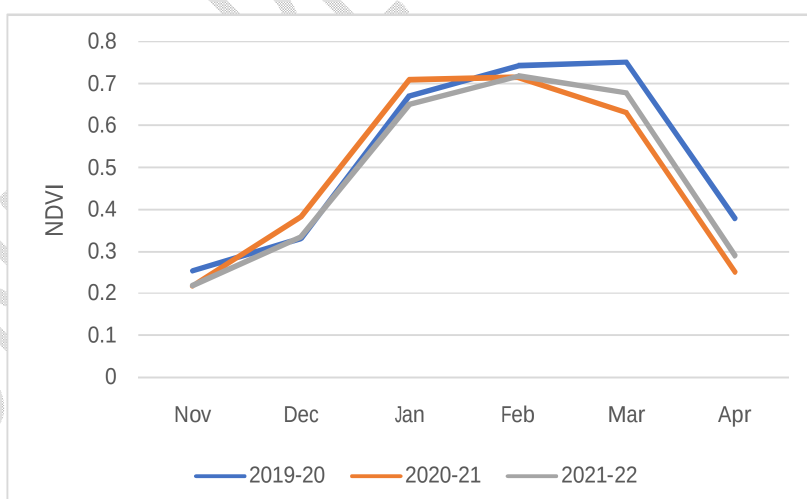


Fig.2: NDVI Comparison of 2021-22 with Past Years

Analysis of Meteorological Parameter

In addition to NDVI analysis, meteorological parameters such as temperature and rainfall deviations are considered to understand their influence on crop health. Temperature data, specifically weekly mean maximum (T_{max}) and minimum temperatures (T_{min}), are examined for deviations from normal conditions during critical growth stages.

During the wheat grain filling/development stage, consistently higher temperature was recorded compared to normal, indicating potential stress on the crops. Similarly, a marked reduction in rainfall during February and March exacerbated the heat wave conditions, potentially leading to yield reduction in wheat.

Weekly temperature data is presentedin Table2 which highlights the deviations from normal temperatures for the year 2022.

At Ludhiana, the weekly mean maximum (T_{max}) and minimum temperatures (T_{min}) were consistently higher than normal during the March month except the first week (which was recorded near to normal), coinciding with wheat's grain filling/developmentstage. The deviation of weekly mean T_{max} andT_{min} ranged from -0.4 to +7.2 °C and +0.8 to +5.8 °C, respectively (Source – NASA).

Table 2:Comparison of Average Temperature with Jan-Mar 2022

Week	Normal Temperature	Temperature. in 2022	Deviation from Normal Temperature
1	14.6	18.8	4.2
2	15.8	17.8	2.0
3	16.2	17.9	1.7
4	19.1	16.4	-2.7
5	19.7	19.4	-0.3
6	20.1	20.5	0.4
7	21.9	23.2	1.3
8	22.5	24.2	1.7
9	23.8	23.4	-0.4
10	25.2	28.5	3.3
11	27.7	34.5	6.8
12	29.2	36.1	6.9
13	31.1	38.3	7.2

(Source – NASA; ICAR-Central Research Institute for Dryland Agriculture)

Temperature Condition Index

GEE (Google Earth Engine) was used to calculate the TCI, which is represented in Fig. 3. In the March month for almost all the week'sconditions for the crop were unfavourable ascompared to the past decade, which falls in the range most stressed condition.

GEE was used to generate the precipitation maps from the CHIRPS dataset, which is represented in Fig. 4. All the images indicate the weekly total precipitation that occurred for the year 2022 for the Ludhiana district of Punjab.

