Chapter 5

IMPACT OF MINIMAL HUMAN INTERACTION ON RIVER THERMAL PATTERN FLUCTUATION

5.1 Introduction

The mapping of the river or the inland water quality using remote sensing technology was not new to the scientific community and this activity has been practiced since the 1970s with the launch of the Landsat series of satellites (Klemas et al., 1971; Ritchie et al.,1976). The conventional procedures for testing the water quality parameters are expensive as well as time-consuming, and it provides information only for the point(s) under measurement. The remote sensing technology can be utilized as an advantageous alternative option for the measurement of the water quality parameters. The remote sensing-based satellite images can provide systematic and periodic coverage of an area. More information can be deduced for a place because of the periodic nature of the satellite revisit (Novo et al., 2006; Lamaro et al., 2013). Every earth's surface features behave uniquely while interacting with electromagnetic radiation (EMR). This distinctiveness generates in the form of the spectral signature from each surface feature, and this signature has been utilized to identify the surface feature through satellite images (Elachi, 1987; Joseph, 1996). When a slight change in the composition of a feature occurs, it simultaneously changes the spectral signature (Moore,1980). Several factors accompany the change of the spectral signature for a feature, and the same can be valid for the water physio-chemical characteristics too. Some of the factors responsible for generating the different spectral signatures of water are the incidence angle of the sun, the season of the year, water surface roughness, turbidity, depth of the water, and vegetation growth on the water surface (Garg et al., 2020). By studying these different spectral signatures, the qualitative and sometimes the quantitative assessment of a particular component can be accomplished (Chander et al., 2019; Luis et al., 2019). Several water quality parameters like temperature, turbidity, DO (Dissolved oxygen), pH, TDS (Total dissolved solids), and TSS (Total suspended solids) can be studied with the help of remote sensing technology (Lamaro et al., 2013; El-Din and Zhang, 2017; Garg et al., 2020; Patel et al., 2020).

The temperature of the water is one of the significant parameters because it is helpful in regulating the rate of chemical reactions in the river, and it also controls the DO concentrations along with the nutrient cycle of the aquatic creatures; thus, it influences the freshwater ecology (.Caissie, 2006; Wawrzyniak et al., 2012). The continuum concept of the river signifies that any change in the river temperature can intensely impact the longitudinal distribution of organisms in the fluvial ecosystem (Vannote et al., 1980; Wawrzyniak et al., 2012). The rise of the river temperature above a specific threshold hampers the biological processes like growth, reproduction, and survival rate of the aquatic species (Eaton et al., 1995; Xin and Kinouchi, 2013). According to Vant's Hoff theory, it can be stated that for every 10ºC rise in the temperature of the water, the biological activity nearly doubles within the temperature range of 0-40°C under normal situations (Gillooly et al., 2001; Caissie, 2006). In comparison to the in-situ measurements, the remote sensing techniques provide alluring possibilities for estimating and observing the river temperature as well the spatial thermal pattern of the river (Ling et al., 2017). Several researchers are now using remote sensing technology for estimating the river water temperature. The thermal bands present in the LANDSAT satellite system have been used for this purpose (Lamaro et al., 2013; Wawrzyniak et al., 2016).

The COVID-19 global pandemic caused due to the novel Coronavirus strain has been considered one of the most virulent diseases that affect human lives in around 210 countries (Chauhan and Singh, 2020; Patel et al. 2020). To protect the people from this deadly disease, each country's government had declared the lockdown in a phased manner (Chauhan and Singh, 2020). Similarly, the Indian government had also implemented a complete lockdown from midnight of 24th March 2020 (The Lancet 2020). Several studies have reported that due to the lockdown effect, the major cities' environmental conditions have improved in terms of pruning in pollution of either air or the water (Braga et al., 2020; Lal et al., 2020). The air and water quality of the major Indian cities have improved because the lockdown fully or partially stops factories' work, closes the transport system, and seals commercial activities (Mahato et al., 2020). Due to this lockdown effect, the possible cleansing of the rivers has occurred naturally (Garg et al., 2020), along with the cleansing of the river Ganga, which is one of the most polluted rivers (Hamner et al., 2013) of the world. The pollution level of the Ganga river has been reduced, and it has become much cleaner during the lockdown phase. The discharge during the time frame of the first lockdown has been almost negligible. Anthropogenic activities were also mostly prohibited (Garg et al., 2020).

In this chapter, an attempt has been made to estimate the water temperature for the river Ganga at different stretches. The temporal analysis of the LANDSAT-8 images has been performed for the pre-lockdown, lockdown, and post-lockdown time frame. For this analysis, the year 2019 and 2020 has been chosen.

A comparative study of river thermal patterns during the first (May 2020) and second lockdown (in May 2021) scenarios has also been performed. Cloud-free satellite images have been considered for this study. For processing the image, GEE (Google Earth Engine) platform has been used. GEE is cloud-based technology operated by a massive number of servers worldwide, and it is freely available through the internet medium (Das et al., 2021). Further, as no field data were present for this time period, as the lockdown has been imposed, no in-situ sampling can be performed.

Figure 5.1 shows the location of the stretches for which the work has been performed.

