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RESEARCH ARTICLE

Environmental Impact of Lockdown Amid COVID-19 Over Agricultural Sites in Himalayan Foothills

Shweta Pokhariyal[1] · N. R. Patel[1] · R. S. Rana[2] · Prakash Chauhan[3]

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Abstract
Human life has come to a standstill when the countrywide lockdown was imposed to curb the infection of the highly contagious COVID-19 pandemic. Mass transportation and industrial activities were prohibited, which has proven advantageous for the environmental quality. This study was conducted to investigate the impact of lockdown on the environmental parameters measured over agricultural ecosystems in the Himalayan foothills [Saharanpur Flux Site (SFS) and Palampur Flux Site (PFS)], India. The UV–Aerosol Index obtained from the Sentinel-5 Precursor satellite falls drastically after imposing lockdown particularly in both the agricultural regions. It reached up to −3.082 and −3.522 during the first lockdown in SFS and PFS, respectively. Furthermore, due to the lesser availability of aerosols into the atmosphere, the availability of direct radiant energy increased, thus led to warming the earth's surface. Improvement in direct radiant energy and normalized difference vegetation index positively increases the gross primary productivity in SFS and PFS.

Keywords COVID-19 · Lockdown · Agriculture · UV–Aerosol Index · Land surface temperature

Introduction

The COVID-19 pandemic caused by severe acute respiratory syndrome Coronavirus 2 (SARS-CoV-2) is affecting about 213 countries around the world (Worldometers.info, 2020). It is a highly infectious disease initially originated in December 2019 in Wuhan, Central China, which can be shifted from person to person via respiratory droplets. As of now, over 5.5 million virus-infected cases reported all over the world. (Worldometers.info, 2020). Since there is currently no vaccine available to prevent the pandemic, several countries across the world have resorted to stern actions to maintain social distancing by imposing nation-wide lockdown and restrictions. Human life has come to standstill since February 2020. Due to the contagion nature of COVID-19, the Indian government too followed suit and imposed a nation-wide lockdown on 25 March 2020 for three weeks up to 14 April 2020. This government actions placed its 1.3 billion people to follow the strict regulations for curbing spread of Covid-19 and later it was extended up to 3 May 2020.

It is proved fact that the anthropogenic activities owing to economic growth can trigger many changes in the environment like unhealthy air quality, undrinkable water, and climate change. Since the countrywide mandate prohibited almost all mass transportation and industrial activities, so it is expected that the environment would rejuvenate. Consequently, the pollution level in 88 cities across the country drastically plummeted within four days of commencing lockdown (Sharma et al., 2020). Globally,

✉ Shweta Pokhariyal
shwetapokhariyal6@gmail.com

N. R. Patel
nrpatel@iirs.gov.in

R. S. Rana
rsrana6@gmail.com

Prakash Chauhan
prakash@iirs.gov.in

[1] Agriculture and Soils Department, Indian Institute of Remote Sensing ISRO, Govt. of India, 4, Kalidas Road, Dehradun, Uttarakhand 248001, India

[2] CSK Himachal Pradesh Agricultural University, Palampur, Uttarakhand 176062, India

[3] Indian Institute of Remote Sensing ISRO, Govt. of India, 4, Kalidas Road, Dehradun 248001, India

several studies are carried out to assess the impact of lockdown on environmental quality (Bashir et al., 2020; Mahato et al., 2020; Mandal & Pal, 2020; Muhammad et al., 2020; Sharma et al., 2020). In the same way, the lockdown has an impact on the water quality (Yunus et al., 2020) and proven as a ventilator for most-polluted Indian rivers, namely Ganga and Yamuna. In Ganga River, to assess the water quality during the lockdown period, out of the 36 monitoring systems placed at different points, water quality at the 27 points found suitable for bathing and propagation of wildlife (Down to earth, April 2020). Similarly, Yamuna River looks clearer than before as all the industrial units are at standstill.

Therefore, lockdown presumes to be an effective approach to implement for controlling the pollution levels. Undoubtedly, the nation-wide lockdown had exerted a widespread and strong positive impact on the air quality over the city area, where curbing of anthropogenic activities led to drastic reduction in the emission from vehicles and industries. According to the satellite data published by US space agency National Aeronautics and Space Administration (NASA) on 21 April 2020, over the northern Indian region, a drastic reduction in the aerosol levels reported, particularly over the Indo-Gangetic Plains. While on the other sides, in the southern Indian region, slightly higher aerosol levels than in the past four years have reported. Varied impact of the nation-wide lockdown on the environmental situation in a different region provides an impetus to assess the situation under varied ecosystems.