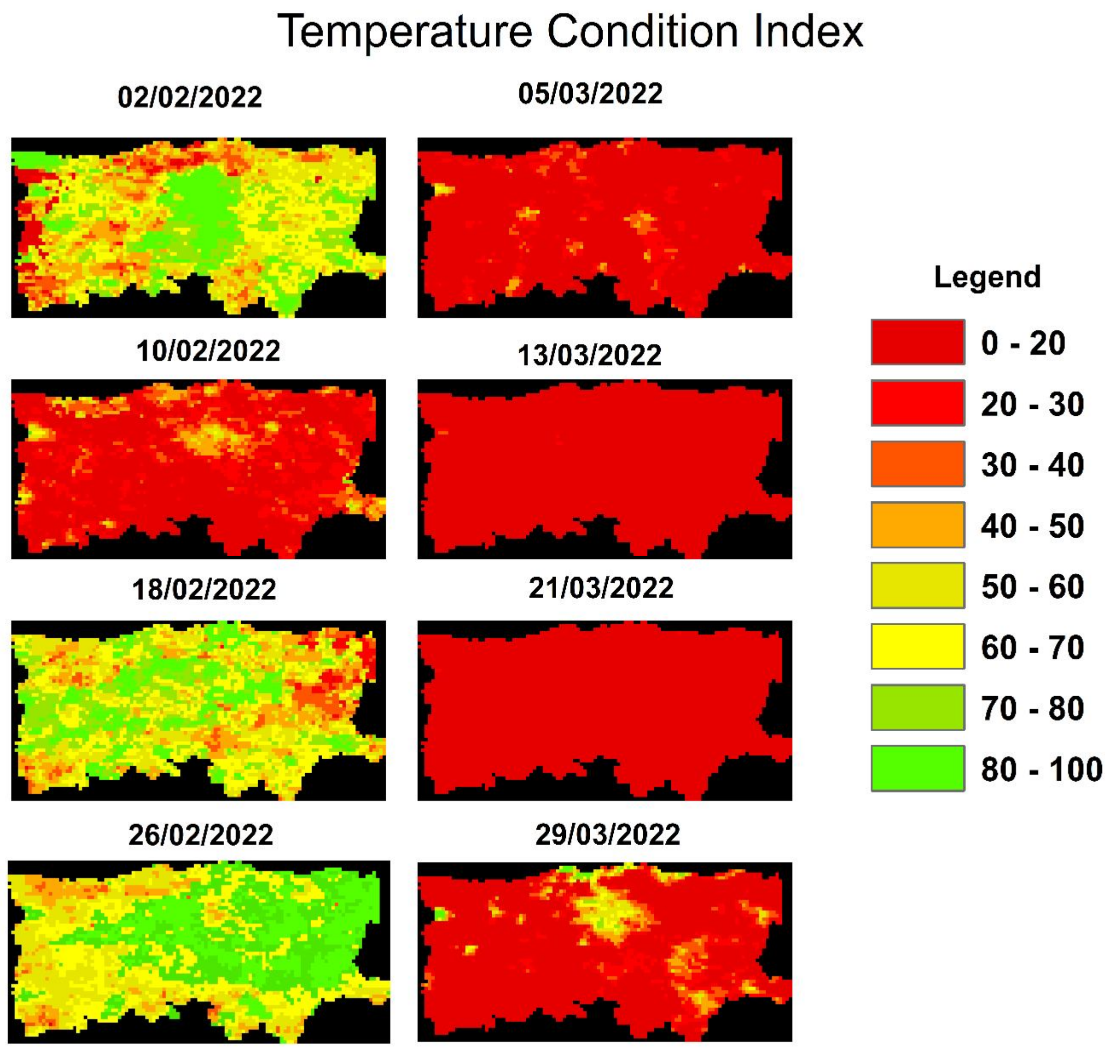
