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Does Urban Heat Island Effect Impact Groundwater Levels? A Case Study of Pune District

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Abstract

In the last sixty years, we have seen a massive spike in the process of urbanisation. This spike has been brought about by a 5-fold increase in global population from 750 million in 1950 to 4.2 billion in 2018. The process of urbanisation has spiked significantly over the last sixty years, experiencing almost a 5-fold increase in the global urban population from 750 million in 1950 to 4.2 billion in 2018. While urbanisation has brought about beneficial impacts in terms of infrastructure development, it has also been accompanied with negative consequences for urban residents in particular. As a consequence of the high presence of built infrastructure and sealed surfaces within cities, urban areas often experience elevated temperatures. This phenomenon is particularly evident during the night time and is termed as the Urban Heat Island (UHI) effect. The UHI effect is significantly influenced by location-specific factors, among which land-use change and presence of vegetation have been studied by numerous scholars. However, the impact of the UHI effect of hydrological factors such as groundwater levels is substantially under-researched a topic. In order to bridge this existing gap in literature, the current study aims to investigate the relationship of Land Surface Temperature (LST) with groundwater levels (pre- and post-monsoon) for Pune district. The findings from the study suggest a positive correlation between SUHII and groundwater levels, thereby implying that an increase in land surface temperature is accompanied by groundwater falling further below the surface level.

Keywords: Urban Heat Island effect, Land Surface Temperature, Urbanization, Groundwater Level, Precipitation, Vegetation

1. Introduction

In recent times, developing countries have witnessed urbanisation at an unprecedented rate with almost half the world's population residing in urban areas. In alignment with the trend, urban dwellers in India are expected to increase by 484 million by the year 2050. Such an increase in urbanisation is likely to put pressure on the ecology and infrastructure within cities and degrade land quality as well as natural resources. Combined with an increase in the proportion of impervious surfaces to compensate for the needs of the new urban residents, we are likely to witness an interference with natural environmental processes that take the shape of phenomenon such as the Urban Heat Island (UHI) effect. This phenomenon is particularly evident post sunset in urban areas and is characterised by higher temperatures in the built environment compared to the natural environment (Oke, 1982; Phelan, et al.,2015; Dutta, Gupta & Kishtawal, 2020; Marando, et al., 2019). Among the various categories of UHI phenomenon, the Surface UHI effect is found to have strong correlation with the UHI effect for which Land Surface Temperature (LST) is most commonly used as an indicator. Change in LST is primarily influenced by location-specific factors, among which land-use change and presence of vegetation have been studied by numerous scholars (Feng et al., 2019).

Considering that demographic and environmental changes occurring in urban regions exert substantial influence on water bodies, exploring the relationship between LST and water resources could provide interesting conclusions regarding the often-overlooked impacts of the UHI effect. Nayan, et al. (2020) point out that urbanisation influences water bodies not only at the surface level but also at a volumetric scale. This conclusion led various scholars to explore the relationship between urbanisation and groundwater levels in urban areas. However, literature on the topic is sparse and there exists a lack of consensus regarding the impact of elevated LST on groundwater levels. The current study aims to bridge these gaps in literature by taking Pune district as the study area. The following sections, namely (i) Background; (ii) Materials and Methods; (iii) Findings and Discussion and (iv) Conclusions, Recommendations and Limitations explore the impact and implications of the UHI effect on Groundwater levels in greater detail.

2. Background

Urbanisation has been on a rise across the world, and by 2050, 70% of the global population is expected to reside in urban areas. India alone is expected to add 416 million urban dwellers by 2050, exerting immense pressure upon the availability of resources and the carrying capacity of cities (Department of Economic and Social Affairs, 2019). While urbanisation brings with itself the scope of improvement in the standard of living and better employment opportunities, it is a complex phenomenon that can also give rise to certain negative environmental changes. Scholars point out that urbanisation involves a transformation of natural green surfaces into impervious surfaces, making urban areas emerge as hot spots for negative environmental impacts ranging from increase in air temperature to alteration of natural water levels (Kantakumar et al., 2016; Phelan et al., 2015; Cox, et al., 2018; Mushore et al., 2018). As a consequence, phenomena like UHI effect, which is characterised by higher temperatures in the built environment compared to the natural environment and is particularly prominent during the nighttime takes shape (Oke, 1982; Phelan et al., 2015; Marando et al., 2019). The UHI effect is influenced by several factors but the primary reason behind its occurrence is higher percentage of built-up regions in urban areas that comprise of man-made materials, absorb and store a relatively higher proportion of solar energy as opposed to the countryside areas (EPA, 2020; Phelan et al., 2015; Marando et al., 2019).

When it comes to UHI effect, a crucial concern is that the presence of UHIs can have a detrimental effect on human health and the lives of urban dwellers, as it results in an increase in energy consumption, photochemical smog, deteriorating air quality and the occurrence of heat waves (Dutta et al., 2020; Cox et al., 2018; Feng et al., 2019; Mushore et al., 2018). Considering the recent rise in heat waves in India, particularly in the north-western part of the country, the UHI effect has increasingly become a matter of concern for second-tier cities in the country which have emerged as the hotspots of urbanisation and growth in recent times. Apart from intensifying the impact of heat stressors, the UHI effect can also interfere with local convection currents and result in extreme and unprecedented precipitation events (Shastri, et al., 2017; Dutta et al., 2020; Marando et al., 2019).

Scholars have categorised UHIs into (i) Atmospheric and (ii) Surface UHIs. Atmospheric

UHI is measured on the basis of air temperature and is further distinguished into canopy and boundary layer UHI (Estoque et al., 2017). As per the results furnished by Oke (1976), the Canopy Layer UHI (or CLUHI) takes into consideration area from the surface to the mean building height for identifying heat islands. On the other hand, the Boundary-Layer UHI is measured within the Urban Boundary Layer (UBL) that exists above the Urban Canopy Layer (UCL) and is influenced by the urban surface existing below (Oke, 1976; Martin et al., 2015). As the use of air temperature data is hindered by the limited monitoring sites available for its measurement, scholars often rely on Surface UHI (SUHIs) for detecting and measuring the UHI effect for a region. SUHIs are measured through LST which can be retrieved through the means of satellite remote sensing. Existing studies have estimated a high correlation between SUHI and CUHI, thereby making LST a suitable proxy measure for the indirect identification of the SUHI effect (Marando et al., 2017; Dutta et al., 2020).