This study perhaps the first attempt to discern the impact of lockdown periods over the agricultural region with in situ and satellite observations. The two-fold objectives of the present study are (i) to assess the variation in satellite-derived and meteorological parameters over the two agricultural regions during the pre-lockdown and lockdown periods, and (ii) to compare the variation with the year 2019 during the same time window from March to May.

Study Area

To assess the variation in the micro-meteorological parameters at agricultural sites during the lockdown period, data from two eddy flux tower stations falling within the agricultural regions have been taken into consideration (Fig. 1). The present study has focussed on the two agricultural sites, namely Palampur (PFS) and Saharanpur flux tower sites (SFS), situated at different elevations. Eddy covariance flux towers installed at these agricultural sites have varied climate regimes and physiographic setting and thus holds suitable for comparative evaluation and assessment of the micro-meteorological parameters. PFS is located at 32° 6′ 54.59″ N and 76° 24′ 59.66″ E

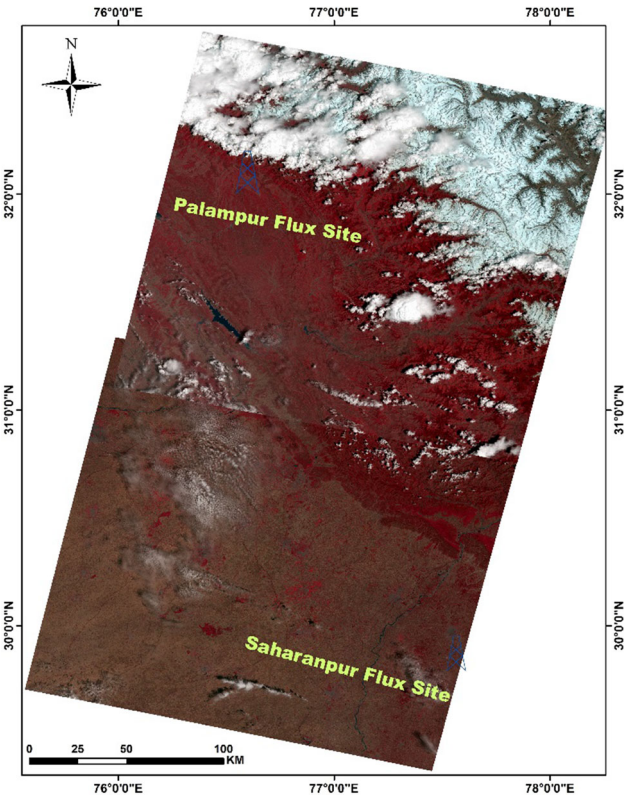

Fig. 1 Location of the flux tower sites selected for the study

coordinates, at an elevation of 1472 m above mean sea level. It is situated in the north-western part of Himachal Pradesh characterized by a monsoon-influenced humid subtropical climate (Cwa), with hot summers and cool winters. The area dominated by the wheat crop during the same time windows in the year 2019 and 2020.

On the other sides, SFS (29°52′19.139“ N and 077°34′01.621” E) is located in the fertile range of Upper Indo-Gangetic Plains at an elevation of 265 m above sea level. SFS is located in midst of the farmer's crop field majorly dominated by sugarcane, wheat, and rice crop. According to the Köppen and Gieger classification, the climate in SFS is characterized by dry sub-humid to semi-arid subtropical climate (Csa). The area dominated by sugarcane plants in the year 2019 and followed by ratooned sugarcane in the following year.

Material and Methods

Satellite Data

MODIS

MODIS (Moderate Resolution Imaging Spectroradiometer) is a payload imaging sensor on board sun-synchronous

polar orbital satellites, namely Terra and Aqua. In the current study, TERRA-MODIS satellite data utilized to extract land surface temperature (LST), gross primary productivity (GPP), normalized difference vegetation index (NDVI) from the respective study sites. The LST data produced using the split-window algorithm, continuously enhanced for quality improvement (Wan, 2014). We utilized the MOD11A2 (version 6) LST data which provides averaged 8-day per pixel LST with a 1 km spatial resolution. In this study, day-time 8-day composite LST data under clear sky conditions were utilized for the year 2019 and 2020 at the same time window from March to May. Each MODIS product delivered in a gridded HDF format with 10:30 local solar time for the LST during the day.

The MOD17A2H gross primary productivity (GPP) product is a cumulative 8-day composite GPP available at 500 m spatial resolution. The 8-day GPP values were extracted from March to May in year 2019 and 2020. Similarly, NDVI was calculated from the MODIS surface reflectance product (MOD09A1) available at 500 m spatial resolution. NDVI was calculated using the formula:

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{RED})/(\mathrm{NIR} + \mathrm{RED})$$

where NIR represents the near-infrared reflectance band, and RED represents the red reflectance band.

