Chapter 8

FINDING AND CONCLUSION

8.1 Introduction

The present study has been performed to determine the responsible factors for the fluctuations of the temperature of surface water of river Ganga in the stretch between Mirzapur to Ghazipur with the help of thermal satellite imageries.

The remote sensing, morphology of the river, and meteorological data have been significant inputs for this work. These datasets have paved the way to peep into a new horizon to transact the innovative findings in the perspective of the thermal pattern scenario of an aquatic milieu. The information extracted from these datasets has been used to identify the suitable areas of rich aquatic habitat and their spatio-temporal variation in the context of dynamic river thermal patterns. This information can be helpful for the environmental policymakers to formulate and implement thereafter for a proper plan for the restoration of the rivers.

The present work illustrated that the spatial datasets are of great help for the periodic study of the temperature pattern for the water bodies. This work also tells us which sensor between the LANDSAT-7 and LANDSAT-8 needs to be used to study the river's periodic thermal pattern. Both of these sensors have thermal bands associated with them. This study shows that anthropogenic, geomorphological, and global warming are some of the prominent causative factors for the thermal pattern fluctuation in the river Ganga for the stretch between Mirzapur and Ghazipur. The overall research revolves around five objectives to accomplish this study “

Investigation of the causative factors for surface water temperature fluctuations." The following section summerise the specific conclusion of all the objectives. This enables us to reach the final aim of the work, i.e., the identification of the dynamic zone(s) of biota richness.

8.2 Specific conclusion of each objective

The specific conclusions have been summarized based on the individual chapters of the thesis:

8.2.1 Conclusion of the objective achieved in Chapter 3

In Chapter 3, a comparative study between the LANDSAT-7 and LANDSAT-8 satellite imageries has been done for studying the periodic river thermal pattern.

The technique applied in this study offers a useful way to fill in the sparse in-situ observational record of surface water temperatures of the rivers. This method can be applied at a global scale for large and wide rivers because LANDSAT-7 and LANDSAT-8 have global coverage. The result portrayed the effectiveness of LANDSAT-7 and LANDSAT-8 thermal imagery in studying seasonal fluctuations of the large rivers. However, suppose images from two satellites are compared with one another. In that case, it can be said that despite having a low resolution in comparison to LANDSAT-7, the performance of LANDSAT-8 is better for estimation of the temperature of the river surface water. The LANDSAT-8 data has an R^2 value of 0.87 with in-situ temperature and an RMSE value of 1.2, but the LANDSAT-7 has an R^2 value of 0.86 with an RMSE value of 1.28. Even with the air temperature also LANDSAT-8 shows a better correlation for all the time periods (Feb, May-June, Oct-Nov) under consideration. For LANDSAT-8 in the months of February, May-June, and October-November, the R^2 value with air temperature has been 0.67, 0.77, 0.71respectively. Similarly, for LANDSAT-7, these values are 0.65, 0.72, and 0.69 for the time period of February, May-June, and October-November, respectively. However, there are certain limitations of this study, as well. Small-scale thermal intrusions in the river cannot be analyzed from LANDSAT images. For narrow rivers, the temperature calculation by LANDSAT satellite images is not feasible because of the poor spatial resolution of thermal bands in both the LANDSAT -7 and 8 imageries. This paper implicates that the accuracy of LANDSAT-7 is hindered due to the presence of scan line errors in the majority of the study area. However, the accuracy assessment of the temperature retrieval from LANDSAT-7 images for a study area free from scan line error can be considered the scope of future work.

8.2.2 Conclusion of the objective achieved in Chapter 4

In Chapter 4, the thermal pattern spatio-temporal fluctuation of the river stretch (Varanasi and its nearby region) has been studied using the LANDSAT-8 data. The temperature variation at the three confluence points polluted by anthropogenic activities has been analysed.

For this study, 29 satellite images were used, out of which 23 were used to prepare thermal maps, and six were used for validation purposes. The validation of satellite-measured temperatures was done by in-situ temperature measurements, for which the Arduino-based portable thermal sensor has been developed. The work has been validated by in-situ temperature measurement with a portable thermal sensor having high accuracy (±0.1ºC). A good correlation (R^2=0.927 & RMSE=0.956) was observed between the sensor's estimated temperature and the in-situ temperature. The results exemplify that water surface temperature at confluence points was relatively higher due to the incoming effluents. The temperature in the middle part of the river is comparatively lower. The ‘confluence point 3’ has the least relative temperature variation. The relative temperature variation has been more prominent for the month of February in comparison to June and November. Relative temperature shows the least variation for the period of June 2020. The "confluence point 3" shows the minimal variation for relative temperature. This could be due to the fact that this point is an industrial outlet, and industries mostly treat the waste before disposing of that in the river. At the same time, the mid-Ganga temperature was not affected by the discharge of the effluent. The river Ganga, due to its self-purification capacity, diminishes the effluents and wastes entering the aquatic milieu to a lesser extent.

8.2.3 Conclusion of the objective achieved in Chapter 5

In Chapter 5, the river thermal fluctuation has been studied for the baseline condition (almost zero discharge condition) and this scenario has come to existence due to COVID-19 induced lockdown. The pre-lockdown, lockdown, and post-lockdown river temperature scenario in the river stretch near Ghazipur, Varanasi, and Mirzapur has been analysed.

