

**URBAN SIGNATURE AND TOPOGRAPHICAL
INFLUENCES ON MONSOON WEATHER OVER THE
NATIONAL CAPITAL REGION (NCR) DELHI**

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**CENTRE FOR ATMOSPHERIC SCIENCES
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by

JERIN B. CHALAKKAL

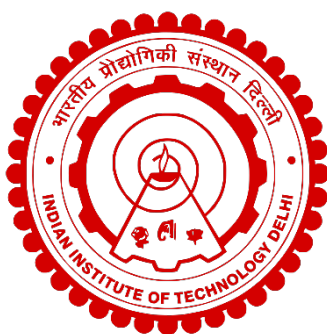
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Forces of nature act in a mysterious manner. We can but solve the mystery by deducing the unknown result from the known results of similar events.

— **Mahatma Gandhi**

CERTIFICATE

This is to certify that the thesis entitled “**Urban Signature and Topographical Influences on Monsoon Weather over the National Capital Region (NCR) Delhi**” being submitted by **Mr. Jerin B. Chalakal** 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.



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Jerin Benny Chalakal

ABSTRACT

Urbanization is a worldwide trend, with more than 50% of the population currently living in urban areas. It is projected that by 2045, the global urban population will increase by 1.5 times to reach 6 billion. The rise in urbanisation contributes to disturbances in surface energy balance and poses health risks related to climate warming. However, it is not yet determined whether urban-induced warming and its impacts differ at the local, regional, or global scale. The National Capital Region (NCR) of Delhi, India is the largest urban area in the Monsoon Zone. There has been a significant increase in urban and built-up areas over the recent decades, resulting in a 17-fold increase in the urban extent. This has led to significant Land-use and Land-cover (LULC) changes. The thesis examines the influences of urbanisation and natural topography on the Monsoon Weather in the National Capital Region (NCR) Delhi and its surroundings. The first chapter includes a general introduction to the essential elements of the Indian summer monsoon (ISM) and addresses urbanisation effects on the alteration of surface energy balance, the resulting Urban Heat Islands (UHI), and urban rainfall modification. The later part of the chapter includes the general methodology employed for the investigations and analysis. Additionally, covers brief descriptions of the datasets and mesoscale models utilised in the investigations. The first two working chapters focus on urbanisation's impact on monsoon weather, while the last two examine topographical factors influencing regional monsoon activity. Both Chapters 2 and 3 explore urbanisation's impact on monsoon weather in the NCR, with Chapter 3 presenting findings from numerical modelling.

The second chapter thoroughly assesses the spatio-temporal characters and decadal changes of monsoonal features. The climatology of Monsoonal rainfall and Monsoon Low-Level Jet (MLLJ) are investigated. The study reveals that the precipitation reduction is alongside the weakening of the MLLJ and marginal reduction of core height over the region. 'Urban Wet

Islands' alongside the UHI are observed and are likely to be coupled with monsoon-urban induced effects under the weakened synoptic regime. The Land Surface Temperature difference (UHI) of ~ 2.5 °C and more than 3.5 °C is observed from the urban centre to the surrounding cropland during the months of August (core monsoon) and September, respectively. In addition to the Urban Wet Islands during August, islands of rainfall in both the upwind and downwind directions of the urban centre are also noted in September. The rainfall patterns indicate the monsoon-rainfall modification signal due to NCR urbanisation.

The third chapter studies the impact of urbanisation on the monsoon weather across NCR Delhi, using mesoscale simulations and the updated LULC. This chapter integrates a new LULC, based on Advanced Wide Field Sensor (AWiFS), into the Weather Research and Forecasting (WRF) model framework for short-term monsoon weather simulation over NCR Delhi. AWiFS provides LULC data at a higher 56 m spatial resolution compared to model-inherent MODIS data. AWiFS LULC is more accurate in representing urban land use, including small suburban settlements outside the core zone of NCR. The study unequivocally highlights the importance of updated LULC in significantly improving model performance. The impact of AWiFS is notable in the planetary boundary layer (PBL) height, convective parameters, precipitation, and other associated variables. Further, suggested that the accurate representation of the Noida suburban in AWiFS has led to an urban-induced downwind effect, resulting in a simulated higher magnitude of Convective Available Potential Energy ($CAPE > 200 \text{ J kg}^{-1}$ in difference) over Faridabad. The final sections analyse urban rainfall modification in case studies during strong and weak regimes.

