Improvement in Land Surface Parameters in Mesoscale Numerical Modelling for Assessment of Industrial Heat Island

Abstract

Urban Heat Island (UHI) effect is an adverse effect of resource consumption on the population in an urban. UHI effect describes as warm weather than its surrounding area and measured on a scale from a few meters to kilometers. It is a global environmental issue faced by cities in developed and underdeveloped countries. UHI studies have become more prevalent in recent two decades. They have been studied in highly developed urban cities such as Delhi, Mumbai, Hyderabad, Chennai, New York, Beijing, Mexico City, London city, Singapore, and many more. UHI effect is not limited to only urban cities but has a similar magnitude of effect on the industrial region, where most of the region is influenced by mining and heavy industrial activity. One such region is the Angul-Talcher region, categorized as India's seventh most polluted industrial region and lies 120 km away from the Bhubaneswar city of Odisha state. The region is famous for its huge coal deposit of fossil fuels reserve in India. The region witnessed mining activity from the early 19th century onward and is still active. The region experiences extreme weather events such as heat waves (temperature reached up to 48 °C) and floods (maximum rainfall up to 300 to 400 mm). Thus, the present study is one of the earlier studies carried out in an industrial region to estimate the heat island effect and the role of urban morphology and anthropogenic heat, which influence the intensity of the heat island effect on the weather of the Angul-Talcher region. The current study refers heat island effect over an industrial region as the Industrial heat island (IHI), mainly influenced by mining and industrial activity. The present study is divided into four sub-studies; the first study focuses on assessing IHI over the Angul-Talcher region using field campaigns and satellite data products A total of fifty micrometeorological instruments were installed throughout the region, measuring air temperature and relative humidity at 2m and land surface temperature. The study covers two seasons: the summer and monsoon season of 2016. A total of 37 out of 50 in-situ measurement stations were installed in the urban and rural settlement areas, industry, and mining to examine the maximum impact of industrialization on the Angul-Talcher region and found that maximum atmospheric IHI to be 7 to 9 °C and minimum atmospheric IHI between 2 to 4 °C throughout the field campaign. Nighttime atmospheric IHI for two seasons was maximum in mining sites (three months mean: 2.74 °C), followed in decreasing order by the industrial sites (2.52 °C), urban and rural settlements (2.13 °C), and croplands (2.06 °C). Daytime atmospheric IHI was maximum in croplands (2.07 °C), followed in decreasing order by the mining sites (1.70 °C), urban and rural settlements (1.68 °C), and Industry (1.45 °C). Surface IHI was also estimated using in-situ and MODIS satellite data product of 1 km spatial resolution and found that in-situ-based three-month mean daytime surface IHI was higher in mining sites (4.89 °C) followed by industry sites (3.77 °C) than settlements sites (3.70 °C) and cropland sites (1.09 °C). While mean nighttime surface IHIs were maximum in mining sites (2.77 °C) followed by industry sites (2.65 °C) than urban and rural settlements sites (2.17 °C) and cropland sites (2.09 °C). A comparison of in-situ surface IHIs with satellite-derived LST-based IHIs revealed that in-situ and satellite-derived surface HINs are closer in magnitude during daytime than nighttime. Settlements and croplands have higher daytime surface HINs in both in-situ and satellite-

derived measurements for the first month of the field campaign. Surface IHIs measured from in-situ for the first months were maximum in urban and rural sites (8.1 °C) followed by croplands (7.4 °C) than mining sites (6.3 °C) and Industry (2.09). Similarly, surface IHIs measured from satellite data for the first months was maximum in urban and rural settlement sites (4.4 °C) followed by croplands (3.4 °C) than mining (2.9 °C) and Industry (2.3 °C).

The other parts of the study focus on using a numerical model such as Weather Research and Forecasting (WRF) model to assess IHI over the region and establishes a relationship between urban morphology and anthropogenic heat with IHI intensity. The second study focus on the suitable parameterization scheme of the WRF model version 3.8 for the Angul-Talcher region. The study conducted a sensitivity analysis on Planetary Boundary Layer, Microphysics, and Radiation schemes available in the WRF model, which have not been tested over this Indian region that often experiences extreme heat in summer (>45 °C) as well as high air pollution. It was found that the combination of the Grenier-Bretherton-McCaa (GBM) PBL scheme, Purdue Lin Scheme (Lin) microphysics, and Revised Rapid Radiative Transfer Model (RRTMG) radiation scheme performs better for near-surface parameters such as Temperature at 2m (overall RMSE of 2.19 °C in daytime and 2.06 °C in nighttime), relative humidity (RMSE: 20.65 %) and wind (RMSE: 2.04 m/s). Therefore, GBM PBL scheme with Lin microphysics and RRTMG radiation scheme has been used to assess IHI, the role of urban morphology, and anthropogenic heat and mitigation measures using the WRF Urban Canopy Model. The third study focuses on an improved WRFUCM model incorporating anthropogenic heat from different industries with stack height information. It was found that the urban canopy contributes 0.77°C in local near-surface temperatures during daytime and up to 2.12 °C during night-time. The modified version of the WRF was found to provide more realistic estimates of IHI (5.62 °C). The influence of urban canopy was found to be higher towards IHI than the influence of AH over the region. Mitigation measures applied in the region were discussed in the fourth study. Altering thermal characteristics of the building and change in LULC were applied to urban and rural settlements, industry, and mining stations. It was found that implementing cool roofs and wall characteristics in urban grids (urban and rural settlements and industry) reduced IHI by 0.5 °C during the daytime, mixed forests in industrial sites reduced IHI by 1 to 2 °C in the nighttime and introducing water bodies in mining reduced IHI by 3 to 5 °C in the daytime and is found to be a most effective mitigation measures in the region. Thus overall, it can be concluded that the impact of the urban morphology and high anthropogenic heat and its associated industrial heat island magnitude over the industrial region can be compared to the magnitude of UHI over metro-cities of India and other Asian cities of the world with similar built-up and anthropogenic heat profile environment.