Satellite imageries have been used for the spatio-temporal analysis of the river water temperature in the considered study stretch for the pre-lockdown, lockdown, and post-lockdown time period. The significant impact of the lockdown had happened on the water temperature of river Ganga in Varanasi and its nearby region. In the Mirzapur stretch, the temperature of the river Ganga decreases most by 12.06% in May 2020 as compared to May 2019. Similarly, in the Varanasi stretch, the temperature had been reduced by 8.62%, and in the Ghazipur stretch, this decline of the river's temperature was noted as 7.14% in May 2020 compared to May 2019. Several polluting industries have been closed, and anthropogenic activities have also been reduced to a great extent due to the lockdown. After four weeks since the lockdown had begun, the government allowed the production of essential items, and other industries were closed. So, there had been lees discharge of the effluent. This situation has taken off the vast chunk of toxic load from the river. The river temperature has shown a decreasing trend during the lockdown. During the lockdown, the way water quality of the river has shown progress; it is evident that the leading cause of water quality degradation is anthropogenic factors. Grossly polluting industries in the river's catchment areas need to be regulated at the earliest because the water quality improvement due to the lockdown phenomenon is just a temporary reprieve. The river rejuvenation, observed during the first lockdown in the summer of 2020, had been deteriorating in the second-wave lockdown (summers of 2021) in the UP (Uttar Pradesh) region. In the second wave lockdown, the industries were not closed, and anthropogenic activities also been carried out, which increased the pollution level of the river. Necessary regulations should be implemented to reduce further deterioration of the river water quality while keeping the increasing rate of urbanization and pollution loading of the river in mind. Undoubtedly, this would be a permanent respite to rejuvenate the river ecosystem. It is recommended that water quality standards concerning the living environment must be properly fixed, and all types of effluents discharged into the river water, including industrial and domestic wastes, should be controlled. One of the biggest challenges will be keeping the river in similar conditions when everything is opened in a full-fledged manner. The COVID-19 global pandemic is a once-in-a-generation occurrence that is currently plaguing the world. Yet, it presents a similarly once-in-a-lifetime opportunity to redesign the existing frameworks and implement a robust as well as a dynamic mechanism to clean one of India's most polluted rivers and the nation's other similarly afflicted watercourses.

8.2.4 Conclusion of the objective achieved in Chapter 6

In Chapter 6, a few geomorphological factors (river depth, sandbar width and ratio parameter) have been considered which can affect the river temperature pattern.

The present work using remote sensing and a GIS-based approach with multi-date satellite data has intended to comprehend the spatio-temporal behaviour of river geomorphology and its impact on the thermal pattern of the river. Sand bars are more prominent in the high sinuous parts of the study stretch. The findings of this study reveal that river temperature showed a positive correlation with the sandbar width and a negative correlation with the ratio parameter. The depth parameter has more impact on the river in the upstream region than the downstream region. The depth values have not been available for the entire stretch. This is the general trend followed mostly through the study stretch of the river under consideration. On the other hand, the study of different types of sandbars in terms of their size, shape, position, persistence, or life cycle can be assumed to be a scope of future work. Evidently, the effect of groundwater vis-a-vis river temperature profiles in different seasons would open new vistas to environmental scientists and planners aiming at maintaining the pristine beauty of the aquatic ecosystem of river Ganga.

8.2.5 Conclusion of the objective achieved in Chapter 7

In Chapter 7, the effect of global warming on the river thermal pattern has been studied for Varanasi and its nearby region.

The global warming effect on river water quality has been analyzed in this work. The river Ganga stretch in and around the Varanasi region has been chosen as the study area for this analysis.

The air temperature over the river stretches has been predicted for the years 2022 and 2025, using SARIMA and Prophet models. The Prophet model has been more accurate, and it has a lower RMSPE value as compared to the SARIMA model. The Prophet model has an RMSPE of 3.2%, and for SARIMA, it has been 7.54%. The river temperature and turbidity have been evaluated for the city river and non-city river stretch. The LSTM model has been used to predict the river temperature and turbidity for the years 2022 and 2025. The average river temperature for the city stretch will rise by approximately 0.6°C in 2025 as compared to 2022. In the non-city river stretch, the average river temperature depicts a rise of approximately 0.65°C. In addition to the river temperature, the average nighttime radiance imageries have also been assessed to describe the role of anthropogenic activities disrupting the aquatic milieu of the river. The average nighttime radiance values have also been predicted by the LSTM model for both surroundings of the city and non-city river stretch for the years 2022 and 2025. The model has predicted that anthropogenic activities will result in a significant rise for the city river stretch in the near future. No doubt, the increase in anthropogenic activities combined with the climate change effect would be detrimental to the river and its ecosystem. The impact of climate change will not only result in severe disasters of floods and drought but will also reduce the carrying capacity as well as the assimilative capacity of the river by affecting its abiotic and biotic components. Elevated temperatures hamper the growth of flora and fauna along with reducing the process of photosynthesis. River Ganga has been the home to a number of reptiles, fish, mammals, and birds. The enhanced river temperature would increase the growth rate of bacteria and phytoplankton, which in turn could aggravate the eutrophication process, thus causing river water quality to deteriorate. The immediate mitigation policy needs to be implemented to prevent any further degradation of the river ecosystem. Plans related to the pollution control of the river Ganga need to be combined with climate change management efforts by employing better policy planning. For sustainable development of the river Ganga basin, aspects related to climate change must be given due significance. Toady collaborative research is the right approach where the team of experts of different subdisciplines (engineers, geoscientists, ecologists, etc.) works closely to face these new challenges to maintain the ecological balance.