The fourth chapter examines pre-monsoon and monsoon conditions, together with intra-monsoonal variations (viz. wet, dry, and withdrawal spells) in wind structure, thermodynamic parameters, precipitation, and the structure of the Monsoon Boundary Layer (MBL) for three consecutive years (2016-2018) using continuous radiosonde observations. This chapter

explores ISM mechanics through consistent observations and quantitative evaluations and investigates the macrophysical features of the monsoonal clouds/systems that maintain their characteristics over the region. The availability of moisture in the boundary layer carried by low-level monsoon winds plays a crucial role in the formation of monsoonal cloud mechanisms. It shifts the Lifting Condensation Level (LCL) closer to the Level of Free Convection (LFC) by supplying moisture from lower levels and raising the Level of Neutral Buoyancy (LNB) near the tropopause region during the monsoonal period. This also impacts Precipitable Water (PW), which exhibits consequential variations in observed LCL height. Additionally, it is observed that the short-term zonal disturbances induced by extra-tropical and sub-tropical flows impact intra-monsoonal weakening and variations. Analysis from several of the convective parameters and indices revealed that deep convective systems might occur throughout the monsoon season, while severe thunderstorms could develop during the pre-monsoon, and thunderstorms are less likely to happen during the withdrawal spell.

The fifth chapter examines the interaction between terrain-flow and convective triggers during the ISM near the Aravali Northern Ridges using a WRF simulation and direct observations from the Doppler Weather Radar (DWR) at New Delhi to investigate the effects of 'Nocturnal-Monsoon' Low-Level Jet (LLJ) interactions with Ridges and leeside convection in NCR Delhi. The LLJ shows a noticeable propagation in the nocturnal to early morning hours, which crosses the Ridges evenly. At the terminus of the crossing LLJ, an interface zone is formed with the eastern low-level flows, which initiate the moisture accumulation and make an ideal environment for triggering the deep convective cloud clusters to rain formation. The other noticeable feature associated is the presence of Mountain Waves (MW) propagating vertically over the mountain range and making fluctuations in the stability fields around the ridges. The last chapter presents the main findings of the present thesis. In addition, the chapter outlines the scope of future work.