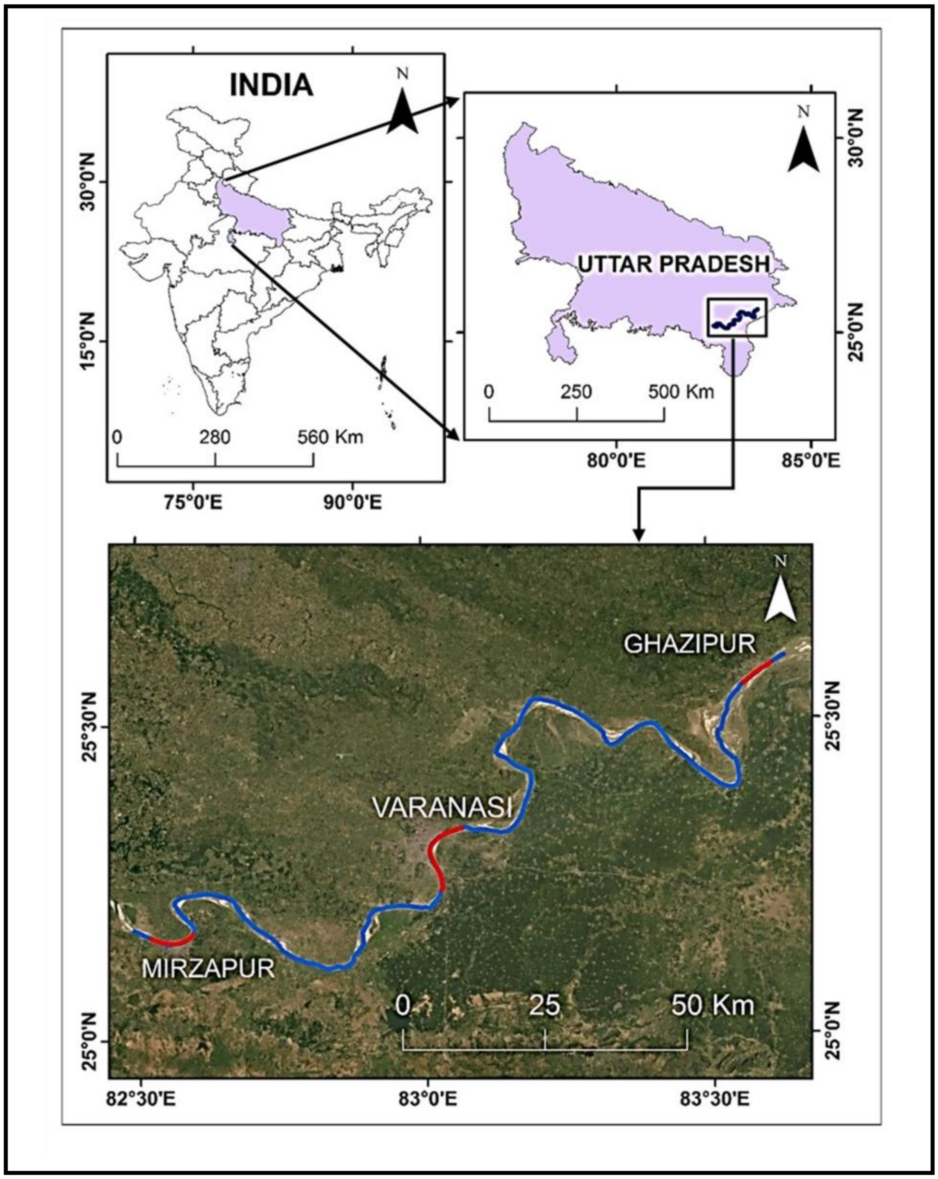

Figure 5.1 Geolocation map of the study area from Mirzapur to Ghazipur. The blue vector represent the river and red patches illustrates the river stretch considered for this analysis

This work has been performed on the river stretch near the three cities in the study area. The three stretches have been marked with red color for which the work has been performed and shown in figure 5.1. The red color stretch for Mirzapur city lies between Ganjia (82.52°E, 25.16°N) and Kirtartara (82.59°E, 25.16°N). The red color stretch for the Varanasi region is situated between Ramna (83.02°E, 25.23°N) and Tatepur (83.06°E, 25.33°N). For the Ghazipur region, the stretch is located between Gorabazar (83.56°E, 25.55°N) and Jamalpur (83.60°E, 25.58°N) and is shown as red color.

5.2 Data

5.2.1 Meteorological datasets

The data used for meteorological parameters (air temperature and precipitation) have been derived from the POWER (The Prediction of Worldwide Energy Resource) datasets of NASA. The meteorological data/parameters in POWER Release-8 are based upon a single assimilation model from Goddard's Global Modeling and Assimilation Office (GMAO). These datasets (interannual and daily time series format) are provided on a global grid having a spatial resolution of 0.5°×0.5° (Suarez et al., 2005). The POWER Data Access Viewer (DAV) is a web mapping application containing geospatially enabled parameters. POWER provides various text, tabular, geospatial datasets, and files that users can download and integrate into custom software and applications for further processing, analysis, and visualization. The time duration for which meteorological datasets have been prepared is presented in a tabular form in table 5.1. The meteorological dataset representation has been shown in Appendix B of the thesis.

Table 5.1 The time period for meteorological data

Time duration
28th January-12th February 2019
20th April-19th May 2019
1st November-15th November 2019
20th January-15th February 2020
15th April-5th May 2020
14th October-28th October 2020
18th April- 24th May 2021

5.2.2 Satellite imagery datasets

In this analysis, Band 10 has been used for the river temperature calculation. For the assessment of the river temperature, 'Surface Reflectance Tier 1' datasets of the GEE domain have been used. These datasets are atmospherically corrected, and the correction has been done by using LaSRC (Land Surface Reflectance Code) algorithm (Vermote et al., 2016). The LANDSAT images used in this study have path145/row 42 and 43. Table 5.2 shows LANDSAT-8 acquisition dates.

Table 5.2 List of satellite images

Satellite sensor	Date of the image acquisition
LANDSAT-8	11 February 2019
LANDSAT-8	18 May 2019
LANDSAT-8	14 November 2019
LANDSAT-8	14 February 2020
LANDSAT-8	4 May 2020
LANDSAT-8	27 October 2020
LANDSAT-8	7 May 2021
LANDSAT-8	23 May 2021

The datasets, namely, Feb-2019, May 2019, Nov-2019, Feb 2020, May 2020, and Oct-2020, have been chosen to study the effect between the previous normal year (2019) and the first lockdown year (2020). The May 2021 dataset has been incorporated to compare the first lockdown period (May 2020) and the second lockdown period (May 2021). The first lockdown was strictly applied from 25th March to June 2020. The second lockdown was applied partially between 24th April to 24th May 2021 in the state of Uttar Pradesh.

5.3 Methodology adopted for this analysis

A flowchart for the spatio-temporal analysis of the river temperature fluctuation during the pre-lockdown, lockdown, and post-lockdown scenario have been drawn in figure 5.2.