8.3 Findings of this research

This research aims to detect the probable causes of river thermal pattern fluctuation of a large river and identify the microbial colony zone(s) based on the dynamic river temperature pattern. The possible causes of thermal pattern variation have already been explained. The flowchart of the work done is given in figure 8.1.

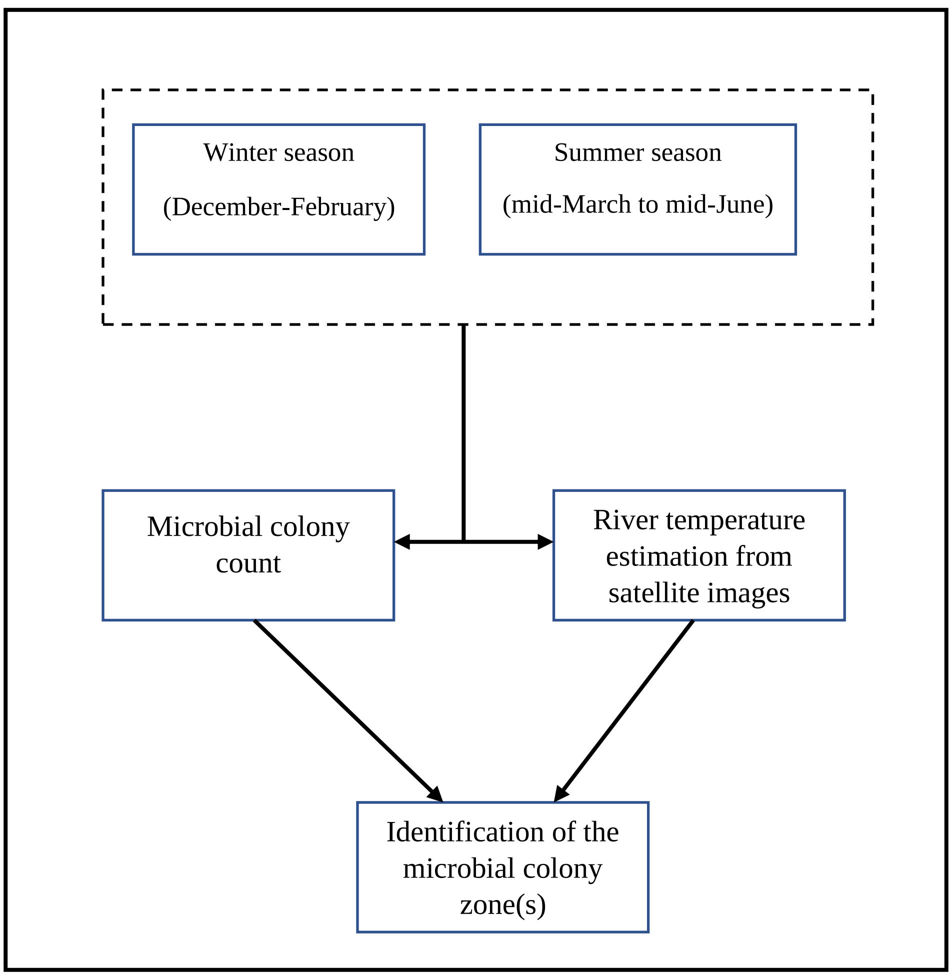

Figure 8.1 Flowchart of the methodology

Now in a part of the study stretch, situated between Bhatauli bridge (82.68°E, 25.19°N) and Bedauli (82.88°E, 25.13°N) at a few points, the river temperature values have been estimated using LANDSAT-8 datasets for the period of Mid-March to mid-June and December to February for the years 2018-19 to 2021-22. For those points, the water samples have been collected, and the microbial colony count has been carried out for the summer period of 2021 (mid-March to mid-June) and the winter period of 2021-22 (December to February). The points have been marked as A-E and 1-5. In totality, there have been 10 points (Figure 8.2). The water samples for microbial count testing have been collected in Falcon tubes of 250 mL. These tubes have been opened and closed inside the river after filling the water so that no (negligible) air bubbles enter inside the tube. This activity has been performed for all 10 points. For each point, one Falcon tube has been used. Then these water samples were tested in the Botany department (BHU).