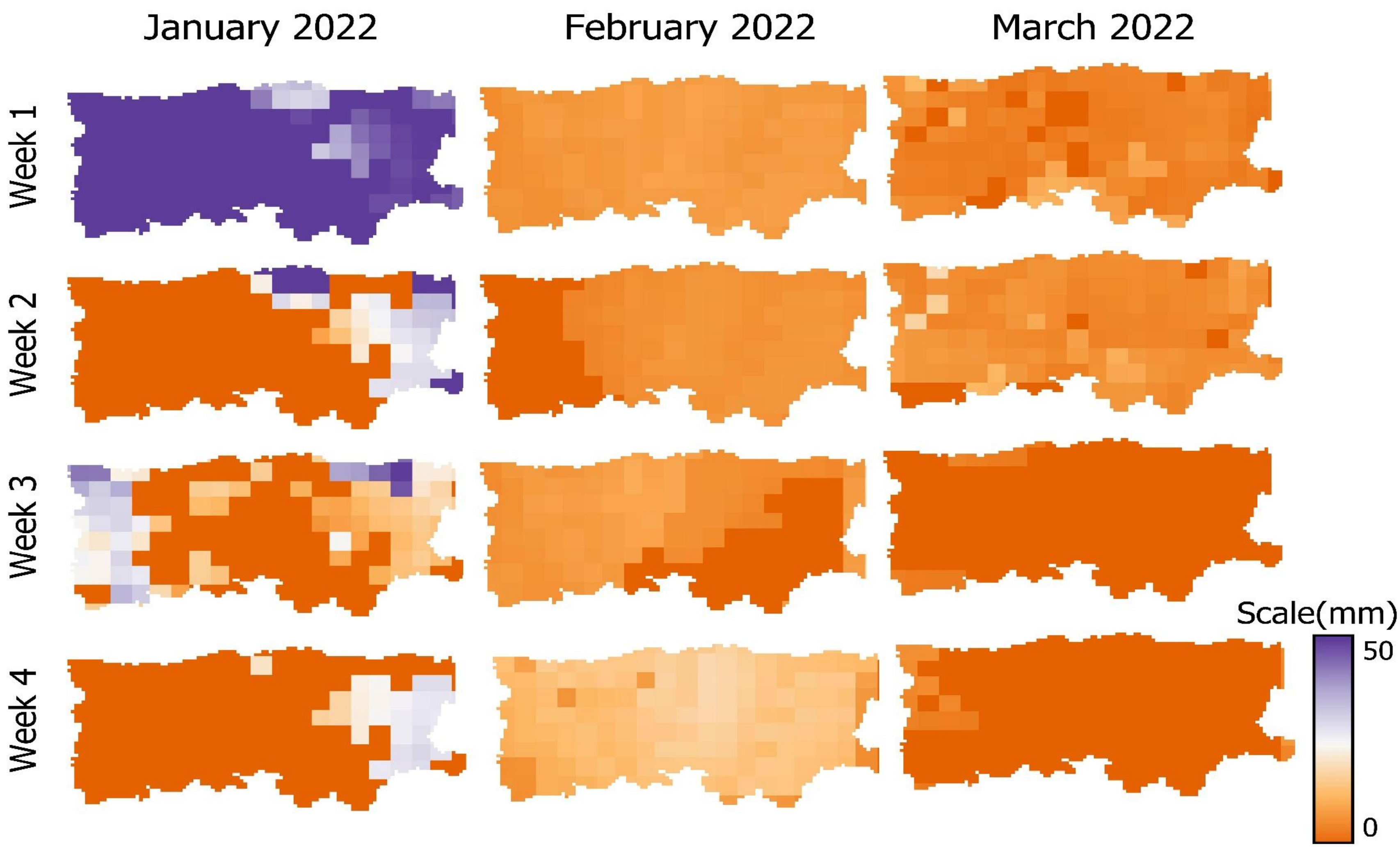