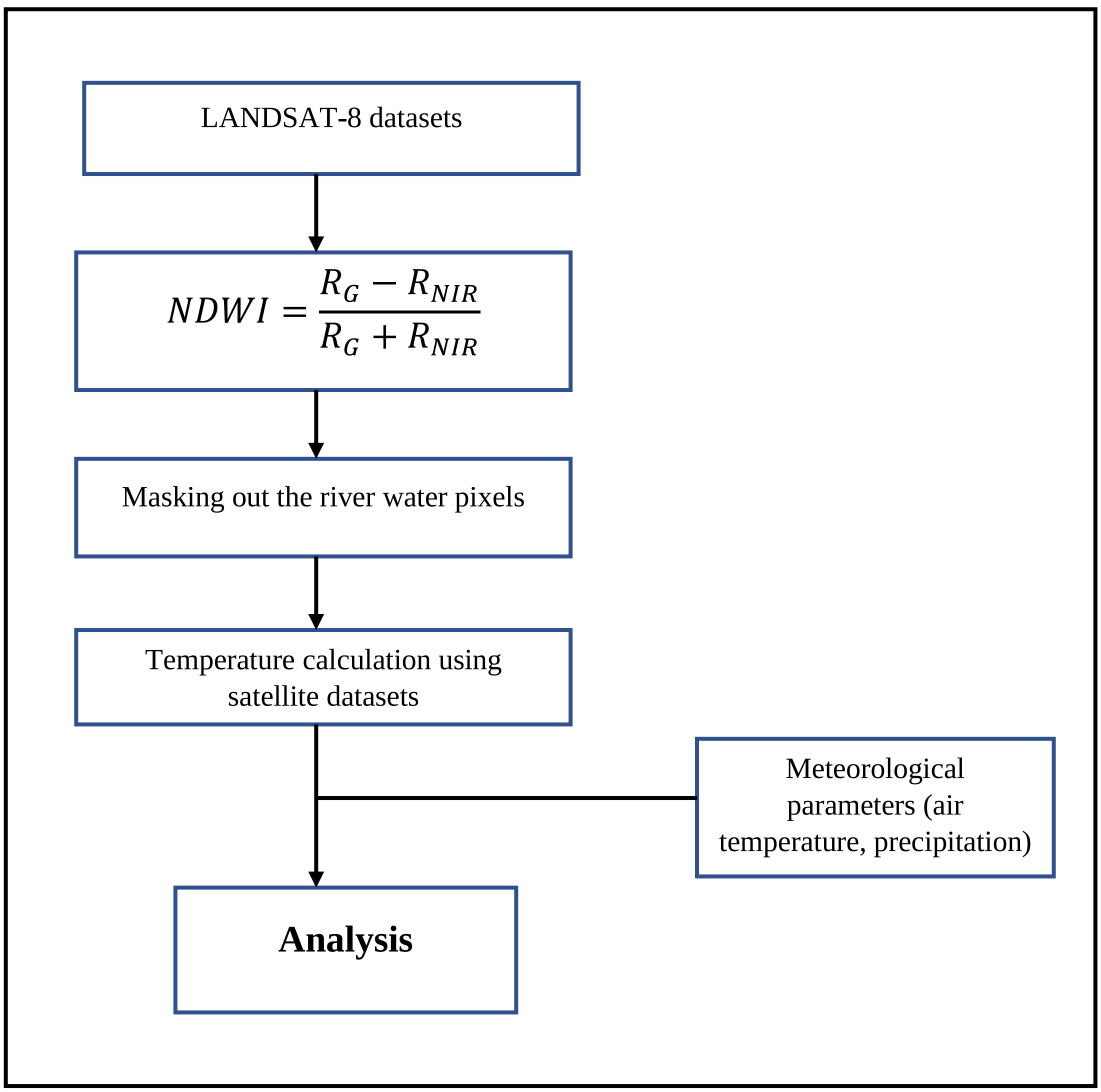

Figure 5.2 Flowchart of the work procedure

The procedure for river water masking and temperature calculation has been mentioned in Chapter 3.

5.4 Results

5.4.1 Statistical representation of river temperature

The result has been presented in the form of the box plot in figures 5.3, 5.4, and 5.5 for river temperature during the time period of pre-lockdown, lockdown, and post-lockdown. For the temperature representation, the month of February 2019 and 2020, May 2019 and 2020, November 2019 and October 2020 have been considered. Different months (October and November) have been chosen for this study because of the cloud cover issue associated with LANDSAT -8 imageries. River temperature in the Ghazipur region (Figure 5.3) during February 2019 lies between 18°C to 21°C, with a majority of the values situated between 19°C to 20°C. But for the period of February 2020, the temperature is ranging in between 19°C and 21°C, with most of the values falling from 20°C to 20.5°C. In May 2019, the temperature lay in the range of 27.5°C to 29°C, and for May 2020 (during lockdown), the temperature ranges between 25.5°C to 26.5°C. November is relatively colder than October, so November 2019 (22.2°C to 23.8°C) has a lower temperature as compared to October 2020 (24.4°C to 26°C). For the Varanasi region (Figure 5.4), the temperature range for February 2019 (19°C to 20.8°C) is lower compared to February 2020 (22°C to 23°C). In the season of May 2019, the temperature ranges from 28.4°C to 31°C, and during May 2020 (lockdown period), the temperature lies in the range of 26°C to 27°C. The month of November is relatively colder as compared to October, so November 2019 had a temperature range between 24°C to 24.8°C, and October 2020 had a temperature range between 26°C to 27°C. The Mirzapur region (Figure

5.5) also shows a similar trend to those of Varanasi and Ghazipur. The significant temperature range of February 2019 (19°C to 20°C) is lower than that of February 2020 (20°C to 21°C). The temperature range of May 2019 (28°C to 30.4°C) is more as compared to the lockdown period during May 2020 (25°C to 27°C). The November 2019 temperature range (22.6°C to 24°C) is lower than that of October 2020 (25°C to 26°C). In figures 5.3 to 5.8, the orange circles have encircled those time frames which represent the lockdown period.