Sentinel-5 Precursor

The UV–Aerosol Index used in this study, produced by a TROPospheric Monitoring Instrument (TROPOMI) on board the Sentinel-5 Precursor (Sentinel-5P) satellite, with a spatial resolution of 7 × 3.5 km observed at 13:30 local solar time. The advanced TROPOMI is a nadir-view imaging spectrometer with the bands in the wavelength of UV–VIS (270 nm–495 nm), NIR (675 nm–775 nm), and SWIR (2305 nm–2385 nm). Sentinel-5P is the first Copernicus mission to monitor the atmosphere and provide the measurements of NO_2, O_3, SO_2, CO, aerosols, formaldehyde, and cloud at high spatial and temporal resolutions.

The TROPOMI aerosol index is unambiguously named as UVAI since it utilized the classical wavelength pair of 340/380 nm in the UV spectral range for retrieval. UVAI calculation is based on the wavelength-dependent changes in Rayleigh scattering where ozone absorption is weak. The difference between measured top-of-atmosphere reflectance (TOA) and pre-calculated reflectance for a Rayleigh scattering produces a residual value. The positive residual value indicates the presence of UV-absorbing aerosols or absorbing aerosol index (like dust, smoke), while the negative residual value indicates non-absorbing aerosols.

Methodology

The satellite-derived variables from the eddy covariance flux tower sites were deduced in this way, as to maintain synchronization in the area coverage by satellite-derived (LST, UVAI, GPP and NDVI) and flux tower derived (ambient temperature and radiation components) variables. To achieve this, 6 × 6 pixels around the centre of the respective flux tower sites were taken into consideration. Google Earth Engine (GEE) platform was utilized to extract the mean values of the mentioned satellite-derived variables from the selected study regions.

The extracted values are grouped into two sections: pre-lockdown period (13 March–24 March), and lockdown period {first lockdown period (25 March–14 April) and second lockdown period (15 April–3 May)}. Furthermore, the 8-day averaged values for the selected variables also computed to match with the MODIS 8-day average values, starting from 13 March.

The percentage anomaly also calculated for the selected variables using the formula:

$$\text{Percentage anomaly } (\%) = \frac{\mathrm{Var2020} - \mathrm{Var2019}}{\mathrm{Var2019}} * 100$$

where Var2019 and Var2020 are the variables extracted for the year 2019 and 2020, respectively.

Results and Discussion

Impact on Satellite-Derived and Meteorological Variables During Pre-Lockdown and Lockdown Periods

Daily UV–Aerosol Index

The daily variation in UVAI values represented in Fig. 2. The negative values of UVAI represent non-absorbing aerosols such as sulphates (Shaeb, 2019). In SFS, significant changes in the UV–Aerosol Index (UVAI) noticed over both the years and, in the same time windows (during pre-lockdown and lockdown periods). In the year 2019, a significant increase in the daily UVAI was observed from 13 March to 3 May, which was not discernible in the year 2020 (Fig. 2a). Furthermore, the levels during pre-lockdown period (13 March–24 March) are almost similar in both the years. While during the lockdown period, there is a significant reduction in UVAI. The values range from 0.019 (2 April 2020) to −3.082 (6 April 2020) in the first lockdown and from 0.095 (28 April 2020) to −2.467 (19 April 2020) in the second lockdown.

Over PFS, there was a marked reduction in UVAI after a lockdown in the year 2020 (Fig. 2b), but it was not so