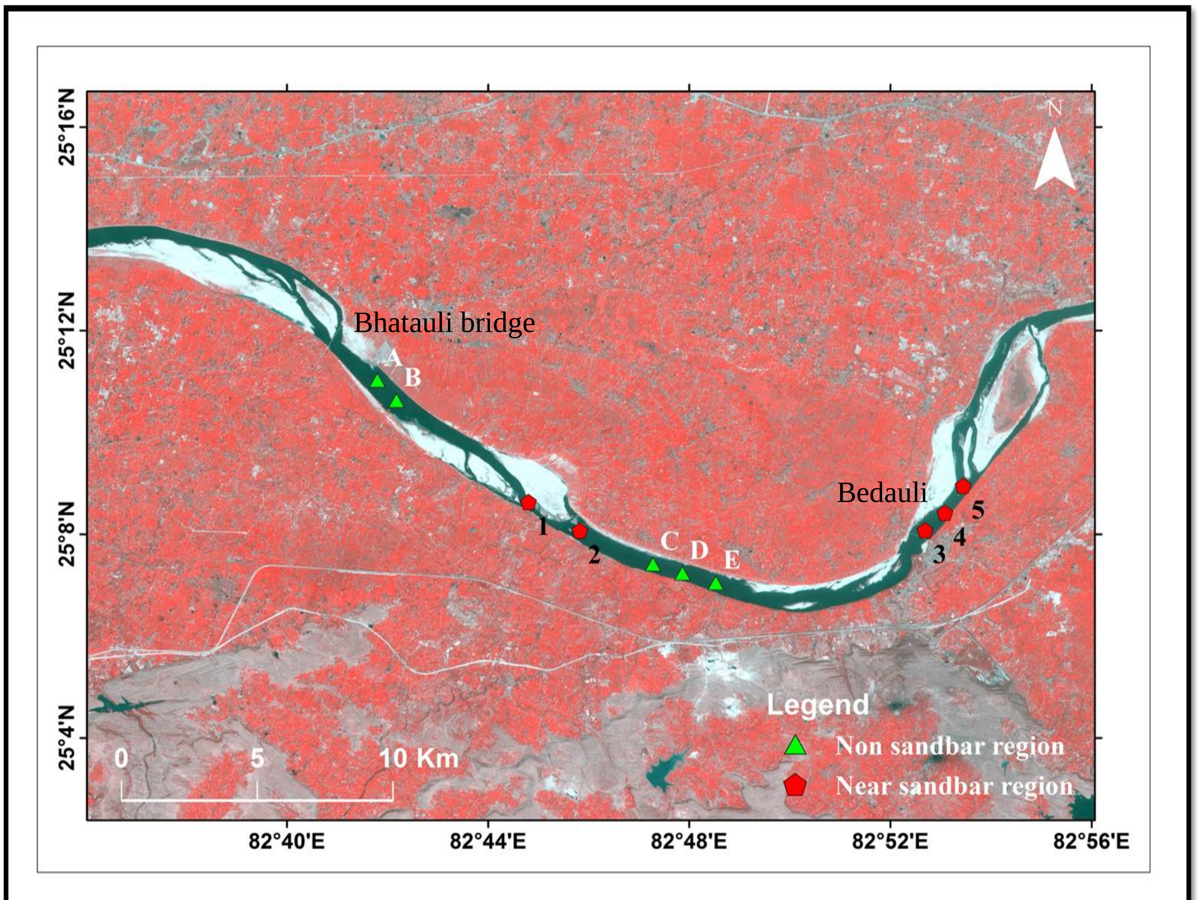

Figure 8.2 River stretch for the microbial colony zone(s) identification

This stretch has been situated in the upstream region of the study area. There has been a minimal anthropogenic disturbance in this region, so the main causative factor for river temperature fluctuation has been the river-geomorphological parameters.

The microbial colony count has been given in table 8.1 for these points marked in red and green in the considered stretch.

Table 8.1 Microbial counts for the selected points

	Colony counts (CFU)	
	Summer	**Winter**
Point 1	5	11
Point 2	4	13
Point 3	12	26
Point 4	11	28
Point 5	10	28
Point A	18	5
Point B	19	5
Point C	23	9
Point D	23	9
Point E	22	7

The microbial colony count has been measured in terms of the Colony Formation Unit (CFU). The point(s) have been chosen and allocated in two categories, i.e., one set of points(s) situated in the non-sandbar region of the river and another group of point(s) located in the near sandbar region of the river.

The temperature variation for these points has been represented in the form of box plots in figures 8.3 and 8.4