LST is substantially influenced by location-specific factors, among which land-use change and presence of vegetation have been studied by numerous scholars. He et al. (2007) analysed SUHI patterns for China and found them to be spatially correlated with regional land use and changes in land cover. The presence of vegetation has been repeatedly associated with a cooling as well as humidifying impacts on the surroundings. This is further validated by the fact that the Normalised Difference Vegetation Index (NDVI) which serves as measure for vegetation coverage has been shown to be inversely correlated with LST. Further, this existing negative correlation between NDVI and LST serves as the basis for recommending urban areas to increase the percentage of green spaces in order to mitigate UHI effects (Yue, et al., 2007; Kumar & Shekhar, 2015; Feng et al., 2019; Marando et al., 2019).

Water bodies, being a crucial element of the land cover composition of an urban area, are also influenced by urbanisation and developmental processes. In urban areas with high population density, water bodies are often encroached upon for supporting high-return activities, resulting in frequent water disputes and rising concerns regarding depletion of local water resources (Kalhor & Emaminejad, 2019; Nayan et al., 2020). Mishra et al. (2014) discuss that urbanisation hinders infiltration of water, reducing groundwater recharge as well as storage. A pan-India study conducted by Shiao et al. (2015), also identified that 54 % of the Indian land mass experiences ‘high’ to ‘extremely high-water’ stress. According to Nayan et al. (2020), changes due to urbanisation on the land use/cover of a region not only occur at the surface level, but at the volumetric scale as well. Further, their investigation of the relationship between land use patterns and groundwater levels in the city of Hyderabad suggested a positive correlation between land use mix and changes in groundwater level. Further analyses using spatial clustering revealed that regions with mid-rise and low-rise development in peri-urban areas have improved levels of groundwater in comparison to commercial areas with high-rise development which displayed widespread attenuation of groundwater levels.

Patra et al. (2018) identified a declining trend in groundwater levels during pre- as well as post-monsoon periods in Howrah Municipal Corporation (HMC) area and attributed it to higher proportion of urban population and reduced infiltration capacity due to increase in built-up area of an impervious nature. Further, the application of Kendall's Tau Test indicated a significant but inverse correlation between average air annual temperature and annual average groundwater (-0.75) as well as annual average rainfall (-0.77). On the same lines, Mohammed et al. (2019) analysed the relationship of SUHI effect with spatiotemporal factors including groundwater for the city of Ahmedabad, India. Here, the authors observed the Pearson correlation between groundwater table level and SUHI intensity to be around 0.64 during Winter daytime as well as Summer nighttime suggesting that an increase in SUHI intensity is accompanied an increase in the depth of the groundwater table.

Studies conducted on the topic of 'Urban Heat Islands' have primarily focused upon identifying UHIs by measuring the increase in temperature brought about by the Heat Island Effect, and comparing this effect alongside the regional and spatial factors such as weather, location, season, airflow, anthropogenic heat, urban geometry, land use land cover (including agriculture and vegetation patterns), building characteristics (including their size, material and density), urban sprawl and increasing industrial and human activities that are likely to have caused it (Phelan et al., 2015; Estoque et al., 2016; Haashemi et al., 2016; EPA, 2019). Patra et al. (2018) diverged from conventional studies on the UHI effect by looking at the association between built-up area and hydrometeorological factors including groundwater level and precipitation. Similarly, Jaiswal & Jhariya (2020) expanded the focus of their study by taking into consideration the impact of agricultural practices and urbanisation on groundwater levels in addition to investigating the impact of LULC on the heat island effect for the city of Raipur, Chhattisgarh. Changnon (1992) even found evidence for UHI resulting in an increase in seasonal rainfall downward of major cities in his early investigations. Yet there remains little consensus on the impact of heat islands on precipitation and groundwater (Shepherd, 2005; Koomen & Diogo, 2017). In light of the gaps in literature outlined above, the following research looks into the relationship of LST with groundwater levels (pre- and post-monsoon) between 2017 and 2019 for Pune district.

3. Materials and Methods

3.1. Study Area

Pune district, the study area for the research falls within the Deccan Plateau towards the foot of the northern part of the Western Ghats. Home to more than 94 lakh residents, Pune district comprises Pune and Pimpri Chinchwad Municipal Corporations. While Western Ghats surround the district on the West and South, the Indrayani River is located in the North and the Daund tehsil in the East. The study stands at an altitude of 559 metres above the mean sea level with rivers Mula and Mutha running through the centre of the district. The district lies at 18° 32″ North latitude and 73° 51″ East longitude. The mean annual temperature for the district is 25°C, and the mean annual precipitation is 650-700 mm. Being a part of the tropical monsoon land, Pune district shows substantial variation in temperature and rainfall across the year (https://pune.gov.in). Pune district has experienced rapid urban growth and transformation since the last three decades. The region has grown not only with regards to its agricultural sector, but also its industrial and service sectors through widespread industrialisation and provision of eminent educational infrastructure and facilities.

In the near future, the Pune city in particular is expected to progress further as it undergoes the transition envisioned for India’s 100 Smart Cities (https://smartcities.gov.in). However, Pune’s growth stands in utter contrast to the sustainability of its development. A large proportion of the ecological resources, particularly those in peri-urban areas, are overexploited and on the verge of being entirely deteriorated. The region’s land and water resources are often found to be insufficient to meet the increasing demand. Socio-economic polarisation within the region, owing to the lack of suitable urban planning is another developmental concern (Butsch et al., 2017; Kantakumar et al., 2016). As pointed out by Butsch et al. (2017), Pune's growth and urban expansion trajectory resembles that of various cities across the world, which have experienced substantial urban growth yet continue to struggle with the sustenance of their ecological resources (*Figure* 1). In light of the same, Pune city makes for an appropriate study area for conducting the current research.