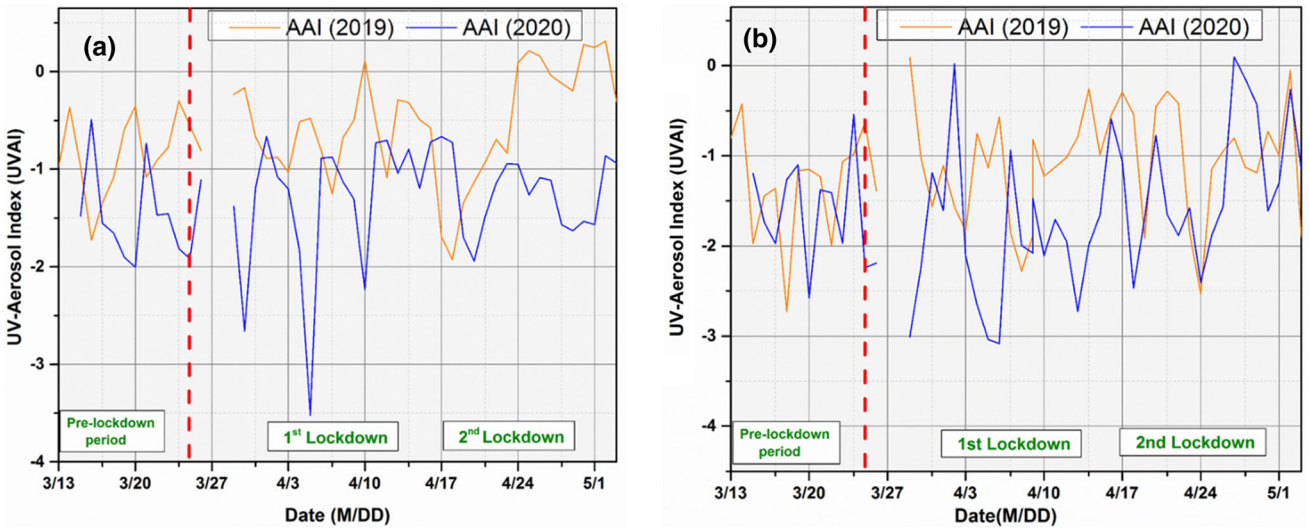

Fig. 2 Daily variation in UV–Aerosol Index value in **a** SFS and **b** PFS. Orange and blue coloured lines represent the values for the years 2019 and 2020, respectively. Red-dashed line represents the start of lockdown period (25 March 2020)

prominent in case of SFS. During the pre-lockdown period, the UVAI values range from −0.42 to −2.72 and 0.126 to −2.73, in the year 2019 and 2020, respectively. Noticeable and drastic decline in UVAI from −0.414 on 27 March to −3.522 on 5 April) was observed during first lockdown. While second lockdown also caused diminishing of UVAI from −0.666 (17 April) to −1.941 (20 April) in the beginning but it was not moderate in nature. The aerosol content of the atmosphere decreased by 24–25% as reported by (Pathakoti et al., 2020) in the Indo-Gangetic Plains. The decreasing aerosol content is the positive indicator of radiation budget and forthcoming seasonal rains in India (Pathakoti et al., 2020).

Net Radiation and Shortwave Incoming Radiation

The hourly evaluation of net radiation (R_n) and shortwave incoming radiation (R_s) was attempted at both the study sites during pre-lockdown and lockdown periods. The dataset averaged on an 8-day basis and designated as the week numbers. Diurnal variation was discernible in every week (Figs. 3 and 4). During the pre-lockdown period (1st and 2nd week), in SFS (Table 1), a negative anomaly for R_s (−9.264%) was noticed which was slightly deviated over PFS. During the lockdown periods, maximum R_s observed in the 5th and 6th week with the value of 493.812 W/m^2 and 448.599 W/m^2, respectively. Similarly, the average R_n noticed was at the higher levels in the 5th and 6th weeks, with the value of 144.210 W/m^2 and 161.30 W/m^2, respectively (Fig. 3).

In PFS, during the pre-lockdown period particularly in the 1st week, higher R_s anomaly noticed. This could be due to almost the same UVAI levels in both the years, with a difference of only about −0.136 (Table 2). An increase in R_s observed in the 4th week during the lockdown period with the maximum value of 850.942 W/m^2. The major variation in R_n noticed in the 4th and 5th week, during the 1st lockdown period with the average value of 142.599 W/m^2 and 133.443 W/m^2, respectively. It is also evident from the percent anomaly for R_n in Table 2.

Percent Anomaly Variation in LST and T_{amb}

The variation in the LST anomaly and T_{amb} anomaly represented in Fig. 5. During the pre-lockdown period, LST and T_{amb} anomalies were highly negative over both the agricultural sites (Tables 1 and 2), respectively. This represents lower LST and T_{amb} values in the year 2020. During the lock down period, the higher anomalies of LST and T_{amb} were observed in the 4th and 5th weeks in both the study sites. The percent anomaly for LST ranges from 0.942% to 1.865% and 6.600% to −9.139%, in SFS and PFS, respectively. Similarly, the percent anomaly for T_{amb} ranges from 4.426% to 4.068% and −4.366% to 4.800% in SFS and PFS, respectively.

The opposite trend in R_n and LST anomalies during the whole study period can be implied to energy partitioning and soil moisture availability. This trend is illustrated through Fig. 6, in which the LE and soil moisture anomalies are considered over PFS. During the pre-lockdown phase, the wheat crop was at its peak stage, while the lockdown period more or less corresponds to its maturity and harvest stage. Opposite sign of R_n and LST anomalies during pre-lockdown period was primarily ascribed to more partitioning of R_n into LE under optimum soil moisture conditions and consequently led to cooling of the surface.