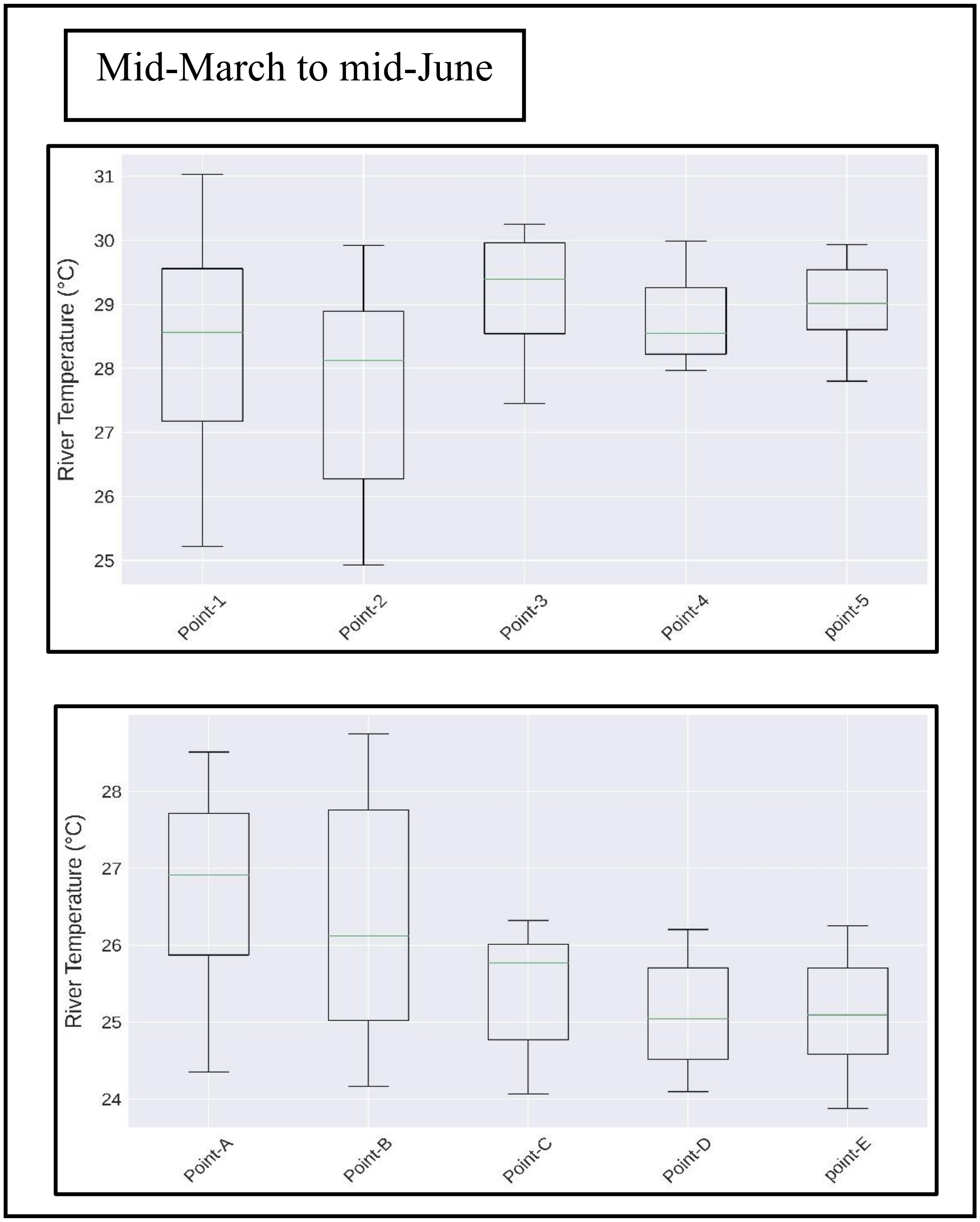

Figure 8.3 Summertime temperature fluctuations

In the summertime, it can be seen that the temperature of the river near the sandbar region is higher than in the non-sandbar region. More microbial colony count is present in the non-sandbar region.