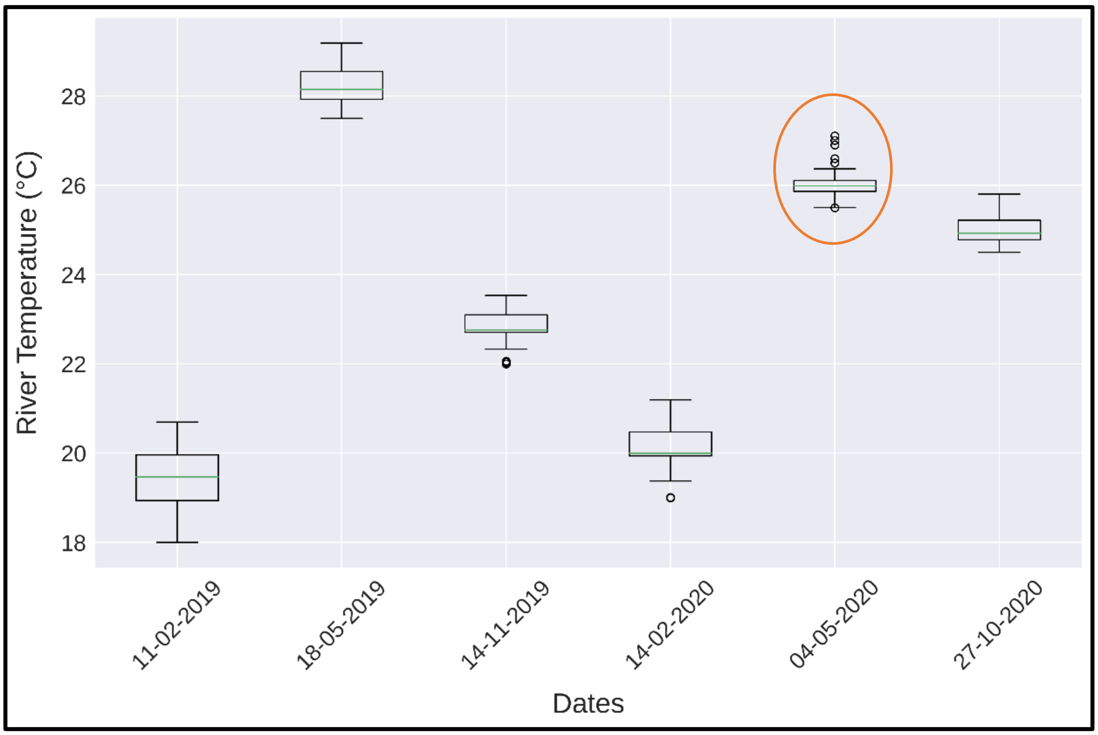

Figure 5.3 Box plot representation for river temperature in the Ghazipur stretch

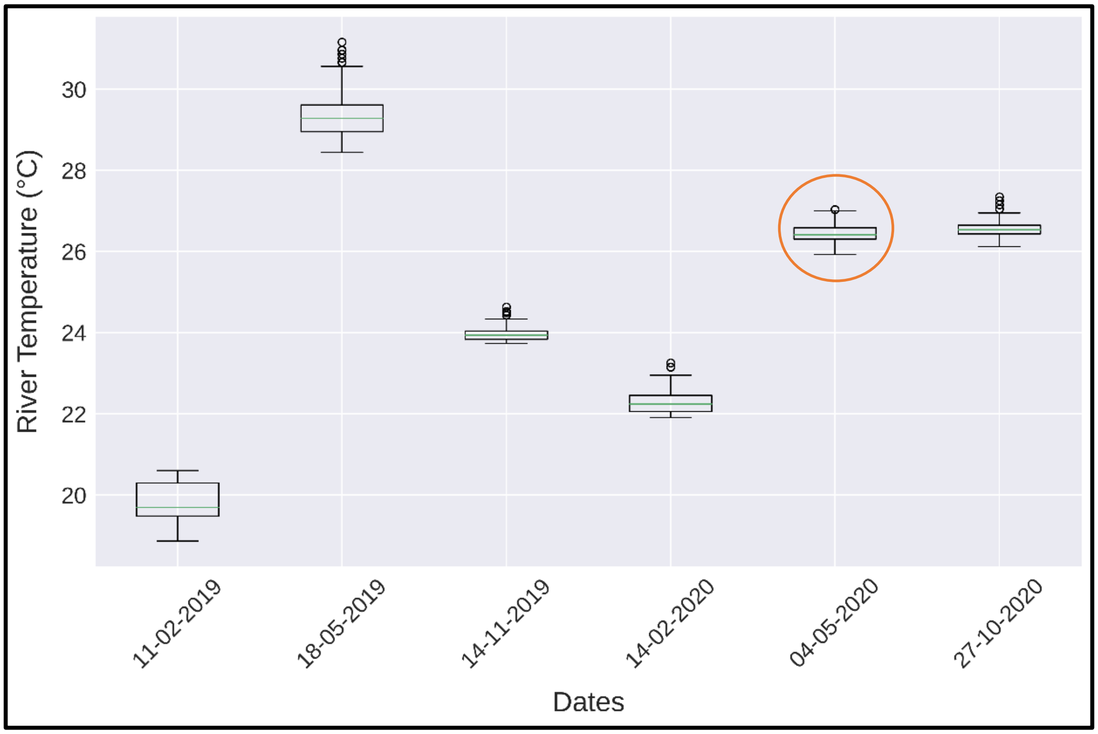

Figure 5.4 Box plot representation for river temperature in the Varanasi stretch

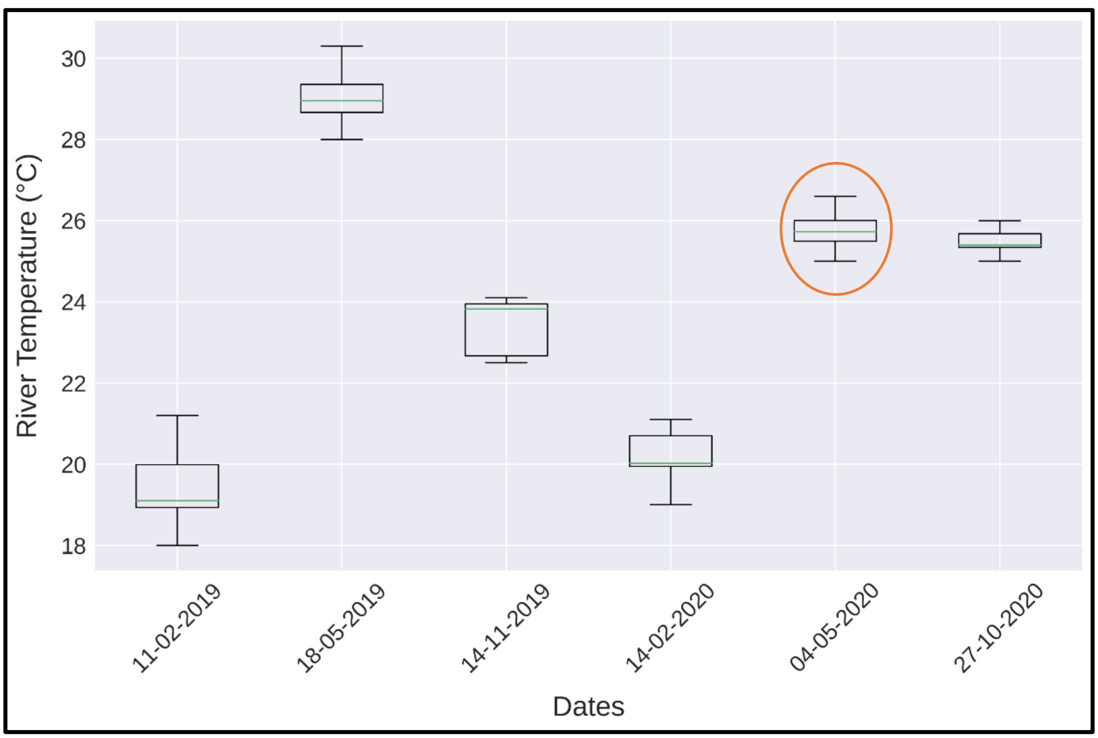

Figure 5.5 Box plot representation for river temperature in the Mirzapur stretch

During the period of the second lockdown, the river temperature shows a steady increase for the region of Ghazipur, Varanasi, and Mirzapur. In early May 2020, the river temperature in the Ghazipur stretch (Figure 5.6) ranges between 25.5°C to 26.5°C. In early May 2021, at the same place, the temperature varies between 27°C to 28.8°C. In late May 2021, the temperature further increased from 28.7°C to 31.5°C. The same pattern has also occurred in the Varanasi and Mirzapur river stretch. In comparison to early May 2020, early May 2021 shows an increment of approximately 