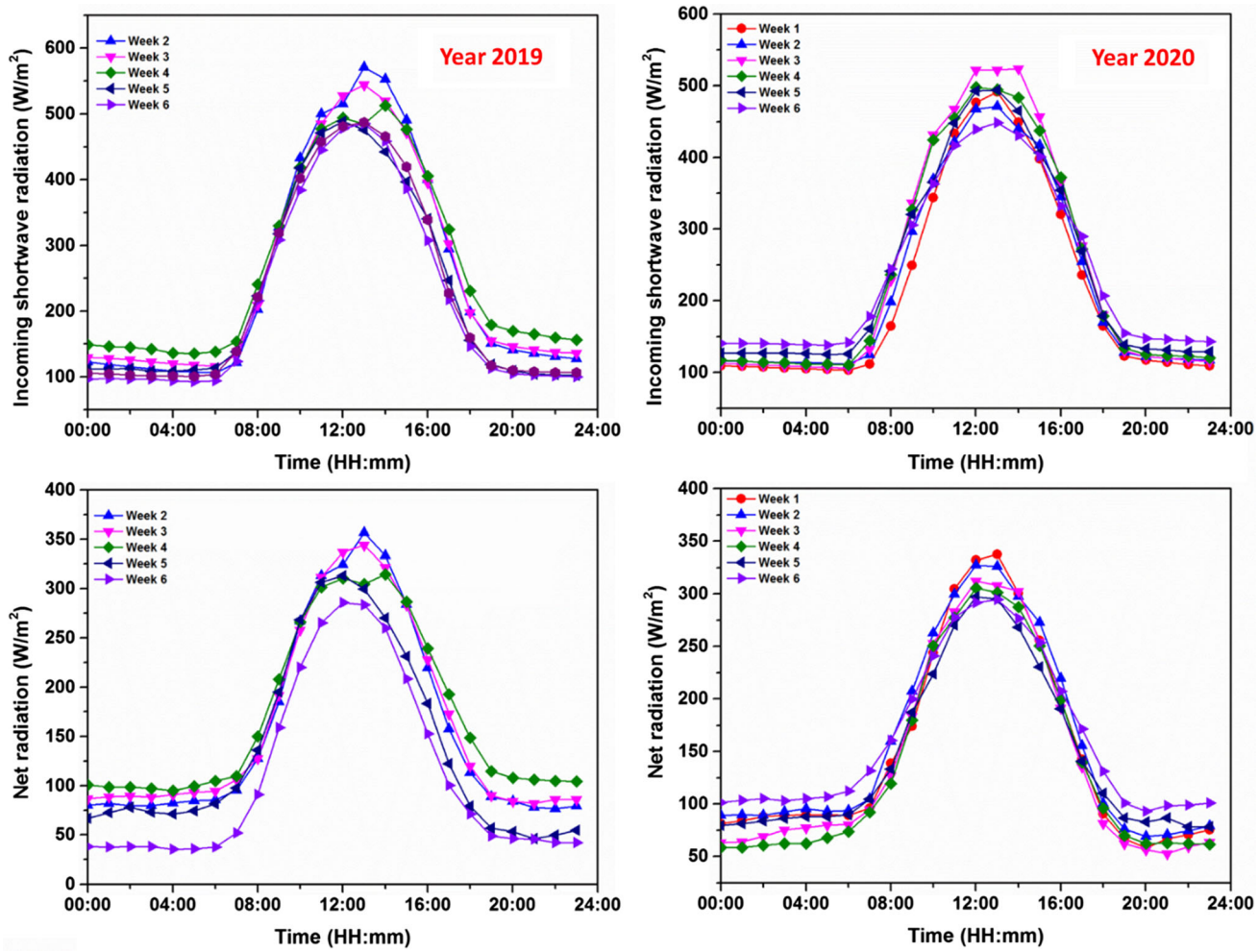

Fig. 3 Weekly diurnal variation in net radiation and shortwave incoming radiation in SFS. Left section represents the graphs for the year 2019, while the right section represents the diurnal variation for the year 2020

The higher negative anomaly on 2nd week is attributed to the higher soil moisture availability in comparison to the 1st week. During the 3rd week, positive soil moisture anomaly induces negative LST anomaly through an increased evaporative cooling over the study site, while on the 4th week, R_n outweighs the impact of soil moisture, thus increasing LST. On 6th week, the impact of lower R_n, soil moisture anomaly and crop maturity phase lead to declining LE anomaly (−16.13%).

Impact of UVAI Levels on the Other Derived Variables During Pre-Lockdown and Lockdown Periods

The above-mentioned UVAI values imply that it drastically reduced from pre-lockdown to lockdown periods, in both the agricultural sites. Consequently, variation in Rn, Rs, LST anomaly, and T_{amb} anomaly was evaluated which goes in line with the 8-day averaged values in both the agricultural regions. Furthermore, higher Rs observed after a drastic reduction in the level of aerosols in the atmosphere (Kushta et al., 2014).