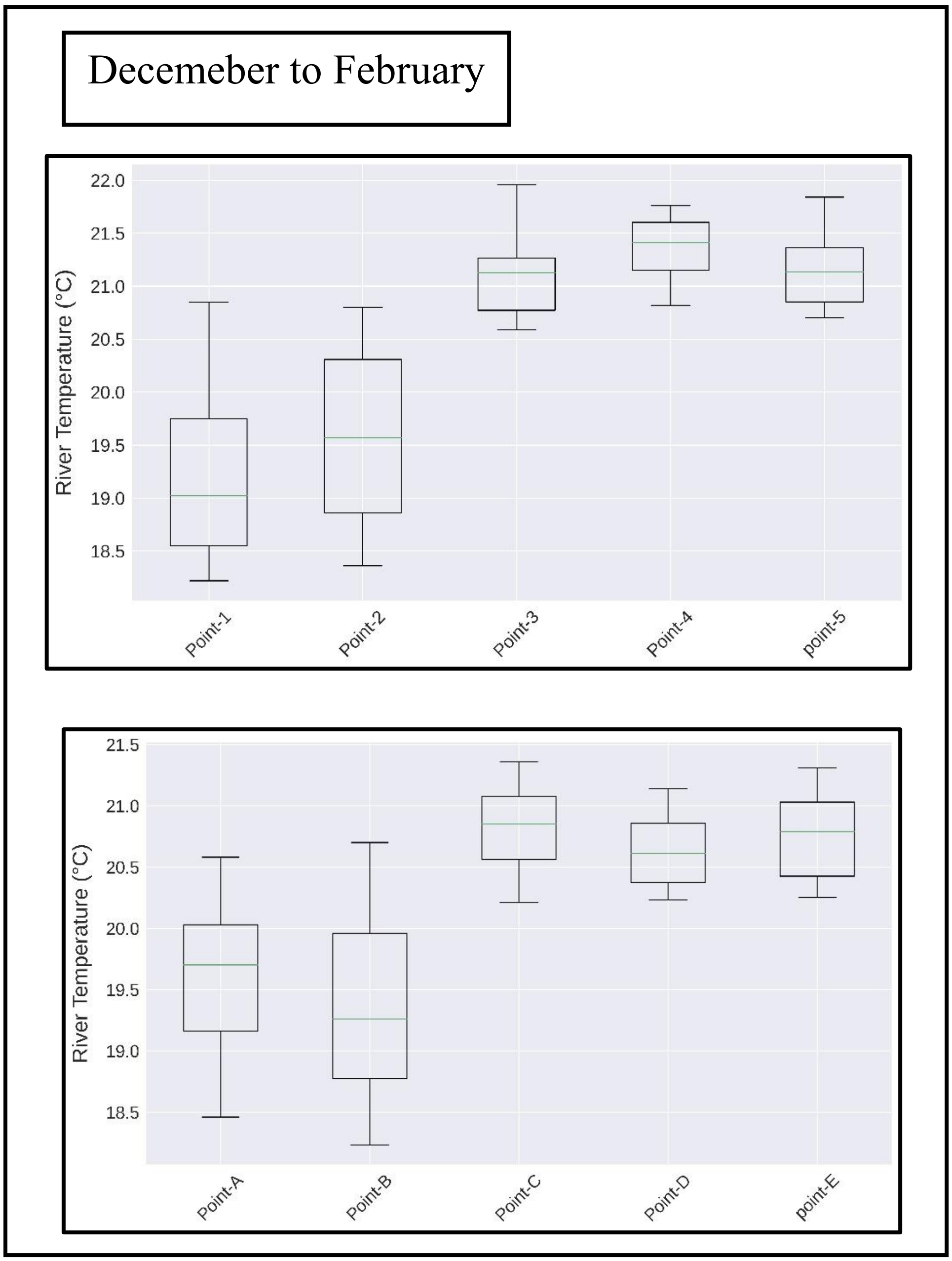

Figure 8.4 Wintertime temperature fluctuations

More colony count is present in the region near the sandbar in the wintertime.

Another observation has been noted: the colony count has been comparatively less at those places (points) where the intra-temperature fluctuations have been more. The scatter plot is also drawn between CFU and river temperature for the summer and winter seasons.

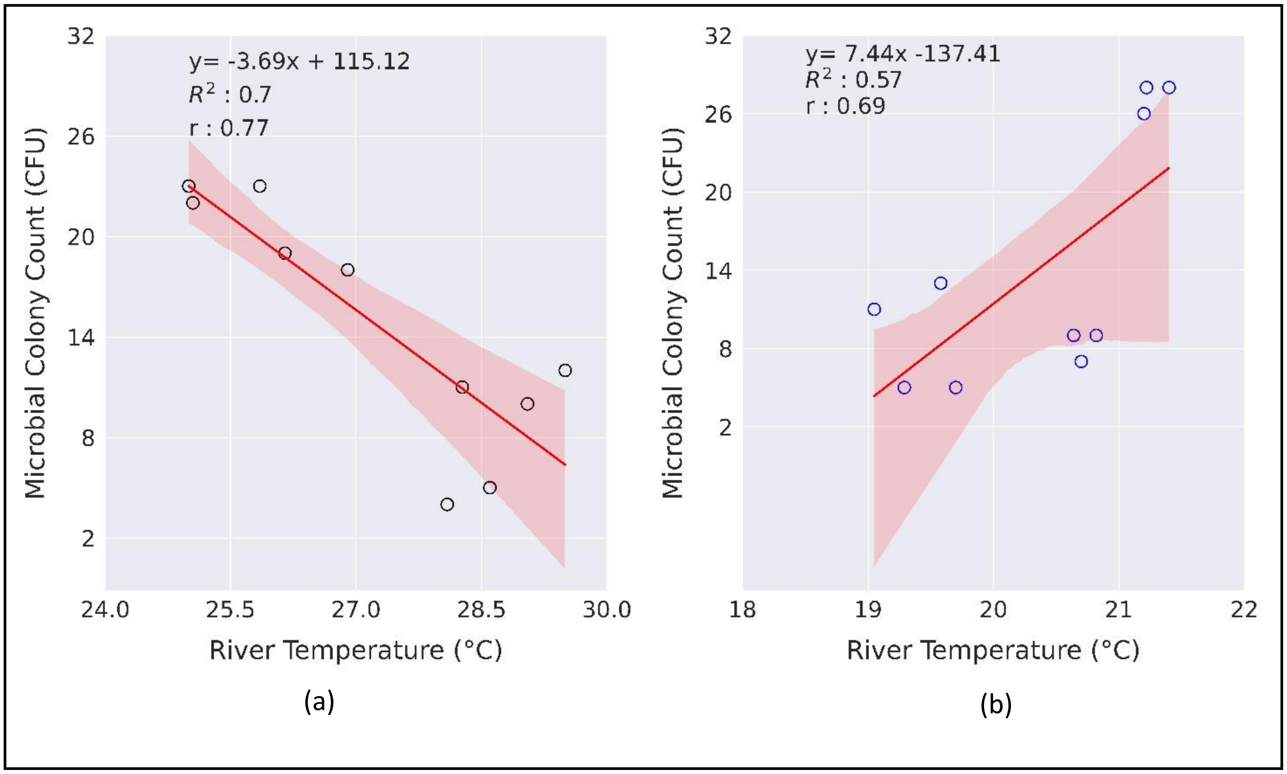

Figure 8.5 Scatter link between microbial colony count and temperature for (a) summer (b) winter

From the scatter plot, it can be seen that the colony count is decreasing at those places where the river temperature is higher. In winter, the trend is reversing. The stretch(s) for the microbial colony count variation has also been drawn for both the summer and winter season.