3.2. Data Collection & Processing

The methodology for the study entails collection of secondary data for precipitation and groundwater levels for the purpose of understanding their statistical and spatial relationship with LST. Analysis of LST alongside precipitation and groundwater levels has been performed for the entire Pune district. Additionally, Land Use/Land Cover classification has been carried out to facilitate the objectives of this research. LST for estimating the SUHI effect has been retrieved using remote sensing data as combined with Geographical Information Systems as it serves as an efficient yet cost effective method for mapping and analysing spatiotemporal dynamics of urban phenomena (Kantakumar et al., 2016). A land cover/land use map for Pune city has been created using SAGA GIS while data processing and statistical analysis has been carried out using Quantum Geographic Information System (QGIS). Finally, Groundwater Level data has been sourced for wells within Pune district and interpolated for the entire district using QGIS. Provided below is a comprehensive explanation of the data utilised and the procedure followed to obtain the desired output for meeting the objectives of this research.

3.2.1 Land Surface Temperature and NDVI

In order to obtain land surface temperature values, Landsat 8 OLI-TIRS imagery was downloaded from the Earth Explorer of the United States Geological Survey (USGS) website for the metropolitan areas of Pune as well as Solapur (*Figure 2, Table 1*). The imagery was retrieved for May and October (representative months for summer and winter respectively) between 2017 - 2019 so as to compare LSTs across seasons as well as time periods. Using the Semi-Automatic Classification Plugin available in the open-source software QGIS, Dark Object Subtraction (DOS1) Atmospheric Correction was applied to the downloaded imagery. Thereafter, the formula and methodology recommended by Weng et al. (2004) and utilised by Avdan & Jovanovska (2016) was considered for obtaining LST values from the imagery. The procedure involved applying DOS1

Atmospheric Correction to Landsat bands 4, 5 and 10 using the SCP Plugin in QGIS. Then using Raster Calculator to calculate the At-satellite brightness temperature (Tb). Using the same bands 4 and 5, Normalised Difference Vegetation Index (NDVI) was obtained for the region using the following formula:

$$NDVI = NIR\ (band\ 5) - Red\ (band\ 4)/NIR\ (band\ 5) + Red\ (band\ 4)$$

Using the imagery retrieved for NDVI, the Proportion of Vegetation can be derived. Thereafter, ground emissivity can be determined and finally LST is retrieved in K. By subtracting the conversion factor (273.15) from the same, LST can be converted into °C. Finally, for the retrieval of both NDVI and LST for Pune district, LST output obtained using the imagery for Pune and Solapur have to be merged and then clipped in QGIS with the Pune district shapefile as the mask layer. The retrieved LST imagery was then classified in order to identify geographical variation in LST. *Table* 1 represents the dates for which Landsat imagery was acquired for both Solapur and Pune metropolitan areas between 2017 and 2019.

3.2.2. Land Use Land Cover

For deriving the Land Use/Land cover map for Pune city, Object Based Image Segmentation was carried out using SAGA GIS for Landsat imagery for May 2019. The process involved combining neighbouring pixels into a polygon based on the similarity of their spectral and spatial characteristics. After performing the segmentation, objects were classified into the defined land cover categories, namely (i) water; (ii) vegetation; (iii) shrub land; (iv) barren land and (v) built up by creating training polygons and assigning a value to specific land cover classes and supervised classification was carried out in order to obtain the land cover classification for the region of interest. Lemenkova (2020) utilised a similar OBIA procedure and carried it out using SAGA GIS for the purpose of distinguishing urban spaces from other land cover types in the region of Yaoundé, Cameroon.

3.2.3. Groundwater Level

Groundwater level data for Pune district was derived from the data collected by Central

Groundwater Board (CWGB) and made available on India - WRIS website (https://indiawris.gov.in/wris/#/DataDownload). Data for pre-monsoon and post-monsoon months between 2017 and 2019 for 48 sites located within the Pune district was retrieved. Using Google Earth Pro, place marks were created for these sites and imported to QGIS. Thereafter, the shape file with place marks was joined with the groundwater data downloaded from India - WRIS. Using Inverse Distance Weighted (IDW) Interpolation, spatial distribution for groundwater levels within Pune district was obtained for pre- as well as post-monsoon. Finally, random points were created for each of the land use/land cover classes, and values for groundwater as well as LST were sampled at each of these points. Using these sampled values, correlation coefficient between LST and groundwater levels was obtained for pre- as well as post-monsoon periods between 2017 and 2019.

4. Results and Discussion

4.1. Seasonal Variation in Surface Urban Heat Island effect

From the descriptive statistics for LST provided in *Table 2*, it can be ascertained that post-monsoon LST values are substantially lower than pore-monsoon LST values across the years. The average LST prior to monsoon is 33.04 C° in 2017, 41.22 C° in 2018, and 41.75 C° in 2019, suggesting an increasing trend over the years. Mean LST, post-monsoon on the other hand is 20.26 C°, 31.61 C° and 23.46 C° in 2017, 2018 and 2019 respectively. Moreover, the mean LST value for 2017 for pre-monsoon is 33.04 C° which is substantially lower than the mean LST value for pre-monsoon observed in 2018 and 2019 which is approximately 41 C°. However, this trend is not observed for the post-monsoon period wherein mean LST value for 2018 is observed to be 31.61 C° which is considerably higher relative to the mean LST value for 2017 and 2019 which is approximately 23 C°. The difference between mean LST for pre-monsoon and post-monsoon months across a year can be observed to be the highest for 2019 suggesting the increasing influence of factors contributing to a rise in LST.

From *Figure* 3, depicting the spatial variation in LST values, it can be interpreted that areas lying towards the west of Pune district have relatively lower LST values in comparison to the areas lying in the centre of the district, particularly for the pre-monsoon period. The map further suggests presence of cloud cover for the post-monsoon imagery for 2017 and 2019, which is likely to be the reason behind their lower mean LST value derived when compared against the post-monsoon imagery for 2018.