In SFS, a drastic reduction in UVAI observed from the 3rd week and positive anomalies in T_{amb} and LST observed in the 4th and 5th week, respectively. Similarly, in PFS, the higher LST and T_{amb} anomalies observed in the 4th and 5th weeks. In both the study sites, the anomalies of LST and T_{amb} were on the higher side in comparison to the other weeks.

This trend could be the result of lower aerosol levels in the atmosphere during the lockdown period, which further prohibited the absorption of radiant energy, and its direct fall on to the land surface. The higher availability of radiant energy leads to warming of the earth's surface (Ohring, 1979).

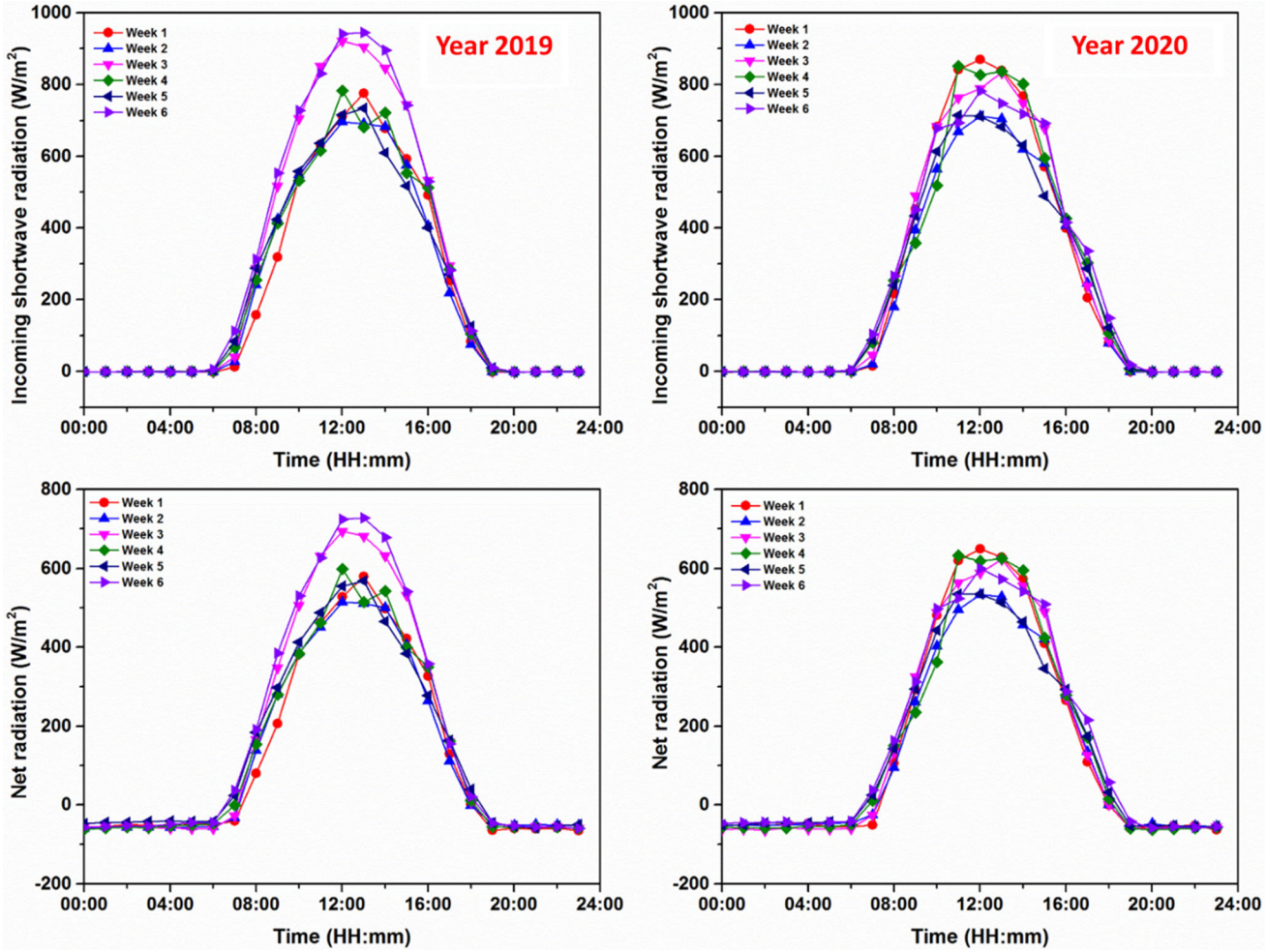

Fig. 4 Weekly diurnal variation in net radiation and shortwave incoming radiation in PFS. Left section represents the graphs for the year 2019, while the right section represents the diurnal variation for the year 2020

