Dedicated to Lord Shiva, my loving Grandparents, parents, and my family

PRELIMINARIES

INVESTIGATION OF THE CAUSATIVE FACTORS FOR SURFACE WATER TEMPERATURE FLUCTUATIONS

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It is certified that the work contained in the thesis titled ***"Investigation of the causative factors for surface water temperature fluctuations"*** by *"NILENDU DAS"* has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy and SOTA for the award of Ph.D. Degree.

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DECLARATION BY THE CANDIDATE

I, ***Nilendu Das***, certify that the work embodied in this thesis is my own bonafide work and carried out by me under the supervision of ***Dr. Shishir Gaur*** from July-2016 to April-2022, at the ***Department of Civil Engineering***, Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma.

I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, etc, reported in journals, books, magazines, reports dissertations, theses, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

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CERTIFICATE BY THE SUPERVISOR(S)

It is certified that the above statement made by the student is correct to the best of my/our knowledge.

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PREFACE

Water is the elixir of life. For centuries, the rivers have played a pivotal role in sustaining life on earth. They have been the source of water and several essential nutrients. The river and its ecosystem have been significantly impacted by the stream's water temperature. The temperature pattern of the river has been crucial for understanding the underlying river dynamics. Several factors like river morphology, river-bed structure, flow discharge, and meteorological conditions influence the fluctuations of the river temperature. The river type also affects the temperature change; for example, in braided rivers, the temperature distribution has been highly heterogeneous because of the channel complexity, habitat diversity, and presence of groundwater inputs. The thermal pattern of the river also varies because of anthropogenic activities like agricultural waste and non-point and point-source pollutant discharge from industrial, commercial, and housing sectors.

The proper analysis of the river temperature has been imperative. The conventional methods for temperature measurements have been expensive, labour intensive, and time-consuming. The spatial and temporal heterogeneity of the river temperature makes it difficult for traditional techniques to determine the thermal pattern accurately. Remote sensing technology has been incorporated to mitigate this heterogeneity. The satellite imageries procured from this technology have a large spatial extent and short temporal repetition. Several pieces of information can be deduced from these images by applying algorithms. The satellite images have become very effective in estimating the river thermal variation owing to these advantages.

In this work, the river's thermal pattern fluctuation and a few causative factors for this variation have been analysed using mainly LANDSAT series satellite imageries and field data. The present

analysis has been performed on the River Ganga for the Mirzapur-Ghazipur stretch. This stretch has been situated in the mid-Ganga plain region, and it has been the adobe for approximately 80 different varieties of fish. The initial study has been a comparative analysis of the LANDSAT series remote sensing satellite (LANDSAT-7 and LANDSAT-8). The LANDSAT satellite consists of thermal bands having different spatial resolutions (120m for LANDSAT-5, 60m for LANDSAT-7, and 100m for LANSAT-8). The work shows that the LANDSAT-8 satellite datasets have a better correlation with the in-situ datasets than the LANDSAT-7 datasets despite having a poorer resolution than LANDSAT-7. The LANDSAT satellite images have been primarily used for the entire thesis work. The following study has been performed to determine the effects of the incoming polluted waters on the river's thermal pattern. The river thermal pattern has been determined by LANDSAT-8 thermal images. The river temperature near the confluence points of the polluted discharge depicts the higher temperature values as compared to the mid-stream temperature. The relative temperature difference between the confluence points and a selected pristine point has been maximum for the February seasons under consideration. In this work, the advantage of the portable sensor has also been mentioned. The portable sensor setup can be used to better validate the satellite-derived algorithm for thermal analysis. The in-situ temperature can be recorded in accordance with the satellite overpass. The subsequent analysis examines the impact of the approximate zero discharge scenario on the river thermal pattern. This scenario came into existence because of the COVID-19-induced lockdown. There are three cities in the entire study stretch, and the river stretch situated nearby these cities have been selected for this work. The temperature has been measured using LANDSAT-8 satellite imageries for the period of pre-lockdown, lockdown, and post-lockdown scenarios. This study illustrates that the river temperature has decreased during the lockdown period (May 2020) in the three city stretches. In

the second lockdown (May 2021), the factories have been primarily open, so the waste has been discharged from the factories during this period, increasing the temperature as compared to the previous lockdown scenario. In the next analysis, some of the river geomorphological parameters like sandbar width, active river width, and river depth have been studied in context with river temperature fluctuation. The river temperature has been calculated using the thermal bands of the LANDSAT-8 satellite images for the entire study stretch. The sandbar width has a positive effect on the river temperature. The active river width and river depth negatively influence the river's thermal pattern. Lastly, the effect of global warming on the possible future river temperature scenario has been analysed. The ERA-5 dataset has been used to measure this region's air temperature. The SARIMA and Prophet models have been applied to predict the future trend of air temperature. The LSTM model has been used for the prediction of the future river temperature. The analysis shows that the predicted future temperature of the river will increase more in the non-city stretch than in the city stretch in the predicted future. The sandbar intrusion will have a higher impact on the non-city stretch, enhancing the temperature further. It is inferred from the above discussion that the temperature of a large river fluctuated due to anthropogenic activities, river geomorphology, and global warming.

The present study can be helpful in identifying the suitable area(s) or zone(s) of rich aquatic habitat and their spatio-temporal variation with respect to dynamic river thermal patterns. Identifying such zones can aid environmental policymakers (river scientists and government authorities) in formulating suitable conservation plans for river rejuvenation based on the scientific findings of this research. Further, the effect of global warming must be considered while framing such conservation plans and policies. Besides, the methodology and findings of the present work might be applied successfully to other rivers assimilating the adverse impact of thermal variations.