

**IMPROVEMENT IN LAND SURFACE PARAMETERS  
IN MESOSCALE NUMERICAL MODELLING FOR  
ASSESSMENT OF INDUSTRIAL HEAT ISLAND**

**VIVEK KUMAR SINGH**



**CENTRE FOR ATMOSPHERIC SCIENCES  
INDIAN INSTITUTE OF TECHNOLOGY DELHI  
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*by*

**VIVEK KUMAR SINGH**

**CENTRE FOR ATMOSPHERIC SCIENCES**

*Submitted*

**in fulfilment of the requirements of the degree of Doctor of Philosophy**

*to the*



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*Dedicated to*

*Papa aur meri Amma*



# CERTIFICATE

This is to certify that the thesis entitled “**Improvement in Land Surface Parameters in Mesoscale Numerical Modelling for Assessment of Industrial Heat Island**” being submitted by **Mr. Vivek Kumar Singh** to the **Indian Institute of Technology Delhi** for the award of the degree of **Doctor of Philosophy**, is a record of original bonafide research work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis.

The results presented in this thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

*Manju Mohan*

(PROF. MANJU MOHAN)  
Center for Atmospheric Sciences,  
Indian Institute of Technology Delhi  
Hauz Khas, New Delhi – 110016

Place: IIT Delhi, New Delhi

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I would like to thank my family and friends.

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VIVEK KUMAR SINGH



# 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 IHIs are closer in magnitude during daytime than nighttime. Settlements and croplands have higher daytime surface IHIs 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 ( $>45\text{ }^{\circ}\text{C}$ ) 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  $2.19\text{ }^{\circ}\text{C}$  in daytime and  $2.06\text{ }^{\circ}\text{C}$  in nighttime), relative humidity (RMSE:  $20.65\%$ ) and wind (RMSE:  $2.04\text{ m/s}$ ). 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  $0.77^{\circ}\text{C}$  in local near-surface temperatures during daytime and up to  $2.12\text{ }^{\circ}\text{C}$  during night-time. The modified version of the WRF was found to provide more realistic estimates of IHI ( $5.62\text{ }^{\circ}\text{C}$ ). 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  $0.5\text{ }^{\circ}\text{C}$  during the daytime, mixed forests in industrial sites reduced IHI by  $1\text{ to }2\text{ }^{\circ}\text{C}$  in the nighttime, and introducing water bodies in mining reduced IHI by  $3\text{ to }5\text{ }^{\circ}\text{C}$  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.



## सार

शहरी हीट द्वीप (यूएचआई) प्रभाव एक शहरी में आबादी पर संसाधन खपत का प्रतिकूल प्रभाव है। यूएचआई प्रभाव अपने आसपास के क्षेत्र की तुलना में गर्म मौसम के रूप में वर्णित है और कुछ मीटर से किलोमीटर तक पैमाने पर मापा जाता है। यह विकसित और अविकसित देशों के शहरों का सामना करने वाला वैश्विक पर्यावरणीय मुद्दा है। यूएचआई अध्ययन हाल के दो दशकों में अधिक प्रचलित हो गए हैं। इनका अध्ययन दिल्ली, मुंबई, हैदराबाद, चेन्नई, न्यूयॉर्क, बीजिंग, मैक्सिको सिटी, लंदन शहर, सिंगापुर और कई अन्य उच्च विकसित शहरी शहरों में किया गया है। यूएचआई प्रभाव केवल शहरी शहरों तक सीमित नहीं है, बल्कि औद्योगिक क्षेत्र पर प्रभाव की एक समान परिमाण है, जहां अधिकांश क्षेत्र खनन और भारी औद्योगिक गतिविधि से प्रभावित है। ऐसा ही एक क्षेत्र अंगुल-तालचर क्षेत्र है, जिसे भारत के सातवें सबसे प्रदूषित औद्योगिक क्षेत्र के रूप में वर्गीकृत किया गया है और ओडिशा राज्य के भुवनेश्वर शहर से 120 किमी दूर स्थित है। यह क्षेत्र भारत में जीवाश्म ईंधन भंडार के विशाल कोयला जमा करने के लिए प्रसिद्ध है। इस क्षेत्र में 19th शताब्दी की शुरुआत से खनन गतिविधि देखी गई और अभी भी सक्रिय है। इस क्षेत्र में गर्मी की लहरें (तापमान 48 डिग्री सेल्सियस तक पहुंच गया) और बाढ़ (अधिकतम वर्षा 300 से 400 मिमी तक) जैसी चरम मौसम की घटनाओं का अनुभव होता है। इस तरह, वर्तमान अध्ययन गर्मी द्वीप प्रभाव और शहरी आकृति विज्ञान और मानवजनित गर्मी की भूमिका का अनुमान लगाने के लिए एक औद्योगिक क्षेत्र में किए गए पहले के अध्ययनों में से एक है, जो अंगुल-तालचर क्षेत्र के मौसम पर गर्मी द्वीप प्रभाव की तीव्रता को प्रभावित करता है। वर्तमान अध्ययन एक औद्योगिक क्षेत्र पर गर्मी द्वीप प्रभाव को औद्योगिक गर्मी द्वीप (IHI) के रूप में संदर्भित करता है, जो मुख्य रूप से खनन और औद्योगिक गतिविधि से प्रभावित होता है। वर्तमान अध्ययन को चार उप-अध्ययनों में बांटा गया है; पहला अध्ययन क्षेत्र अभियानों और उपग्रह डेटा उत्पादों का उपयोग करके अंगुल-तालचर क्षेत्र में आईएचआई का आकलन करने पर केंद्रित है। पूरे क्षेत्र में कुल पचास सूक्ष्म मौसम विज्ञान उपकरण स्थापित किए गए थे, 2m और भूमि की सतह के तापमान पर हवा के तापमान और सापेक्ष आर्द्रता को मापना। इस अध्ययन में