Table 1 Table showing the weekly anomalies and 8-day averaged values over SFS

		Percent anomalies						8-day averaged	
Period	Week	Rn	RS	LST	T_{amb}	GPP	NDVI	UVAI (2019)	UVAI(2020)
Pre-lockdown period	1	–	–	− 14.18	–	50.35	1.22	− 0.94	− 1.12
	2	2.37	− 9.26	− 5.09	− 0.53	21.79	1.00	− 0.60	− 1.29
Lockdown period	3	− 13.73	− 4.79	− 4.14	− 8.38	156.31	0.41	− 0.68	− 1.69
	4	19.74	9.82	0.94	4.43	–	7.80	− 0.57	− 1.12
	5	5.48	5.77	1.87	4.07	19.95	− 5.85	− 1.10	− 1.15
	6	48.07	13.05	− 5.23	− 15.93	50.35	5.56	− 0.06	− 1.21

Changes in the Biophysical Variables

The GPP is an important biophysical parameter of an ecosystem. It plays a very important role in spatial–temporal dynamics of CO_2 (Chagas et al., 2019). The GPP derived from MODIS satellite was higher in year 2020 in comparison to the year 2019, in both the study sites. In SFS, GPP ranges from 0.75 to 3.55 g C $m^{-2}d^{-1}$ and 1.2 to 5.33 g C $m^{-2}d^{-1}$ in year 2019 and 2020, respectively. Similarly, in PFS, the GPP ranges from 3.28 g C $m^{-2}d^{-1}$ to 4.56 g C $m^{-2}d^{-1}$ and 3.4 g C $m^{-2}d^{-1}$ to 4.66 g C $m^{-2}d^{-1}$, in year 2019 and 2020, respectively. The GPP anomaly was

Table 2 Table showing the weekly anomalies and 8-day averaged values over PFS

Period	Week	Percent anomalies								8-day averaged	
		Rn	RS	LST	T_{amb}	LE	Soil moisture	GPP	NDVI	UVAI (2019)	UVAI (2020)
Pre-lockdown period	1	18.34	13.30	− 0.04	− 6.77	12.82	23.03	13.30	5.20	− 1.44	− 1.57
	2	3.24	− 0.58	− 2.16	− 4.58	18.16	29.51	− 0.58	7.97	− 0.99	− 1.59
Lockdown period	3	− 14.29	− 10.71	− 21.03	− 19.79	− 4.15	61.25	− 10.71	− 1.31	− 1.19	− 1.98
	4	7.57	7.95	6.60	− 4.37	2.63	1.56	7.95	14.21	− 1.25	− 1.92
	5	− 2.65	1.12	− 9.14	4.80	7.06	2.55	1.12	12.96	− 0.81	− 1.62
	6	− 14.04	− 13.52	− 21.30	− 14.57	− 16.09	− 1.37	− 13.52	5.19	− 1.29	− 1.38

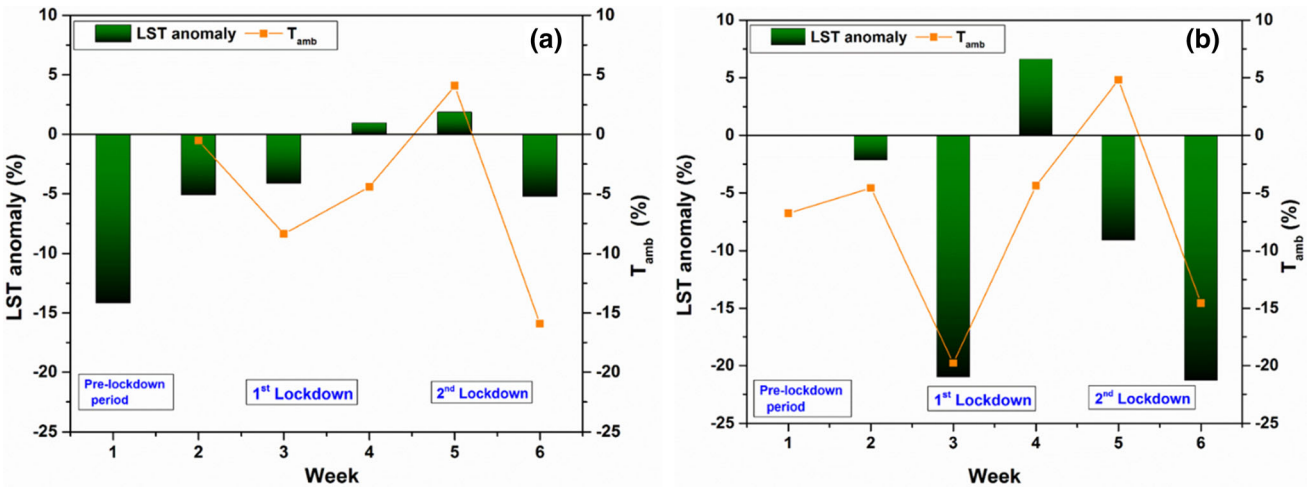

Fig. 5 Weekly percent anomaly for land surface temperature (LST) and ambient temperature (T_{amb}) in **a** SFS and **b** PFS. Column bars represent percent LST anomaly, while the lines represent the percent T_{amb} anomaly