2°C rises in the median river temperature for the Varanasi stretch (Figure 5.7). The median temperature rises by 4°C in later May 2021 as compared to early May 2021. The river temperature value for the Mirzapur stretch (Figure 5.8) ranges from 27.5°C to 30°C in early May 2021 as compared to the 25°C to 26.8°C in early May 2020. The river temperature further increases in the later period of May 2021. In this very period, the river temperature ranges between 29.5°C to 32°C. The box plot for the second lockdown analysis scenario has been shown in figures 5.6, 5.7, and 5.8.

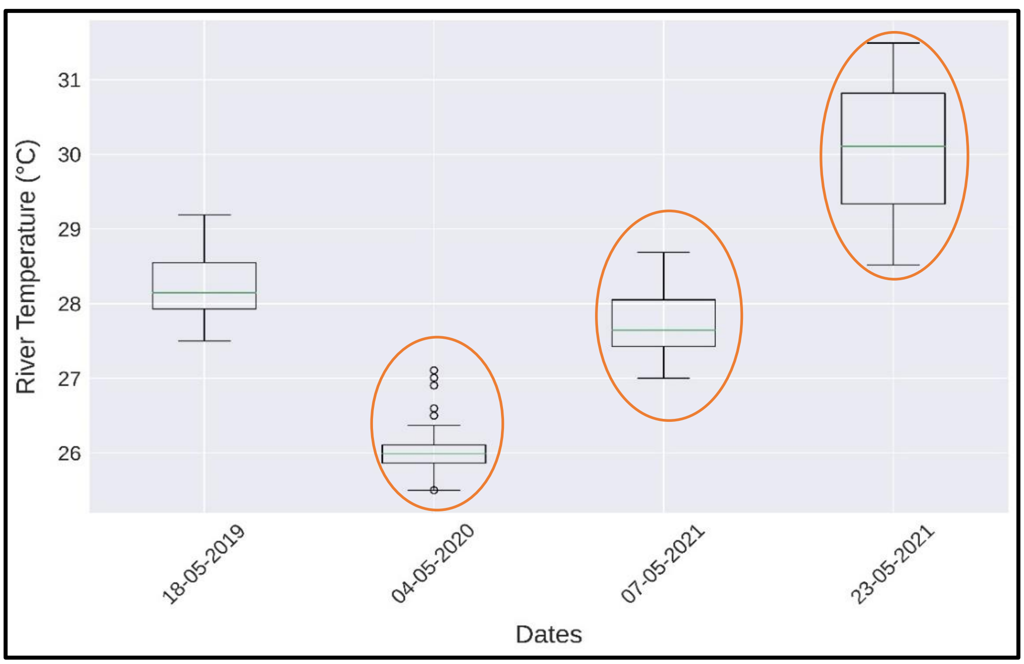

Figure 5.6 Box plot representation of the river temperature for the analysis of the second wave COVID-19 lockdown effect in Ghazipur region

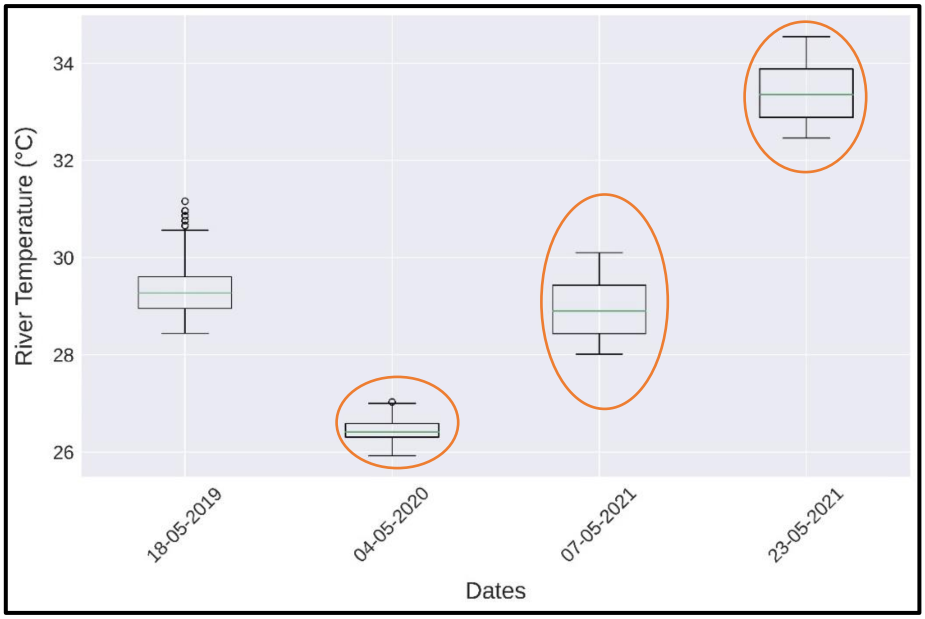

Figure 5.7 Box plot representation of the river temperature for the analysis of the second wave COVID-19 lockdown effect in Varanasi region