दो मौसमों को शामिल किया गया है- 2016 की गर्मी और मानसून का मौसम। शहरी और ग्रामीण बस्ती क्षेत्रों में 50 में से कुल 37 इन-सीटू मापन स्टेशन लगाए गए थे, उद्योग, और खनन अंगुल-तालचेर क्षेत्र पर औद्योगीकरण के अधिकतम प्रभाव की जांच करने के लिए और पाया कि अधिकतम वायुमंडलीय आईएचआई 7 से 9 डिग्री सेल्सियस और न्यूनतम वायुमंडलीय आईएचआई 2 से 4 डिग्री सेल्सियस के बीच पूरे क्षेत्र अभियान के दौरान। दो मौसमों के लिए रात का वायुमंडलीय आईएचआई खनन स्थलों (तीन महीने का मतलब: 2.74 डिग्री सेल्सियस) में अधिकतम था, इसके बाद औद्योगिक स्थलों (2.52 डिग्री सेल्सियस), शहरी और ग्रामीण बस्तियों (2.13 डिग्री सेल्सियस) और क्रॉपलैंड (2.06 डिग्री सेल्सियस) द्वारा क्रम में कमी आई। दिन का वायुमंडलीय आईएचआई अधिकतम फसल भूमि (2.07 डिग्री सेल्सियस) में था, इसके बाद खनन स्थलों (1.70 डिग्री सेल्सियस), शहरी और ग्रामीण बस्तियों (1.68 डिग्री सेल्सियस) और उद्योग (1.45 डिग्री सेल्सियस) द्वारा क्रम में कमी आई। भूतल आईएचआई का अनुमान 1 किमी स्थानिक संकल्प के इन-सीटू और एमओडीआईएस उपग्रह डेटा उत्पाद का उपयोग करके भी लगाया गया था और पाया गया कि खनन स्थलों (4.89 डिग्री सेल्सियस) में इन-सीटू-आधारित तीन महीने का औसत दिन की सतह आईएचआई अधिक था, इसके बाद उद्योग स्थलों (3.77 डिग्री सेल्सियस) बस्तियों के स्थलों (3.70 डिग्री सेल्सियस) और क्रॉपलैंड साइटों (1.09 डिग्री सेल्सियस) की तुलना में। जबकि रात की सतह आईएचआई खनन स्थलों (2.77 डिग्री सेल्सियस) में अधिकतम थी, इसके बाद शहरी और ग्रामीण बस्तियों के स्थलों (2.17 डिग्री सेल्सियस) और क्रॉपलैंड साइटों (2.09 डिग्री सेल्सियस) की तुलना में उद्योग स्थलों (2.65 डिग्री सेल्सियस) थे। उपग्रह-व्युत्पन्न एलएसटी-आधारित आईएचआई के साथ इन-सीटू सतह आईएचआई की तुलना से पता चला है कि इन-सीटू और उपग्रह-व्युत्पन्न सतह एचआईएन रात के समय की तुलना में दिन के दौरान परिमाण में करीब हैं। क्षेत्र अभियान के पहले महीने के लिए सेटलमेंट और क्रॉपलैंड्स में दिन के समय दोनों में उच्च सतह एचआईएन और उपग्रह-व्युत्पन्न माप होते हैं। पहले महीनों के दौरान इन-सीटू से मापी गई सतह आईएचआई शहरी और ग्रामीण स्थलों (8.1 डिग्री सेल्सियस) में अधिकतम थी, इसके बाद खनन स्थलों (6.3 डिग्री सेल्सियस) और उद्योग (2.09) की तुलना

में फसली भूमि (7.4 डिग्री सेल्सियस) थी। इसी तरह, पहले महीनों के लिए उपग्रह डेटा से मापा गया सतह आईएचआई शहरी और ग्रामीण निपटान स्थलों (4.4 डिग्री सेल्सियस) में अधिकतम था, इसके बाद खनन (2.9 डिग्री सेल्सियस) और उद्योग (2.3) डिग्री सेल्सियस ।