सार

शहरीकरण एक विश्वव्यापी प्रवृत्ति है, जिसमें वर्तमान में 50% से अधिक आबादी शहरी क्षेत्रों में रहती है। यह अनुमान लगाया गया है कि 2045 तक वैश्विक शहरी आबादी 1.5 गुना बढ़कर 6 बिलियन तक पहुँच जाएगी। शहरीकरण में वृद्धि सतही ऊर्जा संतुलन में गड़बड़ी में योगदान देती है और जलवायु वार्मिंग से संबंधित स्वास्थ्य जोखिम पैदा करती है। हालाँकि, यह अभी तक निर्धारित नहीं किया गया है कि शहरी-प्रेरित वार्मिंग और इसके प्रभाव स्थानीय, क्षेत्रीय या वैश्विक स्तर पर भिन्न हैं या नहीं। भारत का राष्ट्रीय राजधानी क्षेत्र (NCR) दिल्ली मानसून क्षेत्र का सबसे बड़ा शहरी क्षेत्र है। हाल के दशकों में शहरी और निर्मित क्षेत्रों में उल्लेखनीय वृद्धि हुई है, जिसके परिणामस्वरूप शहरी विस्तार में 17 गुना वृद्धि हुई है। इससे भूमि-उपयोग और भूमि-आवरण (LULC) में महत्वपूर्ण परिवर्तन हुए हैं। थीसिस राष्ट्रीय राजधानी क्षेत्र (NCR) दिल्ली और उसके आसपास के इलाकों में मानसून के मौसम पर शहरीकरण और प्राकृतिक स्थलाकृति के प्रभावों की जाँच करती है। पहले अध्याय में भारतीय ग्रीष्मकालीन मानसून (आईएसएम) के आवश्यक तत्वों का सामान्य परिचय शामिल है और सतही ऊर्जा संतुलन के परिवर्तन, परिणामी शहरी ताप द्वीप (यूएचआई) और शहरी वर्षा संशोधन पर शहरीकरण के प्रभावों को संबोधित करता है। अध्याय के बाद के भाग में जांच और विश्लेषण के लिए नियोजित सामान्य कार्यप्रणाली शामिल है। इसके अतिरिक्त, जांच में उपयोग किए गए डेटासेट और मेसोस्केल मॉडल का संक्षिप्त विवरण शामिल है। पहले दो कार्यकारी अध्याय मानसून के मौसम पर शहरीकरण के प्रभाव पर ध्यान केंद्रित करते हैं, जबकि अंतिम दो क्षेत्रीय मानसून गतिविधि को प्रभावित करने वाले स्थलाकृतिक कारकों की जांच करते हैं। अध्याय 2 में अवलोकन और जलवायु संबंधी विश्लेषण शामिल है, जबकि अध्याय 3 में संख्यात्मक मॉडलिंग का उपयोग करके एनसीआर में मानसून के मौसम पर शहरीकरण के प्रभाव का पता लगाया गया है।

दूसरा अध्याय मानसूनी विशेषताओं के स्थानिक-लौकिक चरित्रों और दशकीय परिवर्तनों का गहन मूल्यांकन करता है यूएचआई के साथ-साथ 'शहरी गीले द्वीप' देखे गए हैं और कमजोर सिनॉप्टिक शासन के तहत मानसून-शहरी प्रेरित प्रभावों के साथ युग्मित होने की संभावना है। अगस्त (कोर मानसून) और सितंबर के महीनों के दौरान शहरी केंद्र से आसपास की फसल भूमि में क्रमशः ~ 2.5 डिग्री सेल्सियस और 3.5 डिग्री सेल्सियस से अधिक का भूमि सतह तापमान अंतर (यूएचआई) देखा जाता है। अगस्त के दौरान शहरी गीले द्वीपों के अलावा, सितंबर में शहरी केंद्र के ऊपर और नीचे दोनों दिशाओं में वर्षा के द्वीप भी देखे जाते हैं। वर्षा पैटर्न एनसीआर शहरीकरण के कारण मानसून-वर्षा संशोधन संकेत का संकेत देते हैं।

तीसरे अध्याय में मेसोस्केल सिमुलेशन और अपडेट किए गए एल्यूएलसी का उपयोग करके एनसीआर दिल्ली में मानसून के मौसम पर शहरीकरण के प्रभाव का अध्ययन किया गया है AWiFS मॉडल में निहित MODIS डेटा की तुलना में 56 मीटर के उच्च स्थानिक रिज़ॉल्यूशन पर LULC डेटा प्रदान करता है। AWiFS LULC शहरी भूमि उपयोग का प्रतिनिधित्व करने में अधिक सटीक है, जिसमें एनसीआर के मुख्य क्षेत्र के बाहर छोटी उपनगरीय बस्तियां शामिल हैं। अध्ययन स्पष्ट रूप से मॉडल के प्रदर्शन में उल्लेखनीय सुधार करने में अद्यतन LULC के महत्व पर प्रकाश डालता है। AWiFS का प्रभाव ग्रहीय सीमा परत (PBL) की ऊंचाई, संवहनीय मापदंडों, वर्षा और अन्य संबंधित चर में उल्लेखनीय है। इसके अलावा, सुझाव दिया कि AWiFS में नोएडा उपनगरीय क्षेत्र के सटीक प्रतिनिधित्व के कारण शहर से प्रेरित हवा के प्रभाव को बढ़ावा मिला है, जिसके परिणामस्वरूप फरीदाबाद के ऊपर संवहनीय उपलब्ध संभावित ऊर्जा ($CAPE > 200 \text{ J kg}^{-1}$ अंतर में) का नकली उच्च परिमाण हुआ है।