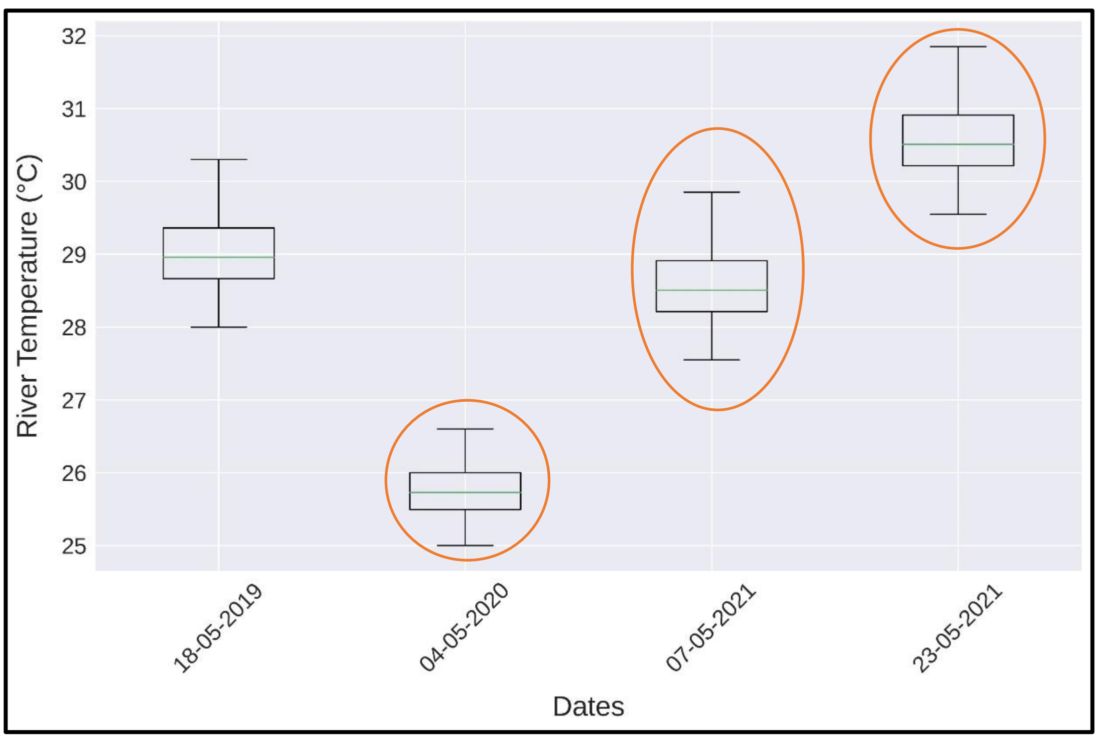

Figure 5.8 Box plot representation of the river temperature for the analysis of the second wave COVID-19 lockdown effect in Mirzapur region

5.4.2 Changing patterns of river temperature for Varanasi stretch

The temperature map has depicted the change in the river thermal pattern for the Varanasi stretch. For the time period of February 2019 and February 2020, the river temperature shows an upward trend for the considered stretch for the timestamp of February 2020. During the lockdown time (May 2020), the river temperature portrays a considerable decline compared to May 2019 temperature. The temperature mostly lay between 28.5 °C to 29.5°C in May 2019. However, in May 2020, the temperature mostly ranges from 26.5°C to 27°C. November usually becomes colder as compared to October in this part of the world, so the temperature of November 2019 (mostly ranges between 23.8°C to 24°C) is less than that of October 2020 (mostly ranges between 26.2°C to 26.8°C). The maps depicting the change are shown in figures 5.9, 5.10, and 5.11.

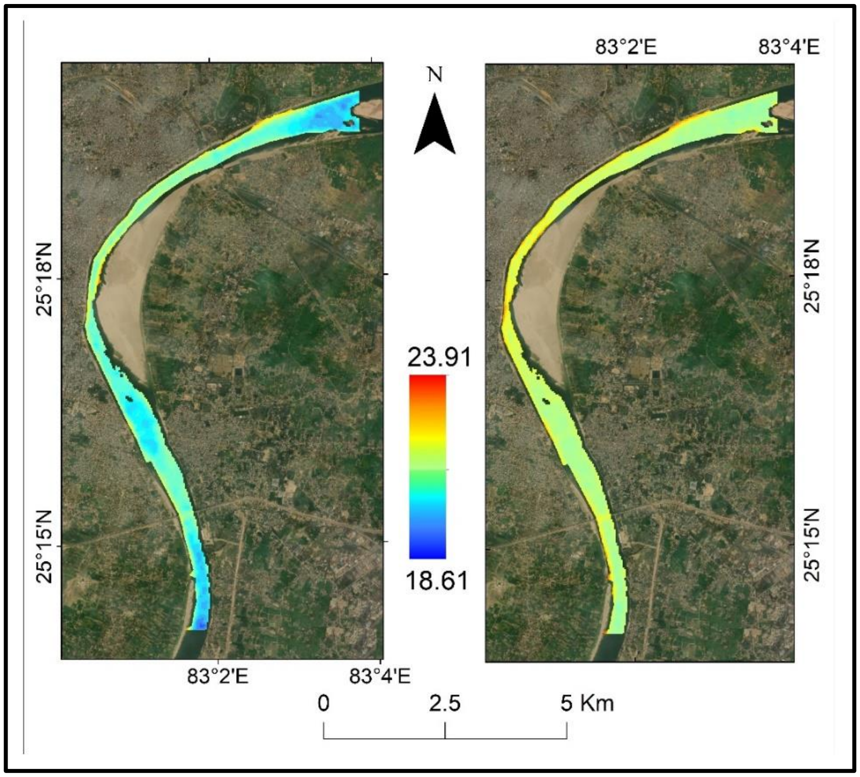

Figure 5.9 River temperature variation for the Varanasi stretch during the time-period of February 2019 and February 2020

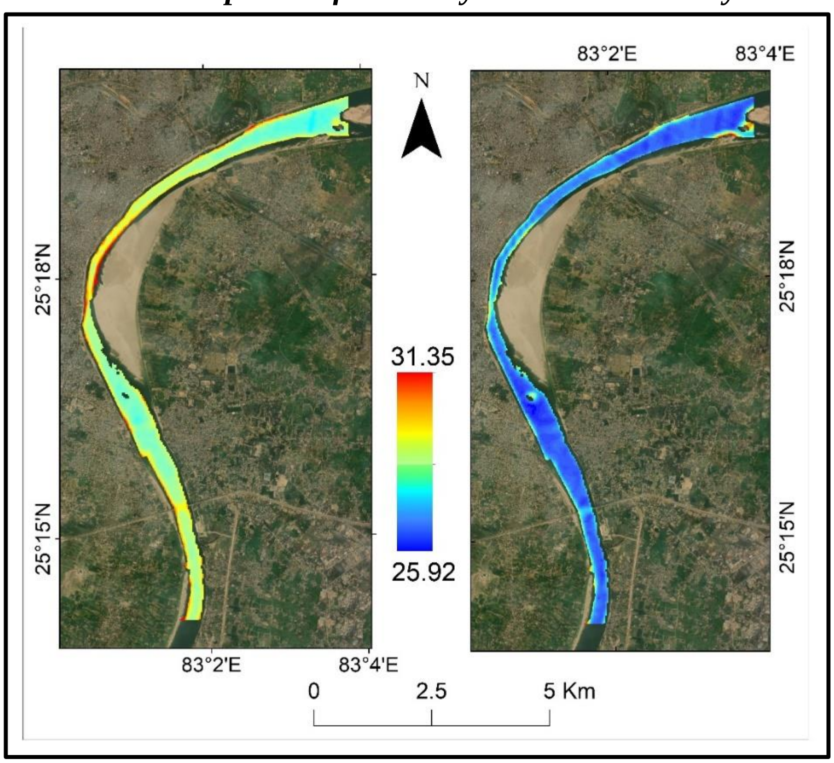

Figure 5.10 River temperature variation for the Varanasi stretch during the time-period of May 2019 and May 2020

