ABSTRACT

Urbanisation 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 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.