Fig.3: Temperature Condition Index

Other sources also confirm the lack of precipitation from February to March. As per Bal *et al.*, 2022 therewas a marked reduction in rainfall fromFebruary toMarch (a reduction of 48.5 mmcompared tothe normal). Both of these changes may cause considerable yield reduction in wheat.

Thedeviation of maximum daytime temperature ranged from +6.3to +7.2 °C during 11-14 standard meteorological weeks (SMW), while the minimum nighttime temperature varied from +2.3 to +5.8 °C. No rainfall was recorded at Ludhiana during 10-20 SMWs, which might haveaggravated the heat waveconditions there. During this time, a rainfall deficit of 55 mmwas recorded. (Bal *et al.,* 2024)


January 2022
February 2022
March 2022
Week 1
Week 2
Week 3
Week 4
Scale(mm)
50
0

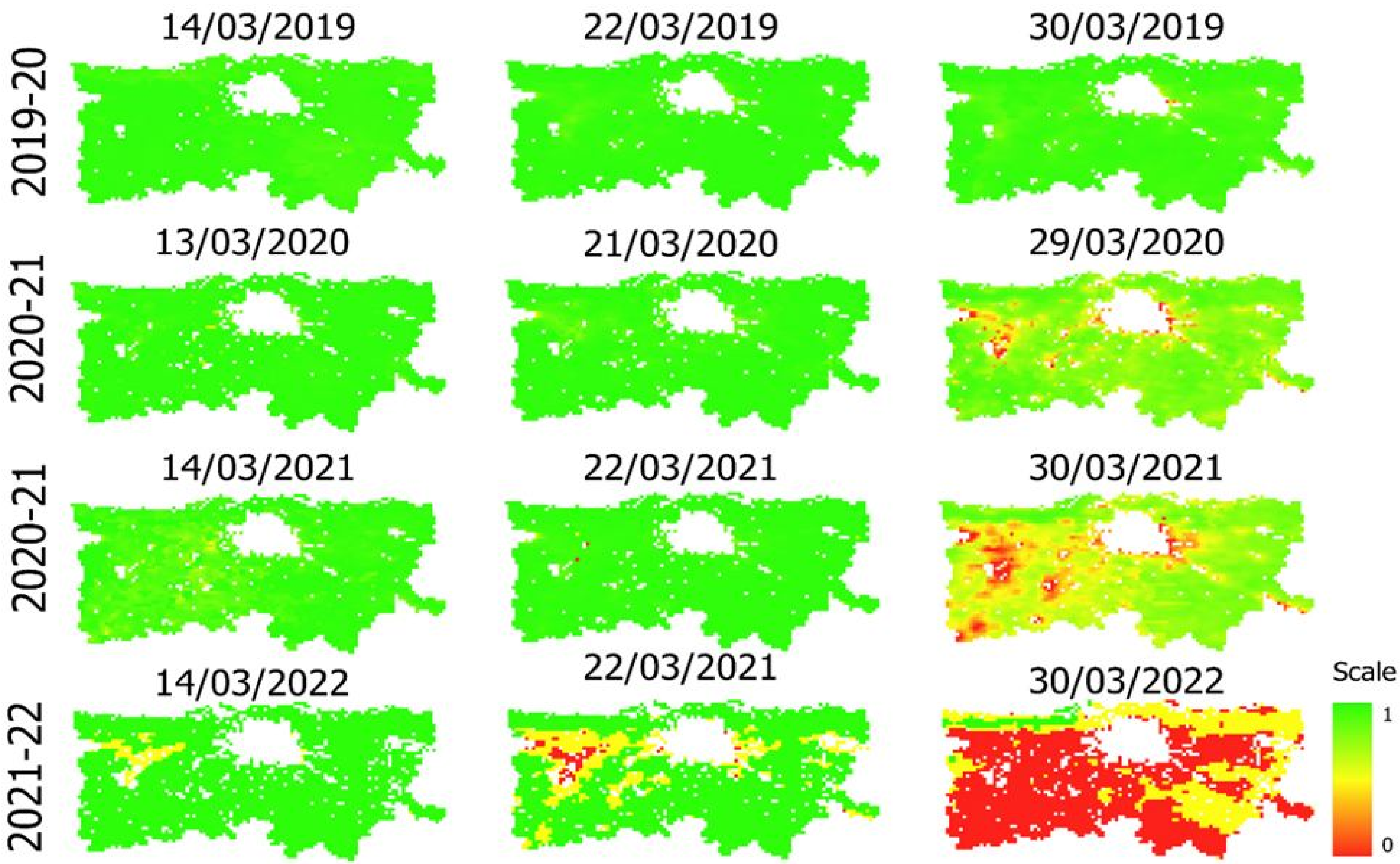


Fig. 5: Temperature Stress

Temperature Stress Index

GEE was used to calculate the temperature stress which is represented in Fig. 5. In the year 2021-22 it is visible that at the end of the month above the favourable condition for the wheat which impacted the grain-filling stage and ultimately impacted the production and productivity.