4.2. Relationship between NDVI and LST

During the pre-monsoon season between October to May, agricultural lands are harvested across the country, transforming crop lands into barren lands. This decreases the vegetation cover prior to monsoon and therefore lowers NDVI and evaporative cooling. Reduced evaporative cooling plays a dominant role in contributing towards UHI and is evident in the form of elevated LST. This inference is evident from *Table* 3 which depicts that mean NDVI is consistently lower during pre-monsoon with respect to post-monsoon months. Similarly, *Figure* 4 also suggests that during the pre-monsoon period, vegetation (or NDVI) is lower, while UHI effect (or LST) is on the rise. Post-moon, vegetation is replenished which increases NDVI and therefore decreases UHI effect (or LST) in comparison to the pre-monsoon period. Additionally, it can be visually interpreted that areas within the district with greater vegetation, depict a reduced presence of the UHI effect while areas with a lower presence of vegetation, show a strong presence of the UHIs. Further, the correlation coefficient derived for the relationship between NDVI and LST was found to be negative, and having a value of 0.84 particularly for vegetation as land cover during pre-monsoon of 2018. This negative correlation between NDVI and LST was observed to decrease to 0.70 for vegetation considered within the post-monsoon period in 2018 implying that the presence of vegetation had a greater influence on LST during the pre-monsoon period.

4.3. Seasonal Variation in Precipitation and Groundwater Level

From the data extracted through the India-WRIS portal for precipitation within Pune district and depicted using a graph in *Figure* 5, it is evident that Pune district witnessed exceptionally high levels of precipitation in 2017 in comparison to 2018 and 2019, when the region experienced modest levels of precipitation. Precipitation largely occurs between June and September, making a case for the extraction of pre-monsoon LST data in May, and the retrieval of post-monsoon LST in

October. On comparing the data for groundwater levels presented in *Table* 4 with the precipitation graph in *Figure* 5, it is evident that groundwater levels are positively associated with precipitation levels. The mean groundwater level ranges around 6-8 metres bgl prior to monsoon, it rises to 2-5 metres bgl during post-monsoon months implying that water is nearer to the ground post-monsoon when compared against pre-monsoon months due to precipitation in the monsoon months.

Figure 6 further illustrates the fluctuation in groundwater level across monitoring sites within the district and validates the rise in groundwater levels post-monsoon for a majority of sites. Due to the substantial rainfall experienced in 2017, significant variation is found in the pre- and post-monsoon groundwater levels across monitoring sites. Additionally, it is evident from the graph that the monitoring sites of Nimbgaon-Ketke and Otur, groundwater levels were abysmally below the surface across the years. For the site of Kauthe however, groundwater levels worsened considerably in 2019 and went as low as 30 metres below ground level. From *Figure* 7, it can be observed that some regions within the district, particularly those located towards the western ghats have groundwater located merely 0.01 metres below the ground post monsoon, approximately at the surface level. Areas located towards the northern part of the district on the other hand, experience extremely low levels of groundwater. In the pre-monsoon months of 2019, the groundwater level can be observed to have decreased to 32 metres bgl in the northern regions of the district. The considerably lower value for groundwater observed in the pre-monsoon of 2019 towards the northern part of the district is likely to be representing the dip in groundwater levels for the site of Kauthe and neighbouring areas.

4.4. Relationship between GW level and LST

With regards to the relationship between Groundwater level and LST, it is evident from *Figure* 8 that prior to monsoon, when LST is high, groundwater levels are lower or groundwater is located further below the ground. On the other hand, post-monsoon, the LST decreases while the groundwater levels are found to rise such that groundwater is found nearer to the land surface. A visual comparison of LST and groundwater levels for Pune district suggests that areas towards the western part of the district experience lower LST levels along with improved groundwater levels, while the northern and eastern parts of the district find strong presence of increased LST and relatively worse levels of groundwater. The highest correlation between LST and groundwater levels is observed for vegetation as land cover post-monsoon in 2018, that is 0.80. This positive correlation between LST (in °C) and groundwater level (in m bgl) implies that for areas with prominence of vegetation, as LST increases, the groundwater levels fall further below the surface level.

5. Conclusion, Limitations & Recommendations

The present study aimed to investigate the impact and implications of the urban heat island effect on groundwater levels for Pune district between 2017 and 2019. The study involved application of GIS techniques for the retrieval of Land Surface Temperature data using Landsat-8 OLI/TIRS sensor and its comparison with presence of vegetation (NDVI) and groundwater levels. Validating results from studies conducted by Marando et al. (2019) and Feng et al. (2019), a negative correlation of 0.84 was observed between NDVI and LST for the pre-monsoon of 2018 suggesting that regions with a higher presence of vegetation observe lower land surface temperature. As recommended by Marando et al. (2019), the negative relationship between NDVI and LST is suggestive of the contribution of green infrastructure towards improvement of cooling capacity of the region. On the basis of this evidence, it can be concluded that increasing the proportion of green infrastructure in the city could serve as a beneficial mitigation strategy for increasing the cooling capacity, thereby minimising the negative consequences of the UHI effect.

With regards to the relationship between LST and groundwater levels, investigations from the study identified a positive relationship with the correlation coefficient as 0.80 during the post monsoon of 2018, particularly for vegetation as a land cover. This implies that regions experiencing higher land surface temperature, observe groundwater levels that are far below the surface level. For regions that experience low groundwater levels year after year, field initiatives targeted towards identifying these areas and studying the impact of rapid urbanisation and land cover dynamics of the region on groundwater levels could pave the way for suitable mitigation strategies. In the context of the rising concerns associated with water scarcity and climate change, adopting adequate mitigation strategies for preventing further deterioration of groundwater levels is likely to become a necessity in the coming years.

By comparing the results obtained for association between LST and Groundwater Level alongside those obtained for LST and NDVI, it can be assessed that presence of vegetation and improved groundwater levels collectively contribute to a decrease in LST. Increase in vegetation cover results in an improvement in groundwater levels by making the land surface permeable and letting water seep down the land surface. Moisture and vegetation collectively reduce LST and therefore decrease UHI intensity. This conclusion further suggests that increasing the presence of vegetation cover serves the dual ecological and economic purpose of replenishing the groundwater sources and mitigating elevated temperatures.