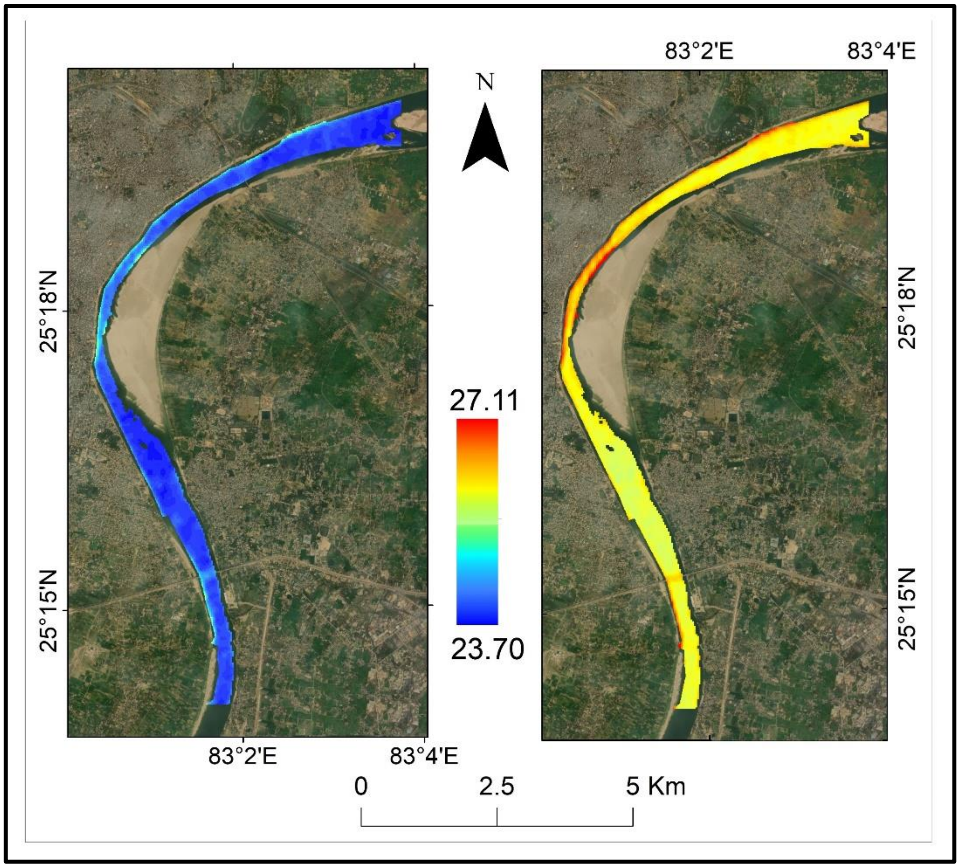

Figure 5.11 River temperature variation for the Varanasi stretch during the time-period of November 2019 and October 2020

The two dates (7th May and 23rd May) have been considered for May 2021. The river temperature lies mainly in a similar range for early May 2021 and May 2019. In May 2019, the temperature ranged between 28.5°C to 30.7°C. In early 2021, the range of the temperature is from 28°C to 30°C. In the later part of May 2021, the river temperature hovers between 32.5°C to 34.5°C. The later May 2021 period has the highest temperature among all the considered time frames. The map representation in figure 5.12 depicts these changes.

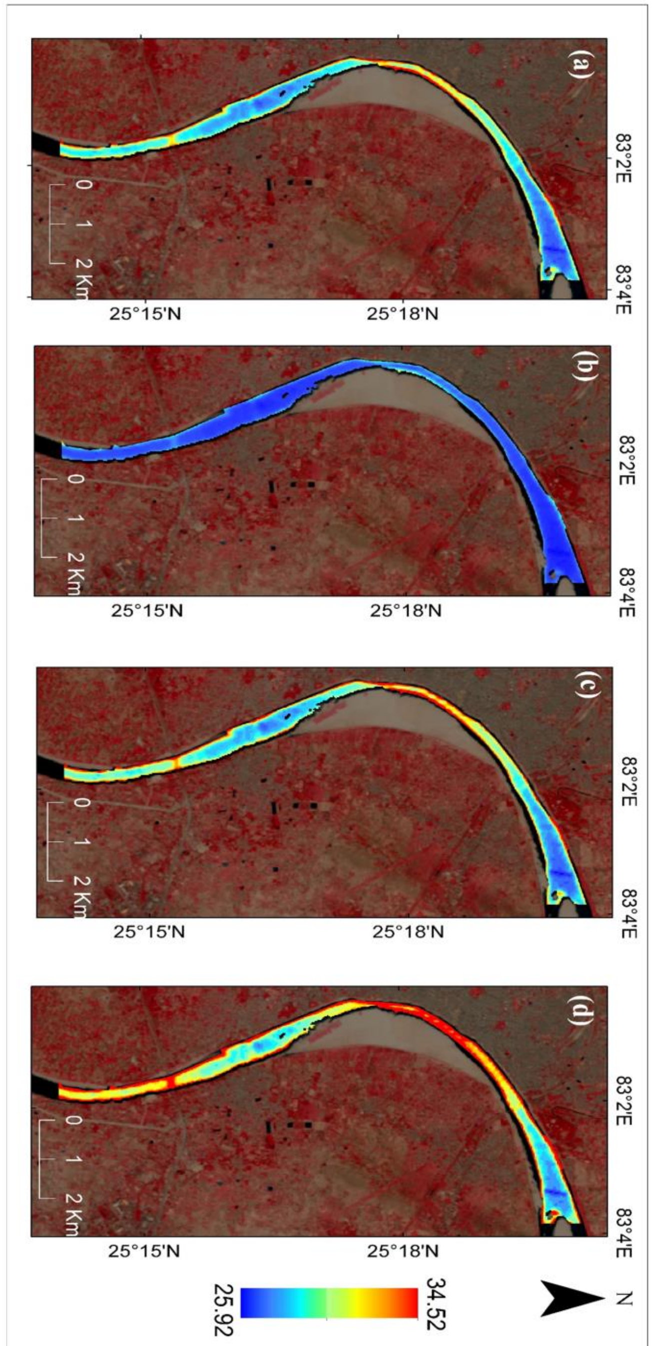

Figure 5.12 River temperature (° C) variation for the Varanasi stretch using LANDSAT-8 datasets during the time period of (a)18th May 2019, (b) 4th May 2020, (c)7th and (d) 23rd May 2021