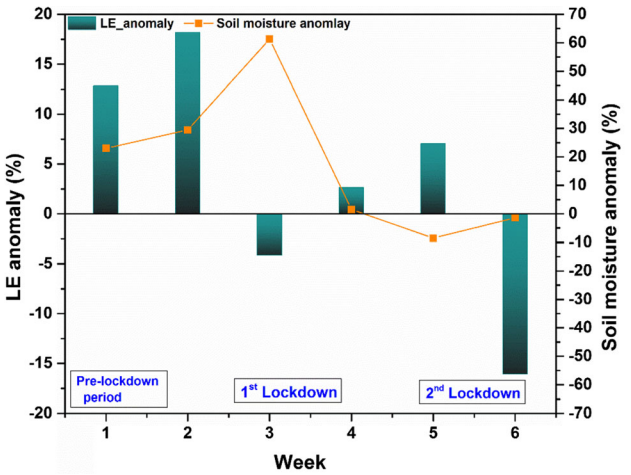

Fig. 6 Weekly percent anomaly of latent heat flux (LE) and soil moisture in PFS. Column bar represents percent LE anomaly, while the line represents the percent soil moisture anomaly

also evaluated for SFS and PFS (Tables 1 and 2). Positive anomaly was observed in GPP specifically during the lockdown period (3rd to 5th week). The observed positive anomaly over the site attributed to higher availability of radiant energy and canopy cover to accelerate the physiological processes (photosynthesis/transpiration) as evident from higher NDVI during the lockdown period. The NDVI anomaly was found positive and ranged from −5.85% to 7.80% and −1.31% to 19.97%, in SFS and PFS, respectively. Saxena et al., 2020 also observed 5% positive NDVI deviation in year 2020 compared to the previous year. The positive NDVI anomaly was in corroboration with the positive GPP anomaly. Further, the observed anomaly in GPP falls in accordance with that of Rs (4th and 5th week) and NDVI during lockdown period. The favourable effect on photosynthesis has resulted into enhanced carbon assimilation and finally crop growth (Kirschbaum, 2011) and productivity (Kirschbaum, 2011; Long et al., 2006).

The changes in environmental parameters due to lockdown have shown visible impact on crop productivity as observed from the satellite-derived parameters. The lower aerosol values, higher net radiant energy during the lockdown period improve the crop condition and crop

productivity as represented by the higher NDVI and GPP during the lockdown period in both the study sites.

Kumar et al., 2020 have reported the long-term socio-economic impact of lockdown amid COVID-19 on agricultural workers, but our results showed the improvement in the photosynthetic productivity and crop condition during the lockdown over both the study sites under favourable state of atmospheric and soil moisture. The improvement in crop area and crop condition over India was also reported in India by Saxena et al., 2020 during the lockdown period. Furthermore, the food ministry stated that the overall wheat procurement reached 341.56 Lakh Metric Tonnes (LMT) as on 24 May 2020 in comparison to 341.31 LMT wheat procurement of year 2019 (https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1626703). The wheat production reached 20.39 LMT and 0.03 LMT in Uttar Pradesh and Himachal Pradesh, respectively.

Conclusion

The authors attempted to evaluate the impact of the nation-wide lockdown amid COVID-19 over the agricultural ecosystem. The selected agricultural sites are far from the main city area, which directed towards the lesser impact of vehicular pollution over the study areas. This fact is addressed through the negative UVAI values in the years 2019 and 2020. Despite this fact, still in the middle of the lockdown period, particularly in the 4th and 5th week, considerable variation in derived satellite and meteorological parameters observed. The more negative values of UVAI noticed in both the agricultural regions after the lockdown period. This further induced the higher availability of direct radiant energy on the earth's surface. Consequently, LST and T_{amb} increased after imposing lockdown, thus warming the earth's surface. The opposite trend of R_n and LST anomalies can be attributed to the energy partitioning into LE and soil moisture availability. Favourable soil moisture along with receipt of available energy has led to partitioning of more R_n into LE which in turn enhanced evaporative cooling of the surface and lowering of LST. GPP and NDVI were found higher during the lockdown period in both the study sites. This represents higher productivity due to higher availability of radiant energy and improved crop condition particularly during the lockdown period.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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