Despite providing valuable insights regarding the often-overlooked factors influencing the Urban Heat Island effect in second tier cities, the current study has certain limitations. In terms of the estimation of spatial variation in LST for Pune district, the retrieved output was subject to the limitations associated with the use of low spatial resolution imagery from Landsat-8 OLI/TIRS sensor. Due to technical constraints with the removal of cloud cover and idiosyncratic factors influencing satellite imagery, only images for the months of May and October were retrieved and assumed to be representative of pre- and post-monsoon fluctuations in LST as well as groundwater levels. Further, the time period taken into consideration for assessing the relationship between LST and groundwater was insufficient to provide an understanding of the influence of LST on groundwater over time. Another concern associated with the research is that correlation coefficient values derived were found to be varying substantially across land cover categories as well as across time periods.

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7. Tables and Figures

Table 1: Acquisition Date for Landsat-8 Imagery downloaded from USGS Earth Explorer

2017			
Pre-monsoon		Post-monsoon	
Path 147 Row 47	Path 148 Row 46	Path 147 Row 47	Path 148 Row 46
15th May	8th May	22nd October	31st October
2018			
Pre-monsoon		Post-monsoon	
Path 147 Row 47	Path 148 Row 46	Path 147 Row 47	Path 148 Row 46
2nd May	11th May	9th October	2nd October
2019			
Pre-monsoon		Post-monsoon	
Path 147 Row 47	Path 148 Row 46	Path 147 Row 47	Path 148 Row 46
5th May	14th May	12th October	5th October

Table 2: Descriptive Statistics for retrieved Land Surface Temperature values in Celsius across Seasons (2017 – 2019)

LST - 2017							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
-	50.25	33. 04	5.24	-	39.20	23.33	5.63
LST - 2018							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
20	53	41.22	3.85	8	47	31.61	4.21
LST - 2019							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
23	63	41.75	4.36	6	36	23.46	2.86

Table 3: Descriptive Statistics for NDVI values in Celsius across Seasons (2017 – 2019)

NDVI - 2017							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
- 0.38	0.94	0.39	0.15	- 0.21	0.91	0.50	0.19
NDVI - 2018							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
- 0.64	1.00	0.20	0.24	- 0.71	0.93	0.27	0.32
NDVI - 2019							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
- 0.45	0.92	0.18	0.21	- 0.57	0.97	0.27	0.32

Table 4: Descriptive Statistics for Groundwater Level across Seasons for Pune district (2017- 2019)

GW level - 2017 (in m bgl)							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
0.6	15.85	6.79	2.17	0.01	10.1	3.08	1.53
GW level - 2018 (in m bgl)							

Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
0.085	15.35	6.4	1.91	0.01	14.5	4.45	2.42
GW level - 2019 (in m bgl)							
Pre-monsoon				Post-monsoon			
Min	Max	Mean	St.dev.	Min	Max	Mean	St.dev.
0.011	32	7.94	3.2	0.01	14.52	2.92	1.56

Figure 1: Land Use Map for Pune district - Sourced from 'SWOT Analysis of Pune District' (Department of Agriculture)

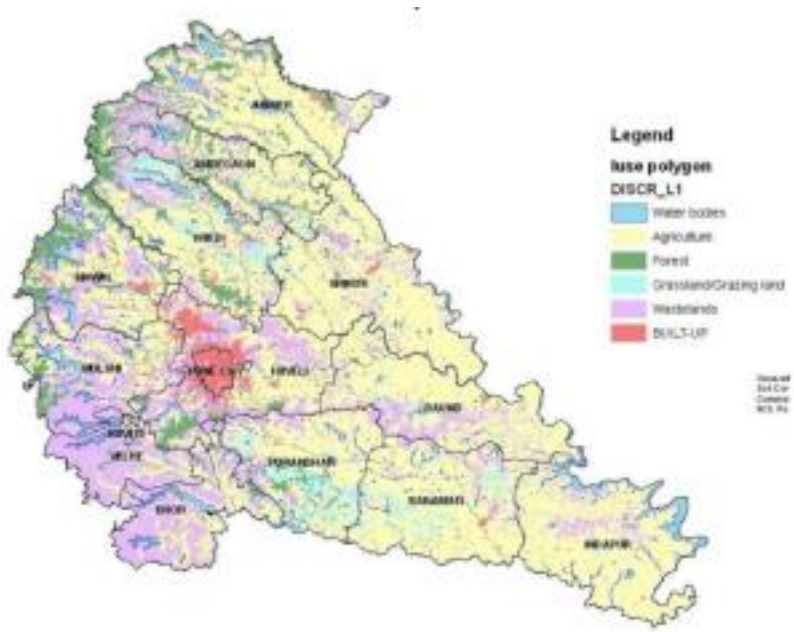

Figure 2: Merging of Landsat Imagery for the Retrieval of Imagery for Pune district