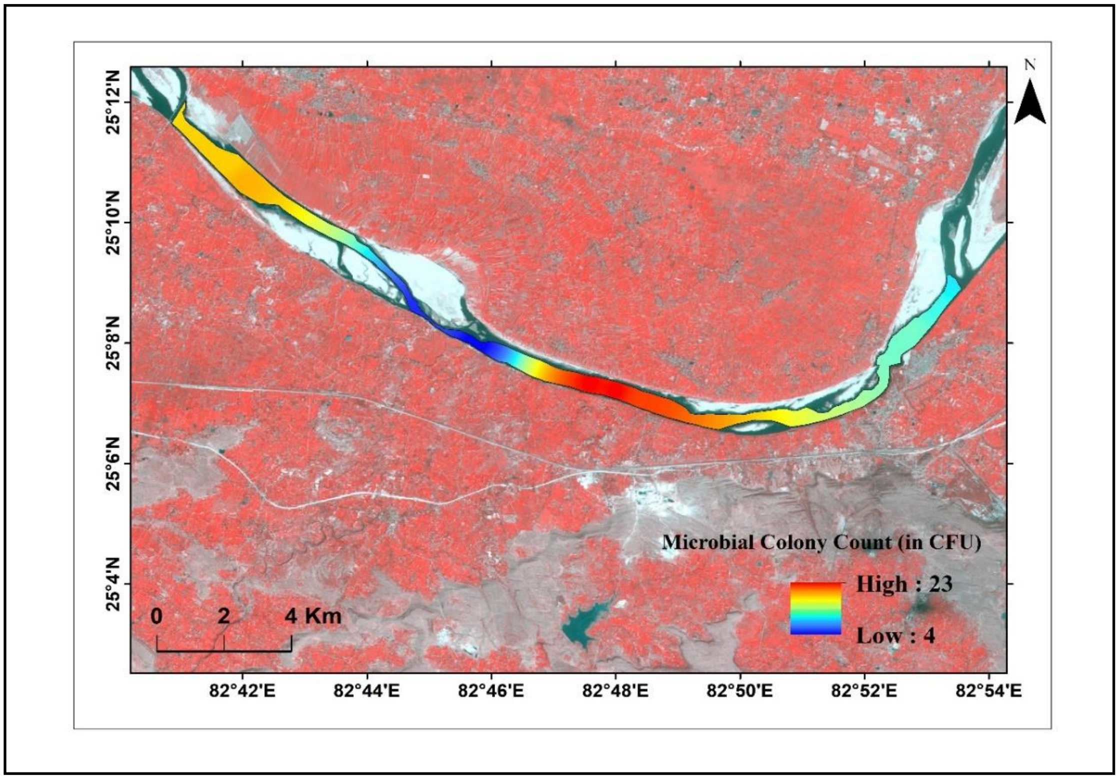

Figure 8.6 Microbial colony count variation for summer season

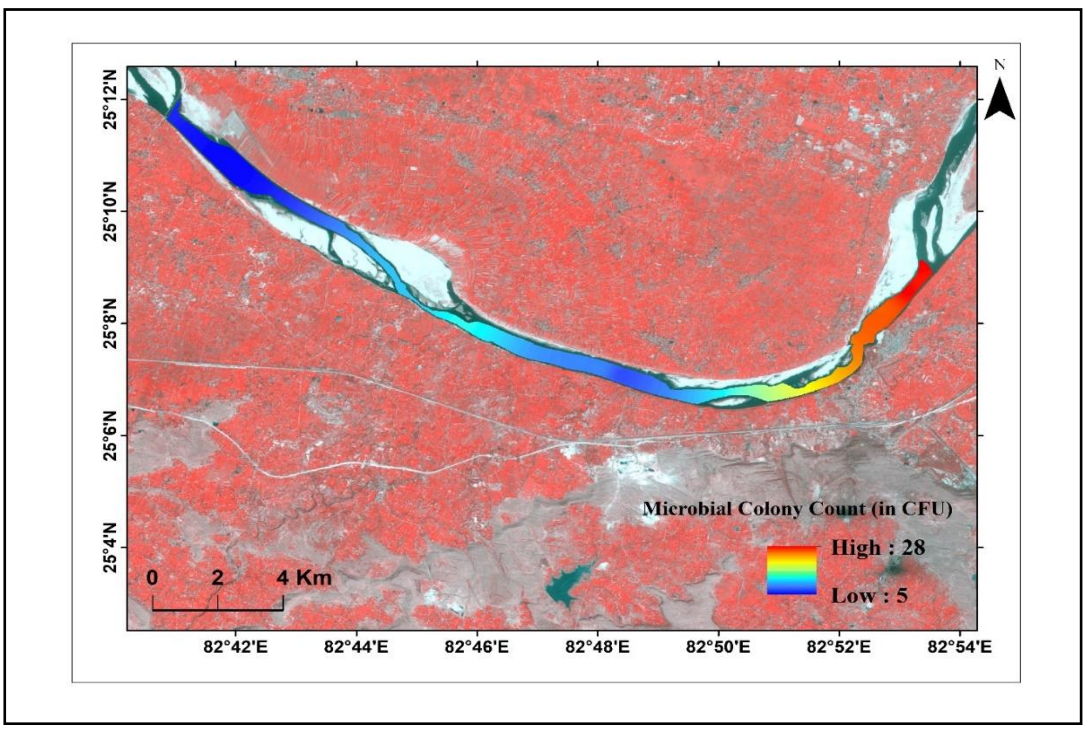

Figure 8.7 Microbial colony count variation for winter season

It has been observed that these zone(s) are dynamic in nature. The microbial-rich zone(s) are primarily situated in a region far from the sand bar during the summertime. In winter, these zone(s) are located nearby sandbars. The microbial colony can be an indicator of biota pattern variation in the river. These microorganisms can provide micronutrients to aquatic animals, which in turn are helpful for their proper growth and development. The river area where the microbial count has been more region has been more populated with aquatic animals (Wang et al., 2020).