Analyse the Effect of Heat Wave using Market Dynamics

For analyzing the effect of the heat wave on the market dynamics were used data such as production, productivity, price, and procurement done by the Government of India

Effect of the Heat Wave on the Price

The price of the produce in the market such as APMC depends on the demand and supply of the commodity traded. The lower supply at higher demand will increase the price of the commodity.

In the year 2019-20, price of the wheat was less than the MSP in the market. In the year 2021-22 the price of wheat increased by almost 20 % from the previous year at the same time, MSP only increased by 2% only.

Table 3: Prices of the Wheat

Year	Price (Rs/Qt)	MSP (Rs/Qt)
2018-19	1884	1840
2019-20	1911	1925
2020-21	1840	1975
2021-22	2095	2015

(Source – Indiastat)

Fig. 7 shows the market price of the wheat and its comparison with the MSP from 2018-19 to 2021-22. It is visible that price of the wheat was high as compared to the past three years. (Source – Indiastat).

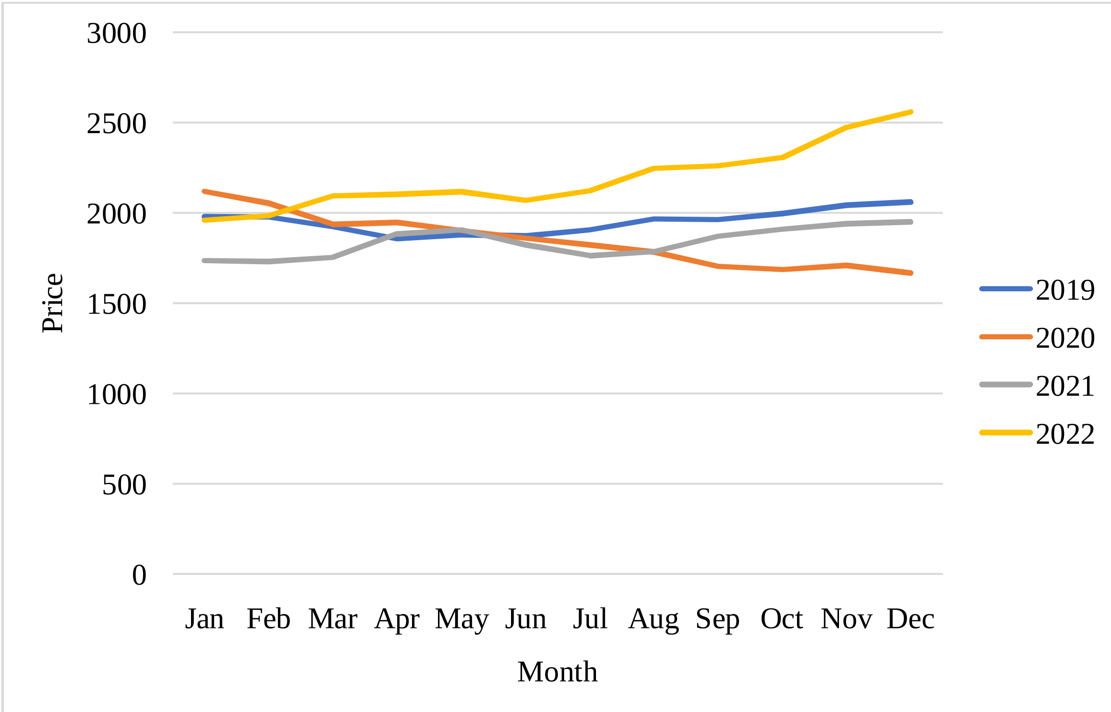


Fig.6:Market Price of Wheat

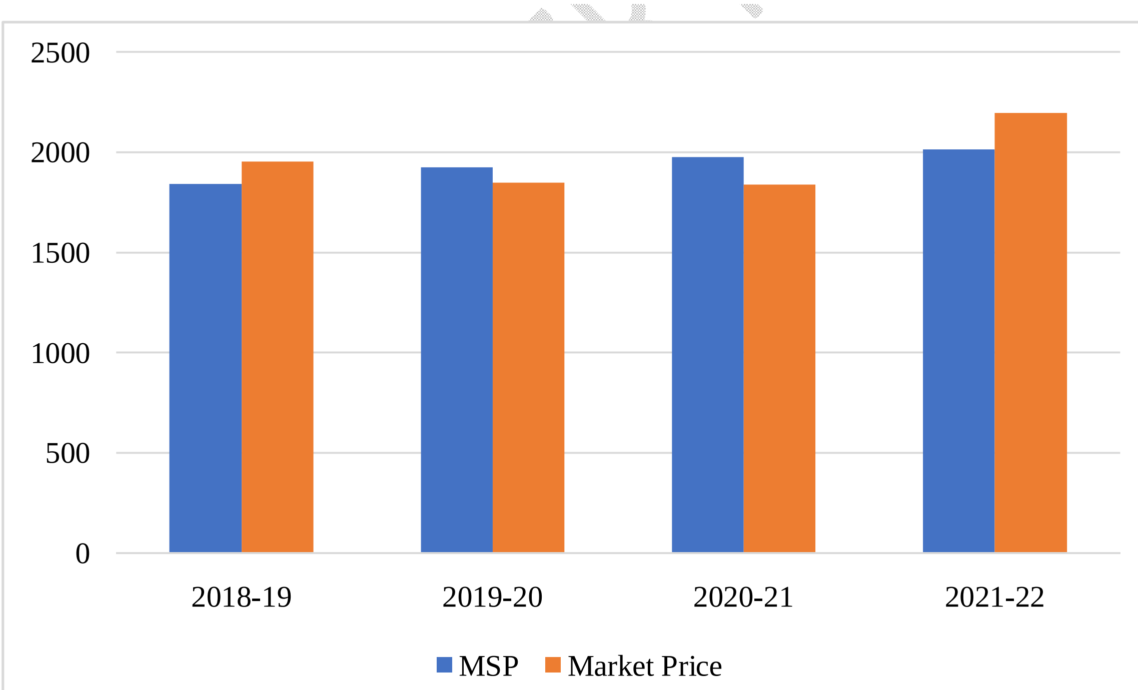


Fig.7:Comparison of Market Price of Wheat with MSP

Effect of the Heat Wave on the Production

As per literature review,estimation of the wheat production cut varies between 4.5% to 15% in the different parts of India (Sindhu, 2023). Table4 shows the production of wheat in the Ludhiana district of Punjab.

Table 4: Wheat in

Production of Ludhiana

Year	Production (LMT)
2018-19	12.88
2019-20	12.75
2020-21	12.41
2021-22	10.44

(Source - Directorate of Economics and Statistics, India)