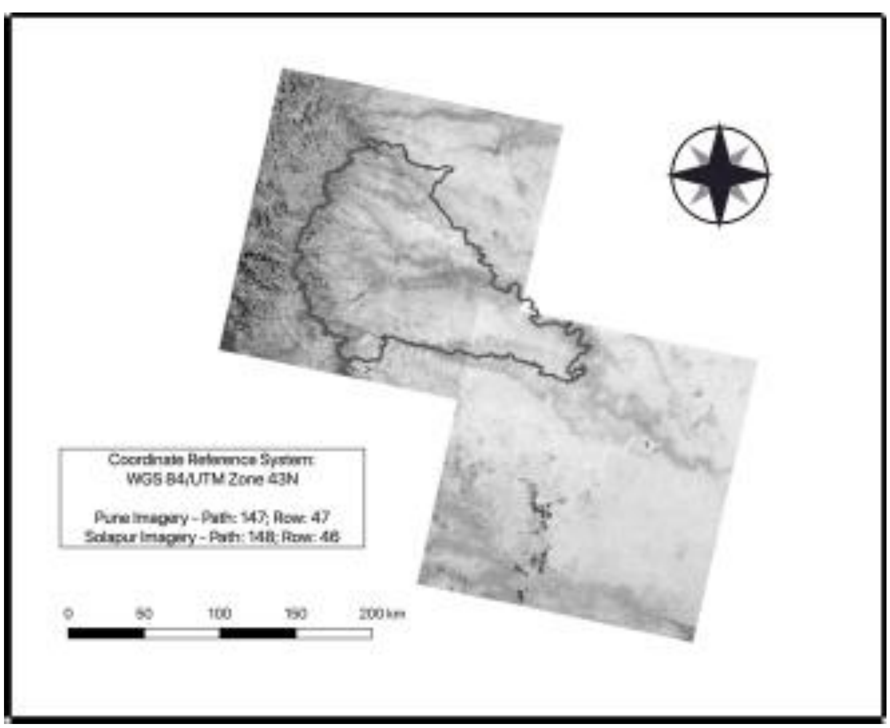

Figure 3: Spatial Variation in Pre-monsoon v/s Post-monsoon LST for Pune district (2017 – 2019)

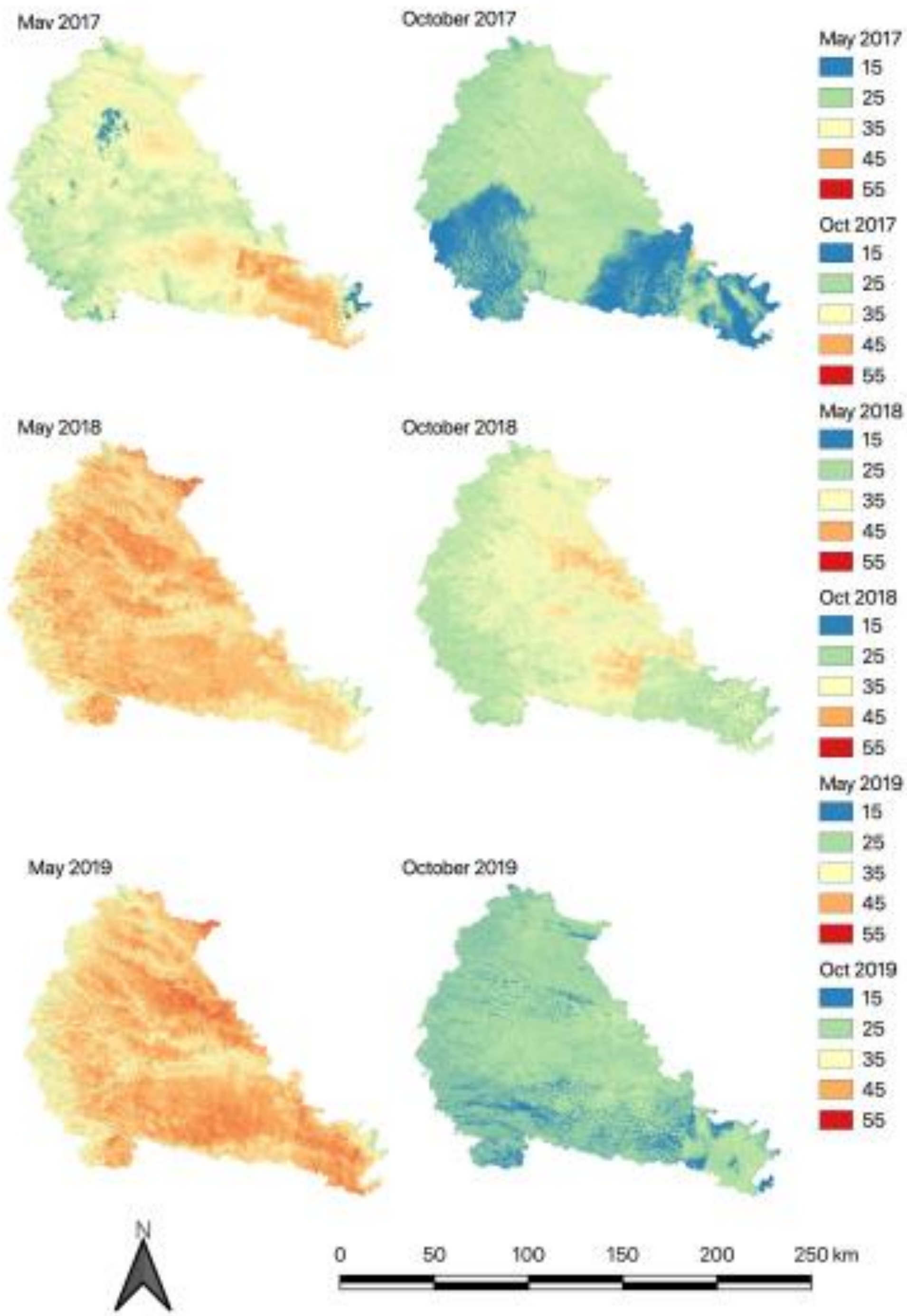

Figure 4: Spatial Variation in Pre-monsoon v/s Post-monsoon LST and NDVI for Pune district in 2018