अध्ययन के अन्य हिस्सों में इस क्षेत्र में आईएचआई का आकलन करने के लिए मौसम अनुसंधान और पूर्वानुमान (डब्ल्यूआरएफ) मॉडल जैसे संख्यात्मक मॉडल का उपयोग करने पर ध्यान केंद्रित किया गया है और आईएचआई तीव्रता के साथ शहरी आकृति विज्ञान और मानवजनित गर्मी के बीच संबंध स्थापित किया गया है। दूसरा अध्ययन अंगुल-तालचर क्षेत्र के लिए डब्ल्यूआरएफ मॉडल संस्करण 3.8 की उपयुक्त पैरामीटराइजेशन योजना पर केंद्रित है। इस अध्ययन में प्लैनेटरी बाउंड्री लेयर पर संवेदनशीलता का विश्लेषण किया गया, माइक्रोफिजिक्स, और WRF मॉडल में उपलब्ध विकिरण योजनाएं, जिनका इस भारतीय क्षेत्र पर परीक्षण नहीं किया गया है, जो अक्सर गर्मियों में अत्यधिक गर्मी (> 45 डिग्री सेल्सियस) के साथ-साथ उच्च वायु प्रदूषण का अनुभव करते हैं। यह पाया गया कि ग्रेनियर-ब्रेथर्टन-मैकका (जीबीएम) पीबीएल योजना का संयोजन, पड्यूलिन योजना (लिन) माइक्रोफिजिक्स, और संशोधित रैपिड रेडिएटिव ट्रांसफर मॉडल (आरआरटीएमजी) विकिरण योजना 2m पर तापमान (दिन में 2.19 डिग्री सेल्सियस और रात के समय में 2.06 डिग्री सेल्सियस के समग्र आरएमएसई) जैसे निकट-सतह मापदंडों के लिए बेहतर प्रदर्शन करती है, सापेक्ष आर्द्रता (आरएमएसई: 20.65 %) और पवन (आरएमएसई: 2.04 मी/से। इसलिए, लिन माइक्रोफिजिक्स और आरआरटीएमजी विकिरण योजना के साथ जीबीएम पीबीएल योजना का उपयोग आईएचआई, शहरी आकृति विज्ञान की भूमिका, और मानवजनित गर्मी और डब्ल्यूआरएफ शहरी चंद्रवा मॉडल का उपयोग करके शमन उपायों का आकलन करने के लिए किया गया है। तीसरा अध्ययन एक बेहतर डब्ल्यूआरएफयूसीएम मॉडल पर केंद्रित है जिसमें स्टैक ऊंचाई की जानकारी के साथ विभिन्न उद्योगों से एंथ्रोपोजेनिक गर्मी शामिल है। यह पाया गया कि शहरी चंद्रवा दिन के दौरान स्थानीय निकट-सतह के तापमान में 0.77degC और रात के समय 2.12 डिग्री सेल्सियस तक का योगदान देता है। डब्ल्यूआरएफ का संशोधित संस्करण आईएचआई (5.62 डिग्री सेल्सियस) के अधिक यथार्थवादी अनुमान

प्रदान करने के लिए पाया गया था। शहरी चंदवा का प्रभाव इस क्षेत्र पर एएच के प्रभाव की तुलना में आईएचआई की ओर अधिक पाया गया। चौथे अध्ययन में क्षेत्र में लागू शमन उपायों पर चर्चा की गई। इमारत की थर्मल विशेषताओं को बदलना और एल्यूमीनियम में परिवर्तन शहरी और ग्रामीण बस्तियों, उद्योग और खनन स्टेशनों पर लागू किया गया था। यह पाया गया कि शहरी ग्रिड (शहरी और ग्रामीण बस्तियों और उद्योग) में ठंडी छतों और दीवार विशेषताओं को लागू करने से दिन के दौरान आईएचआई में 0.5 डिग्री सेल्सियस की कमी आई, औद्योगिक स्थलों में मिश्रित वनों ने रात के समय आईएचआई को 1 से घटाकर 2 डिग्री सेल्सियस कर दिया, और खनन में जल निकायों को पेश करने से दिन में आईएचआई 3 से 5 डिग्री सेल्सियस कम हो गया और यह क्षेत्र में सबसे प्रभावी शमन उपाय पाया जाता है। इस तरह कुल मिलाकर, यह निष्कर्ष निकाला जा सकता है कि शहरी आकृति विज्ञान और उच्च मानवजनित गर्मी और औद्योगिक क्षेत्र पर इसके संबद्ध औद्योगिक ताप द्वीप परिमाण के प्रभाव की तुलना भारत के मेट्रो शहरों और इसी तरह के निर्मित और मानवजनित गर्मी प्रोफाइल वातावरण के साथ दुनिया के अन्य एशियाई शहरों के ऊपर यूएचआई के परिमाण से की जा सकती है।

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