Table 5.3 Temperature pattern for non-point and point region in Varanasi stretch

	Non-point temperature (°C)	Point temperature (°C)
February 2019#	21.07	19.13
May 2019#	30.84	29.78
November 2019#	24.78	24.05
February 2020#	22.47	21.35
May 2020*	26.02	25.94
October 2020#	26.87	26.04
7th May 2021a	33.69	31.44
23rd May 2021a	34.23	32.54

Non-lockdown period, * Lockdown period, a Partial-lockdown period

The confluence point (C-3, described in Chapter 4) has been considered the point source. The ghats of Varanasi have been taken as the non-point source. The non-lockdown, lockdown, and partial lockdown time frame river temperatures have been depicted in the above table.

5.5 Discussion

5.5.1 Analysis of the spatio-temporal change in river temperature

The quantitative analysis has been done for the river temperature parameter for the considered stretches and for the stipulated period. The temperature estimation formula is a well-known formula and has already been applied by several researchers across the globe, including India (George et al., 2017; Barbieri et al., 2018; Rongali et al., 2018). The river temperature is one of the essential parameters for the sustainable development of the aquatic ecosystem (Wawrzyniak et al., 2012; Ling et al., 2017). Fishes are one of the important indicators of the aquatic ecosystem because they act as contributors of nutrients to this ecosystem (Layman et al., 2103). At Varanasi and nearby (Ghazipur and Mirzapur) stretches, 82 different variety of fish species were recorded in the river Ganga (Dwivedi et al., 2016). Changes in the river temperature can affect the fish network structure in the river (Brown and Krygier, 1970) posing an adverse impact on its population.

For all of the considered stretches, the temperature was higher in February 2020 as compared to February 2019, and global warming can be one of the causes for this increase in the river temperature (Wawrzyniak et al., 2016). The river temperature shows a declining trend in the lockdown period (i.e., May 2020) compared to May 2019. The decrease in the river temperature can be attributed to the fact that the river temperature is reduced because of the air temperature's dwindling effect. The air temperature is directly related to the river water temperature (Webb, 1996; Poirel et al., 2009). The air temperature gets reduced because the lockdown has forced to shut down the industries, due to which the carbon emissions get depleted. Concentrations of PM_{10} and $PM_{2.5}$ have witnessed the maximum reduction (Mahato et al., 2020). The region of Mirzapur and Varanasi is an industrial belt. Mirzapur is quite rich in metalware and utensil manufacturing industries. In Varanasi and the nearby region, several industries like textile, chemical, and metal processing are situated (Sharma et al., 1992; Rai and Tripathi, 2008; Rai et al., 2010). Heavy metals like Zn, Cu, Cd, Pb, Cr, and Ni have been found in the river during these stretches (Sharma et al., 1992; Rai et al., 2010). These heavy metals are very harmful to the aquatic ecosystem (Baby et al. 2010). Heavy metals can increase the river's EC (electrical conductivity), thus enhancing the river's temperature (Das et al., 2021). But in the lockdown, the industries were mostly shut, so there has been less discharge of heavy metals in the river, which can also be another factor for low river temperature during the lockdown period. The strict lockdown was implemented in India from the last week of March 2020 to July 2020 (Saravanan, 2020). Several industries in this region still have not become fully functional even after July 2020. The river thermal pattern during post lockdown (October 2020) has shown an increasing trend as compared to November 2019. This is a natural phenomenon as the air temperature in October is more than that of November, and the river temperature also follows the same pattern. The additional meteorological effect (rainfall and air temperature) has also been analysed. The average precipitation and average air temperature of the study stretch have been considered for this work. There is not much variation in the meteorological parameters for the season of 2019 and 2020. In the season of April-May 2020, only one day had some considerable amount of rainfall (> 10mm), but for other days rainfall is less than 4mm. The meteorological parameter (rainfall and air temperature) graph has been given in Appendix B.

5.5.2 Analysis of the river temperature fluctuations due to lockdown imposed in the second COVID-19 wave in the summers of 2021

In the middle of March 2021, the second wave of COVID-19 had begun to spread its tentacles throughout the country. Then in the upcoming months, the situation turned from bad to worst. The major affected states in the second wave were Maharashtra, Kerala, Karnataka, Andhra Pradesh, Tamil Nadu, Andhra Pradesh, Delhi, Uttar Pradesh, and West Bengal. In March 2020, the Indian central government had imposed a nationwide lockdown. As health is a state subject as per the constitution of the country, so in the year 2021, the central government had given the responsibility of the lockdown to the respective states (Kar et al. 2021). The UP government had not posed a complete lockdown; instead, it opted for the weekend lockdown rule starting from the 24th April to the 24th May. Due to the weekend lockdown, the industries were running, and even the anthropogenic activities were also going on along the *ghats* of the river. The river's temperature had also been more in May 2021 compared to May 2020. In the later half of May 2021, the river temperature increased further than in early May 2021.

5.5.3 Special emphasis on the Varanasi stretch

Varanasi city is one of the very famous places of Vedic culture. It is the most populated and important city of the considered river stretch. The absolute thermal difference maps have been drawn for this region only. The temperature pattern variation due to anthropogenic activities of ghats and industrial waste has been shown in table 5.3. The non-point disturbance causes more rise in river temperature as compared to the point disturbance in the Varanasi stretch.

This region has been affected by polluted water of the river as the huge number of the population in this region depends on the river water for their numerous day-to-day works. The aquatic ecosystem in this region has been impeded due to anthropogenic and industrial activities. Moreover, in this stretch, two rivers, *Varuna* and *Assi*, have joined the river Ganga and these rivers also carry some domestic and industrial waste along with them. The river rejuvenation program for sustaining the aquatic ecosystem is highly desired.