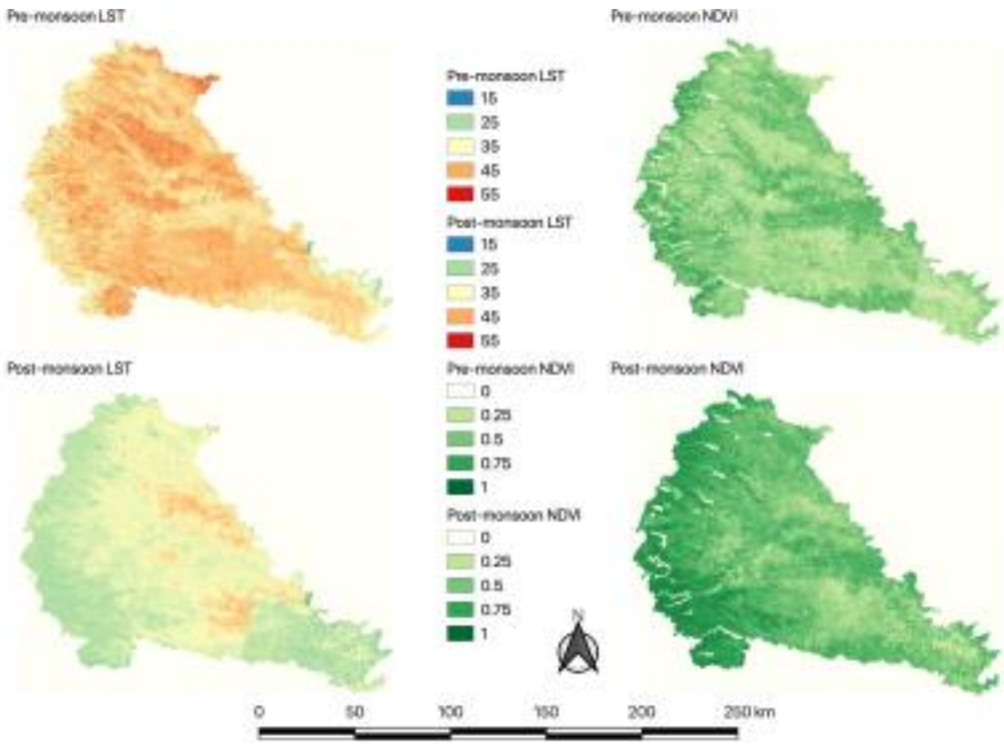

Figure 5: Bar Graph representing Normal v/s Actual Precipitation Levels within Pune district between 2017 and 2019

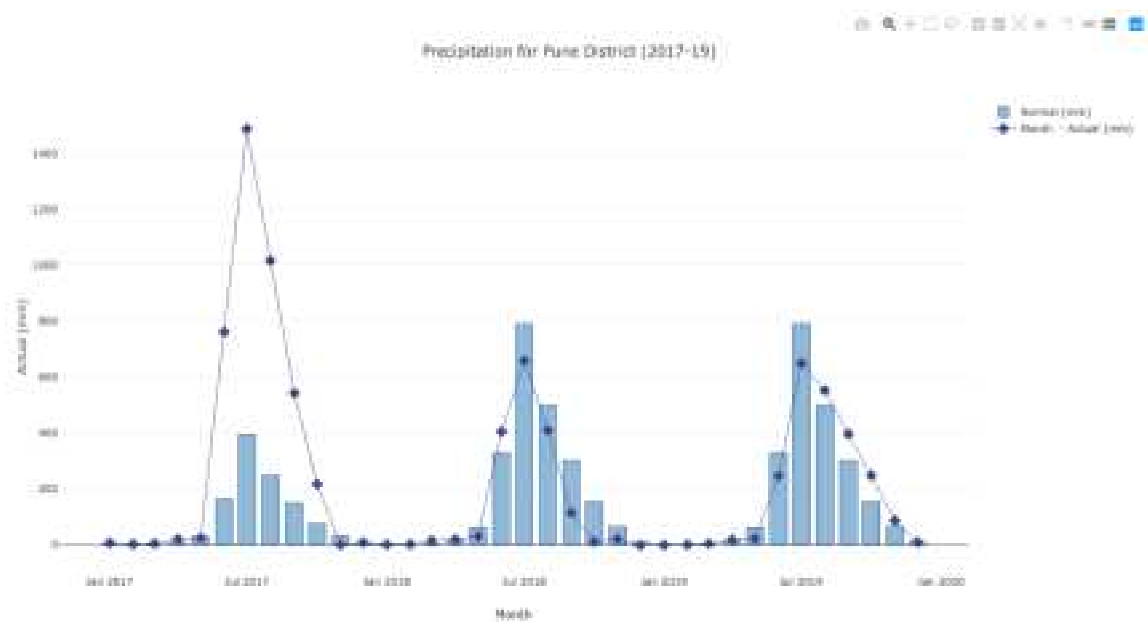

Figure 6: Seasonal Variation in Groundwater Level for Groundwater Monitoring Sites within Pune district (2017-19)