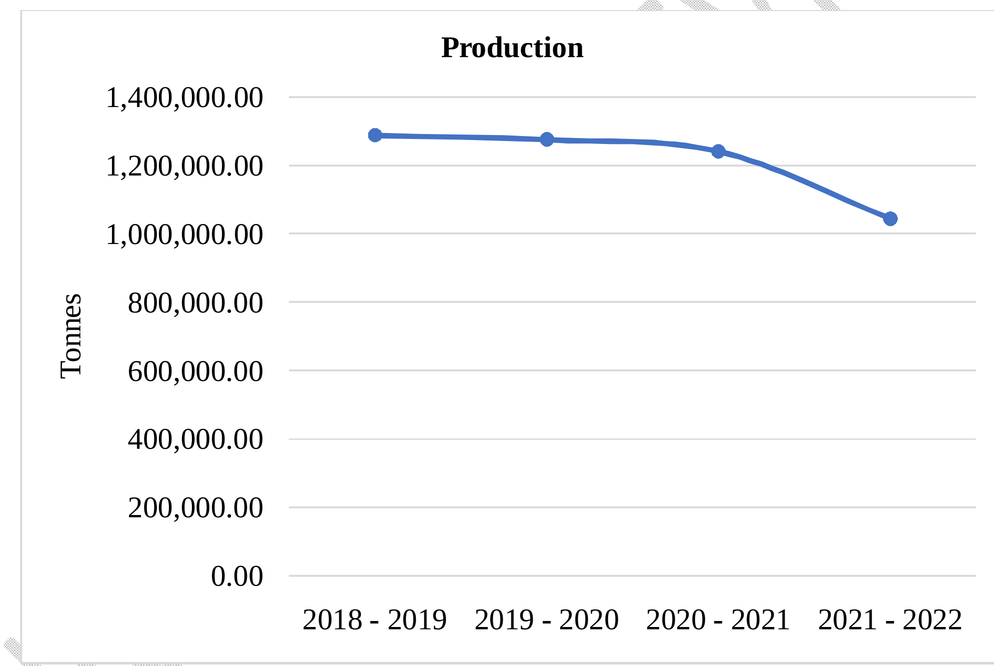


Fig.6:Wheat Production in Ludhiana

Effect of Heat Wave on the Productivity

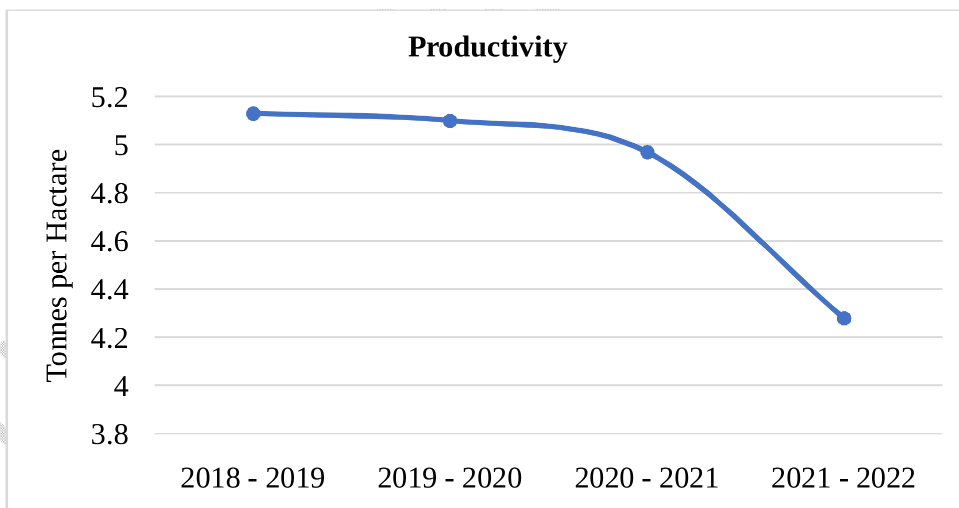
Heatwave occurred at the time of the grain-filling stage of the wheat crop. The grain-filling stage in the wheat is very sensitive to slight temperature fluctuations which severely impacts the yield and productivity (Asseng *et al.*, 2011). As per the study conducted before ±2 fluctuation in the temperature could impact yield by up to 50% (Asseng *et al.*, 2011). We have previously discussed the temperature fluctuation that occurred at the Ludhiana. Table 5 shows the yield of wheat in the Ludhiana district of Punjab.

Table 5: Yield of Wheat in Ludhiana

Year	Yield(Tonnes/Hectare)
2018-19	5.05
2019-20	4.88
2020-21	4.79
2021-22	4.10

(Source - Directorate of Economics and Statistics, India)

Fig.7: Yield of Wheat in Ludhiana



Effect of the Heat Wave on the Wheat Procurement

FCI procures the wheat for the public distribution system from the various states which majority of the procurement is done from Punjab, Haryana, Utter Pradesh, Madhya Pradesh, and Rajasthan. As per FCI data around 30-50% of wheat procurement is done from Punjab only (Source – FCI). This also makes the procurement more dependent on the states which ultimately depends on the total production and productivity of the state itself.

To analyze the effect of the heatwave past procurement data is recorded from the FCI reports which is shown in Table 6 with a graphical representation in Fig. 10. Table 6 shows that procurement of wheat from Punjab was down by almost 30% in RMS 2022-23.