चौथा अध्याय निरंतर रेडियोसॉन्ड अवलोकनों का उपयोग करके लगातार तीन वर्षों (2016-2018) के लिए पवन संरचना, थर्मोडायनामिक मापदंडों, वर्षा और मानसून सीमा परत (एमबीएल) की संरचना में अंतर-मानसून विविधताओं (अर्थात् गीला, सूखा और वापसी काल) के साथ-साथ प्री-मानसून और मानसून की स्थितियों की जांच करता है। यह अध्याय लगातार अवलोकनों और मात्रात्मक मूल्यांकन के माध्यम से

आईएसएम यांत्रिकी की खोज करता है और मानसूनी बादलों/प्रणालियों की मैक्रोफिजिकल विशेषताओं की जांच करता है जो क्षेत्र में अपनी विशेषताओं को बनाए रखते हैं। निम्न-स्तरीय मानसूनी हवाओं द्वारा सीमा परत में नमी की उपलब्धता मानसूनी बादल तंत्र के निर्माण में महत्वपूर्ण भूमिका निभाती है। यह निचले स्तरों से नमी की आपूर्ति करके और मानसून अवधि के दौरान ट्रोपोपॉज़ क्षेत्र के पास तटस्थ उछाल के स्तर (एलएनबी) को बढ़ाकर लिफ्टिंग कंडेनसेशन स्तर (एलसीएल) को मुक्त संवहन के स्तर (एलएफसी) के करीब ले जाता है इसके अतिरिक्त, यह देखा गया है कि अतिरिक्त-उष्णकटिबंधीय और उपोष्णकटिबंधीय प्रवाह से प्रेरित अल्पकालिक क्षेत्रीय गड़बड़ी अंतर-मानसून कमजोर पड़ने और विविधताओं को प्रभावित करती है। कई संवहनी मापदंडों और सूचकांकों के विश्लेषण से पता चला है कि मानसून के मौसम में गहरी संवहनीय प्रणालियाँ हो सकती हैं, जबकि प्री-मानसून के दौरान गंभीर गरज के साथ तूफान आ सकते हैं और वापसी के दौरान गरज के साथ तूफान आने की संभावना कम है।

पांचवें अध्याय में एनसीआर दिल्ली में रिज और लीसाइड संवहन के साथ 'निशाचर-मानसून' निम्न-स्तरीय जेट (एलएलजे) अंतःक्रियाओं के प्रभावों की जांच करने के लिए नई दिल्ली के डॉपलर मौसम रडार (डीडब्ल्यूआर) से डब्ल्यूआरएफ सिमुलेशन और प्रत्यक्ष अवलोकन का उपयोग करके अरावली उत्तरी रिज के पास आईएसएम के दौरान भू-प्रवाह और संवहनीय ट्रिगर्स के बीच अंतःक्रिया की जांच की गई है। क्रॉसिंग एलएलजे के टर्मिनस पर, पूर्वी निम्न-स्तरीय प्रवाह के साथ एक इंटरफेस ज़ोन बनता है, जो नमी संचय को आरंभ करता है और गहरे संवहनीय बादल समूहों को बारिश के निर्माण के लिए प्रेरित करने के लिए एक आदर्श वातावरण बनाता है। इससे जुड़ी दूसरी उल्लेखनीय विशेषता पर्वत श्रृंखला पर लंबवत रूप से फैलने वाली पर्वतीय तरंगों (एमडब्ल्यू) की उपस्थिति है और लकीरों के आसपास स्थिरता क्षेत्रों में उतार-चढ़ाव करती है। अंतिम अध्याय वर्तमान थीसिस के मुख्य निष्कर्ष प्रस्तुत करता है। इसके अलावा, अध्याय भविष्य के कार्य के दायरे को रेखांकित करता है।

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