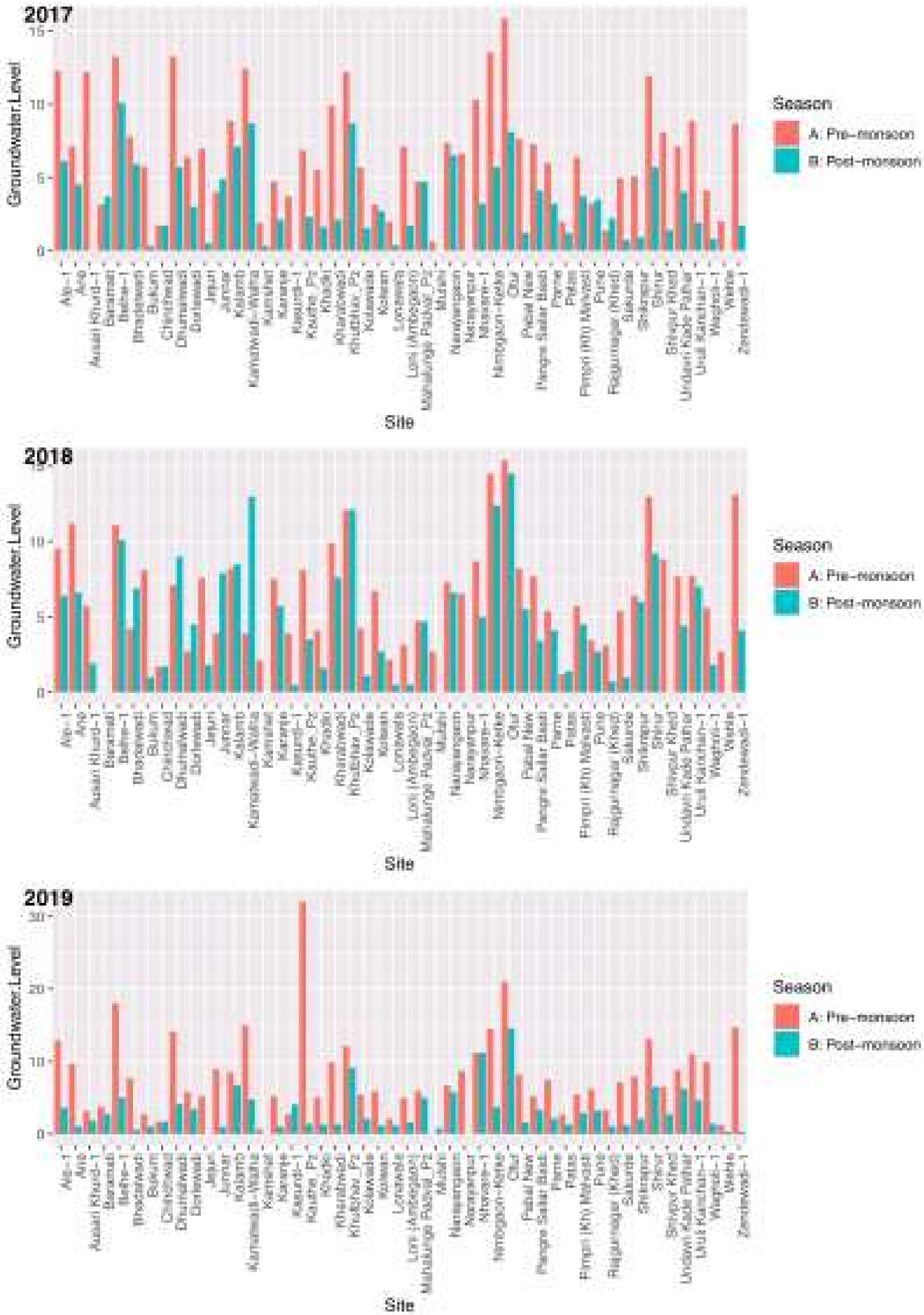

Figure 7: Spatial Variation in Pre-monsoon v/s Post-monsoon Groundwater Level for Pune district (2017 - 2019)

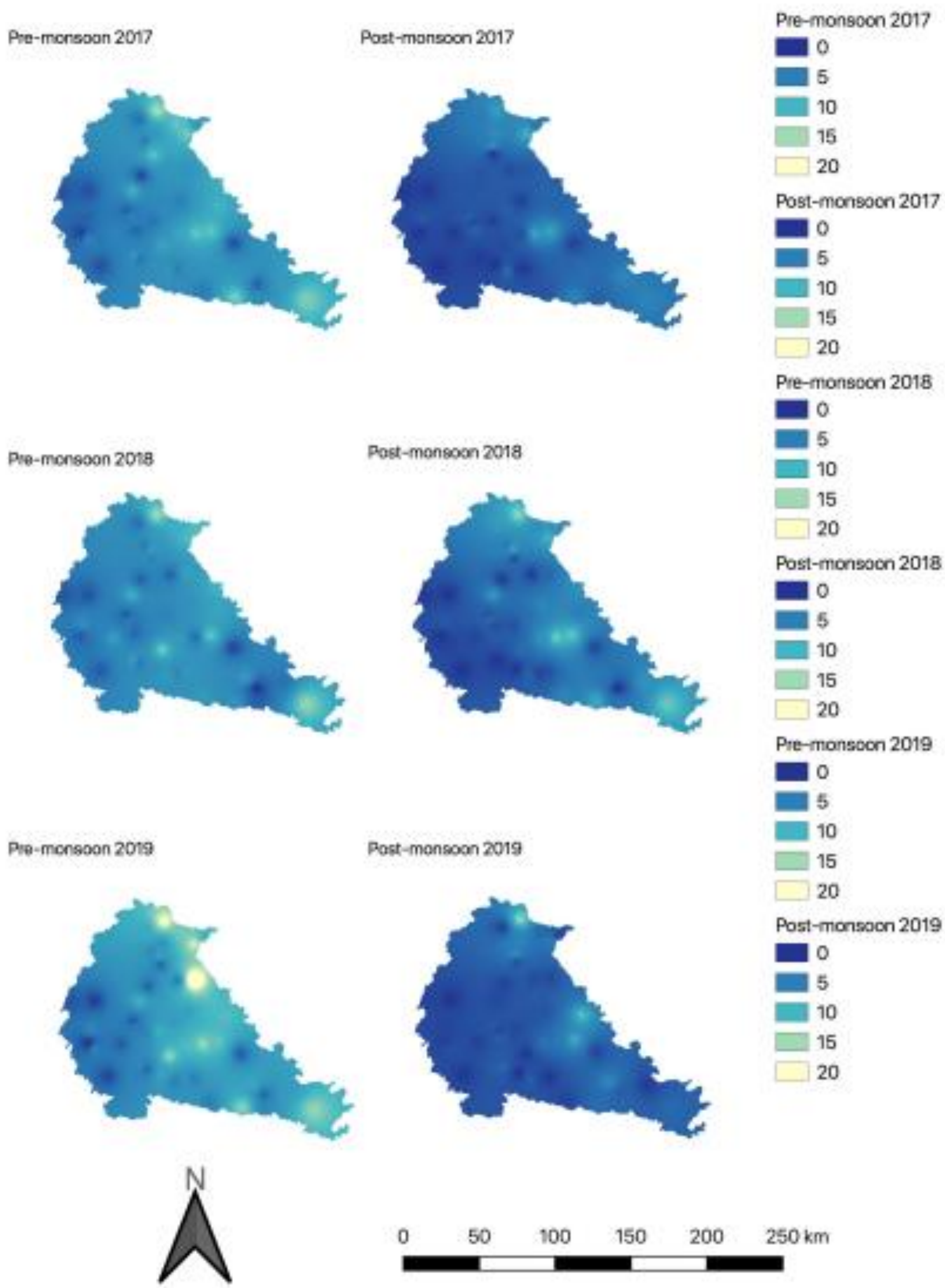

Figure 8: Spatial Comparison between LST (left) and Groundwater Level (right) for Pune district (2018)