Table 6: Total Procurement of Wheat in Punjab

Year	Procurement (in LMT)
RMS 2019-20	129.12444
RMS 2020-21	127.13681
RMS 2021-22	132.22183
RMS 2022-23	96.46954

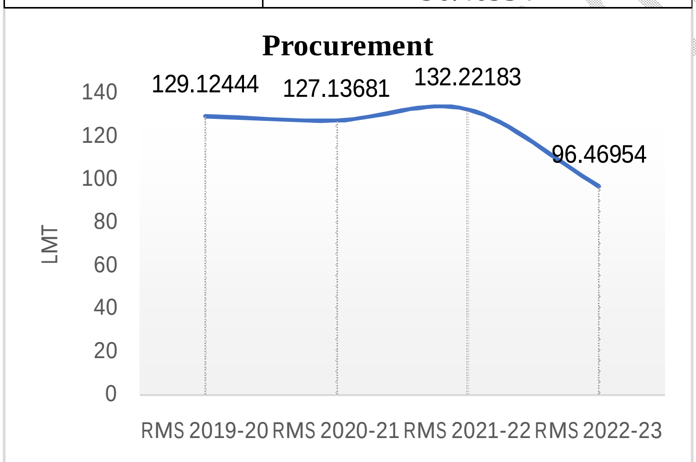


Fig. 10:Total Procurement of Wheat in Punjab (LMT)

At national level, total procurement of wheat was down by 56% in the RMS 2022-23 than the previous year's total procurement which shown in the Table 7. In the RMS 2022-23 the targeted procurementof 444 LMT, which was done only up to 188 LMT, which missed by almost 58%of the targeted estimation due to the heat wave impact on the wheat production. (Source – Food Corporation of India).

Table 7: Total Procurement of Wheat in India

Year	Procurement (in LMT)
RMS 2019-20	341.32
RMS 2020-21	389.92
RMS 2021-22	433.32
RMS 2022-23	188.00

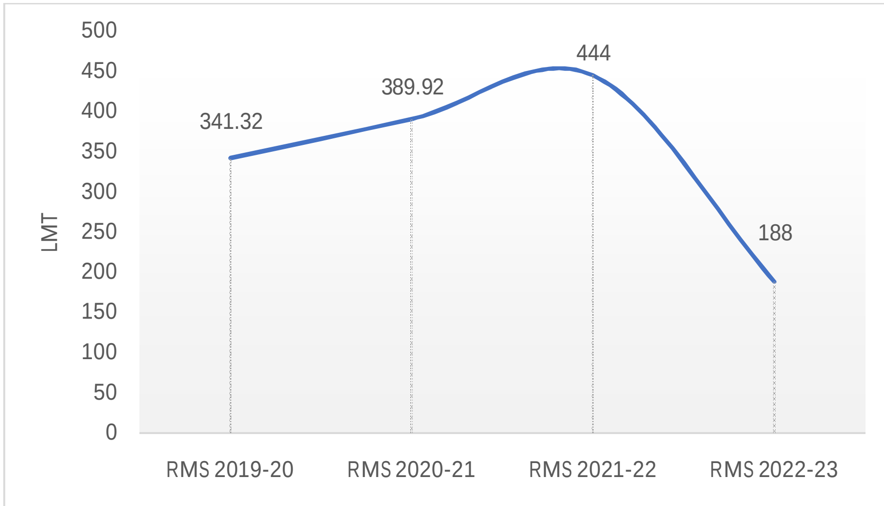


Fig.11: Total Procurement of Wheat in India

CONCLUSION

The grain-filling stage of wheat crops is highly susceptible to temperature fluctuations, which can significantly diminish yields by causing grain shriveling. The devastating impact of heatwaves on wheat yield during the 2021-22 season is a stark reminder of this vulnerability, as evidenced by production, productivity, and procurement data. One potential solution lies in the development of heat-tolerant wheat varieties, offering resilience against such climatic challenges.

However, proactive monitoring of regional temperatures is equally critical, enabling stakeholders to anticipate and adapt to impending shocks. To enhance this approach further, there's an opportunity for refinement through detailed temperature recording, encompassing minimum, maximum, and optimum thresholds specific to each wheat variety and its respective region. Such precision in data collection and analysis holds promise for more accurate predictions of yield losses, empowering agricultural stakeholders to implement targeted mitigation strategies effectively.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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