The aim of identifying the dynamic biota richness zone(s) has been achieved.

8.4 Limitations of this research work

The first limitation of the work is that the LANDSAT-8 satellite has 16 days temporal resolution, so the daily change in the temperature pattern can not be recorded with the satellite images. The satellite imagery thermal pixels have a resolution of 100 meters, so the analysis based on these images can not be applied to small water bodies as the mixed pixel effect can creep in the result. Even the small thermal intrusions in the river also can not be detected by using these imageries. The impact of cloud cover becomes very prominent for these satellite-based images, so the analysis can not be performed during the rainy season. Another major drawback of this work is that satellite images can only capture the surface phenomenon. So the sub-surface changes can not be detected. Last but not least, the drawback is the atmospheric fluctuation. The atmospheric correction has been performed using the 'atmospheric correction calculator,' and the values generated by the calculator depend upon the interpolation technique. The uncertainty factor can be associated with the atmospheric correction parameter values, which can affect the final output. The atmospheric calculator estimates the values of atmospheric parameters at a single point, and then it interpolates. If the work is performed over a considerable spatial region, then the value of parameters may or may not get changed. The fluctuation in the atmospheric parameters can be very uncertain.

8.5 Future scope of the work

The present research work shows that several causative factors exist for the temperature fluctuations of a large river. The factors have been analysed using the thermal bands of LANDSAT-8 satellite imageries on the Mirzapur-Ghazipur section of the river Ganga. In addition to that, the temperature-dependent dynamic biota richness zone(s) have also been identified. The present research has enough scope for further investigation based on the findings. This research may be carried forward in the following directions in the future.

The first area to explore is the use of the thermal drone, which can solve many purposes. It can identify the small thermal intrusion in the river as these drones have a very high spatial resolution. These drones can also take the thermal image of the river during the rainy season when there are enormous clouds in the sky. If the thermal images are required for consecutive days (say for two or three days), then also drone can take the thermal image of the stretch as per requirement. The logistics issue needs to be kept in mind while executing the drone survey.

Secondly, the sensor system which records the temperature below the water surface needs to be developed. The 3-D thermal profile will be much preferable for analysing the effect of river temperature on the aquatic ecosystem of the river. The 3-D profiling can also be helpful in identifying any groundwater intrusion region. The groundwater can be a factor for river thermal pattern variation. The dynamic river aquifer (R-A) exchanges analysis can be also be performed based on groundwater impact.

Another scope of future work can be the development of a better thermal algorithm that will reduce the dependence on the atmospheric calculator and reduce the uncertainty effect.

Besides, the microbial count can be carried for a more considerable stretch, which can offer a more vivid dynamic biota richness zone(s).

More intensive field sampling, more datasets of meteorological parameters, and more satellite imageries can be incorporated further to produce a more pronounced analysis.

8.6 Summary of the research work and the final conclusion

This work examines several causative factors for the temperature variation in the considered study stretch, along with the identification of the dynamic biota richness zone(s). The temperature of the river in the region mainly fluctuated because of the anthropogenic perturbation, river geomorphology, and global warming. The temperature fluctuation has been maximum due to anthropogenic disturbances. The untreated domestic and industrial waste gets mixed into the river Ganga in the region nearby Varanasi, which sometimes inflates the temperature more than 2°C. The geomorphological factors like river depth and sandbars also have their impact on the river thermal pattern. The sandbars are positively correlated with river temperature variation. An increase in the sandbar width of about 1200 meters brings an increment of the river temperature by 0.5°C approximately. The river depth has a negative impact on the thermal profile of the river. If the river depth increases to 12 meters, the temperature gets diminished by 0.3°C. The sandbars are important because in the winter season (December to February), the microbial count is more near sandbar regions as compared to the regions away from the sandbar. The sandbars need to be conserved as it can be helpful for sustaining the river ecosystem, particularly in the winter season.

Global warming is another causative factor for river thermal pattern variation. Due to global warming, the predicted average river temperature increases by approximately 0.2°C (in December 2022 compared to December 2020). In December 2025, the predicted average river temperature will rise by approximately 0.6°C as compared to December 2020. The thermal pattern fluctuation has been at the local scale due to anthropogenic disturbances and sandbars, but due to global warming, the river thermal pattern has varied throughout the entire stretch.

The concerned authorities need to control the anthropogenic disturbance and global warming by reducing the carbon emission in the environment so that the river temperature remains within a permissible limit. Otherwise, if the temperature soars too high, it will be detrimental to the river ecosystem. Identifying biota richness zone(s) can be helpful for formulating suitable conservation plans and policies by the environmental policymakers for river rejuvenation. Furthermore, the global warming effect needs to be contemplated for implementing such policies.