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Satellite based observations for Surface level Urban Heat Island over Bhubaneswar: A case study

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ABSTRACT

We present a case study on identification of surface level urban heat island (SUHI) based on a land surface temperature (LST) of satellite observational data. Further, relevance of air pollution on dynamics of the LST is explained. Ground based observation at KIIT-DU station for air pollution was carried out to assess the climatology of air pollution in Bhubaneswar. Results show that the LST over Khandagiri region exhibits SUHI compared to that over adjoining regions of the city. Analysis of present study suggests that heavy built-up area followed by land-use or land-cover change over Khandagiri made a region consisting of SUHI on its own region. On the other hand, the Chandaka a forest region shows contrasting results being a region full of vegetation. The normalized deviation of vegetative index (NDVI) from Moderate Resolution Imaging Spectrophotometer (MODIS) -Aqua algorithm based data also supports the vegetation information over study region. Efforts to relate pollution and other geographical information are required to infer heat island not only at surface level but also at canopy and at boundary layer level are essential.

Introduction

Rapid urbanization and consequent industrialization in cities pose a challenge to the scientific community to understand the urban environment and the consequent climatic changes. Recent studies on population growth and rapid urbanization suggest that about 55% of population lives in urban areas, which is further projected to be 68% by 2050 (UNDESAP, 2019). Based on the report, this increasing trend in population growth is significant in Asian and African countries with 90% of increase is constituted of these two continents. Urban population growth of state of odisha recorded as ~31%, which is almost equal to that of India (i.e 36%) as reported (BCDP, 2019). The city Bhubaneswar has grown its urban cover with 83% in fifteen years of time between 2000 to 2014 (Swain et al., 2017). On the other hand, there is a decreasing order of 89% and 83% of dense vegetation and crop field cover, respectively, according to their study. Considerable attention must be payed towards the effect of urbanization along with the land surface temperature. This led our study to focus on urban heat island identification, which is likely to act as one of the significant parameter to be taken into account for the urban development in terms of policy making for pollution mitigation and its consequent urban climatic changes.

Surface temperature levels are influenced by several factors such as land cover or land use change (Benjamin et al., 2012), surface albedo and emissivity of objects on land (Abdelmoneim et al., 2017) and green house effect. However, most of these factors and their influence perturb surface temperature in a long-run but not in short-run. Short-term living pollutants (i.e. aerosols) are identified as most challenging pollutants those change the atmospheric Earth's radiation balance, which survive in the atmosphere about a week. Aerosols are solid or liquid particles of size ranging between 0.01 to 100 μm in a air or gas medium. Aerosols play a significant role on temperature level changes in surface, canopy and boundary layer level.

Our study emphasizes much on role of air pollution on anomalies of surface urban heat island (SUHI) through analysing the interrelation between Land surface temperature (LST) and particulate matter pollution.

2. Methodology

2.1 Land surface temperature (LST)

Satellite observations of temperature over the surface of the land is obtained from Moderate Resolution Imaging Spectro-photometer (MODIS) satellite. Surface temperature in the atmosphere is considered as a salient property to analyse the urban heat island as it can be used as a proxy for the SUHI estimation. These observations for day and night time period were obtained from satellite measurements onset each day and captures the temperature at the surface at about 1km x 1 km resolution. Satellite retrieved temperature is evaluated using ground based observations of weather-underground research (airport based weather observation station) of Bhubaneswar city.

Winter episodic days included in this study: Julian day of 345 (11-12-2018) and 353 (19-12-2018) day in December; 1 (01-01-2019) and 17 (17-01-2019) day in January; 45 (14-02-2019) day in February. Whereas in spring the episodic days are as follows: Julian day of 73 (14-03-2019) in March and 105 (15-04-2019) day in April.

2.2 Surface concentration: Particulate matter (PM)

Continuous monitoring of particulate matter for the corresponding episodic days (as mentioned previously) was carried out at a geographical point in Kalinga institute of industrial technology Deemed to be university (KIIT-DU) during pollution episodes during winter and spring months. This was done using Envirotech made dust sampler measures the particulate matter of aerodynamic size less than or equal to 10 μm in an entire day at a height of 10 m above ground level (agl) for each sample collection.

3. Results and discussion

3.1 Surface urban heat lsland (SUHI)

Land surface temperature over the city or urban environment relative to the nearby rural locations are treated as surface urban heat island. It acts as a proxy for the SUHI estimations. Spatial distribution of LST exhibits a high gradient with a difference of 2-3 K in study domain [85.5-86E, 20-20.5N] as shown in Figure 2 (a) & 2 (b). On 11 December 2018, the LST over Khandagiri region depicts 300-307 K and 289-293 K for the day-time and night-time, respectively. Similar features were observed on 19 December 2018, 1 January 2019. These SUHI pattern is reasoned by accumulation of built-up area over the region followed by the low vegetation across the region. It is also supported by low emissivity (0.970) noticed over Khandagiri region compared to that of rest of the locations (0.98) with a difference of about 0.01 over Bhubaneswar. This shows the consistency with the normalized division of vegetation index (NDVI, which represents the amount of vegetation or green cover over the land) that obtained from MODIS-Aqua satellite estimates (refer Figure 3). The NDVI over city built-up environment shows 0.4-0.5 on each study day period.

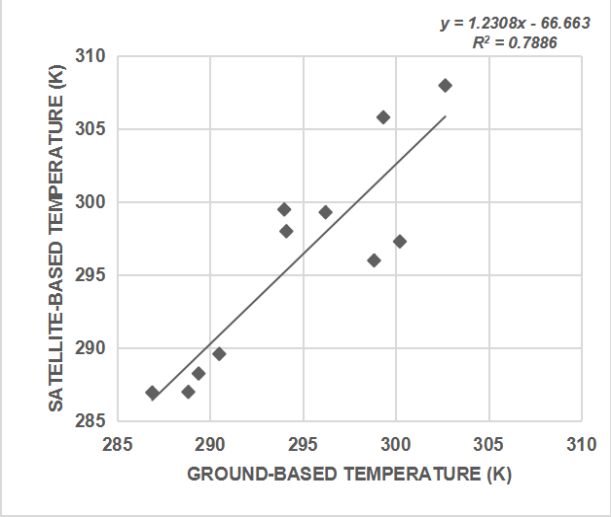


Figure 1. Correlation plot of land surface temperature (LST in Kelvin (K)) between satellite- and ground-based observations during study period (Winter and Spring) 2018-19 over Bhubaneswar.

3.2 Normalized deviation of vegetation index (NDVI)

Fractional difference of radiation between near infrared (NIR) and far infrared (FIR) can be defined as normalized deviation of vegetation index (NDVI).

$$NDVI = (NIR-FIR)/(NIR+FIR)$$

The NDVI over the forest areas of Chandaka region [85.6-87.85E, 20.2-20.25N] were noticed to be very high in all the seasons irrespective of spatio-temporal variation. Taking into account the spatial and temporal difference, relative difference of NDVI is considered to be an indicator of urban settlements. Many of urban-settlement regions study region are identified as built-up areas using land-use and land-cover change in Bhubaneswar. Relative difference of NDVI exhibits 0.2

to 0.4 between built-up area and forest green covered regions. This difference is lower in spring as compared to that in winter days as shown in figure 3. Reduction in green cover in city landscapes is likely to be the reason. However, the NDVI over water bodies and forest land regions are often less varying over the period of time.

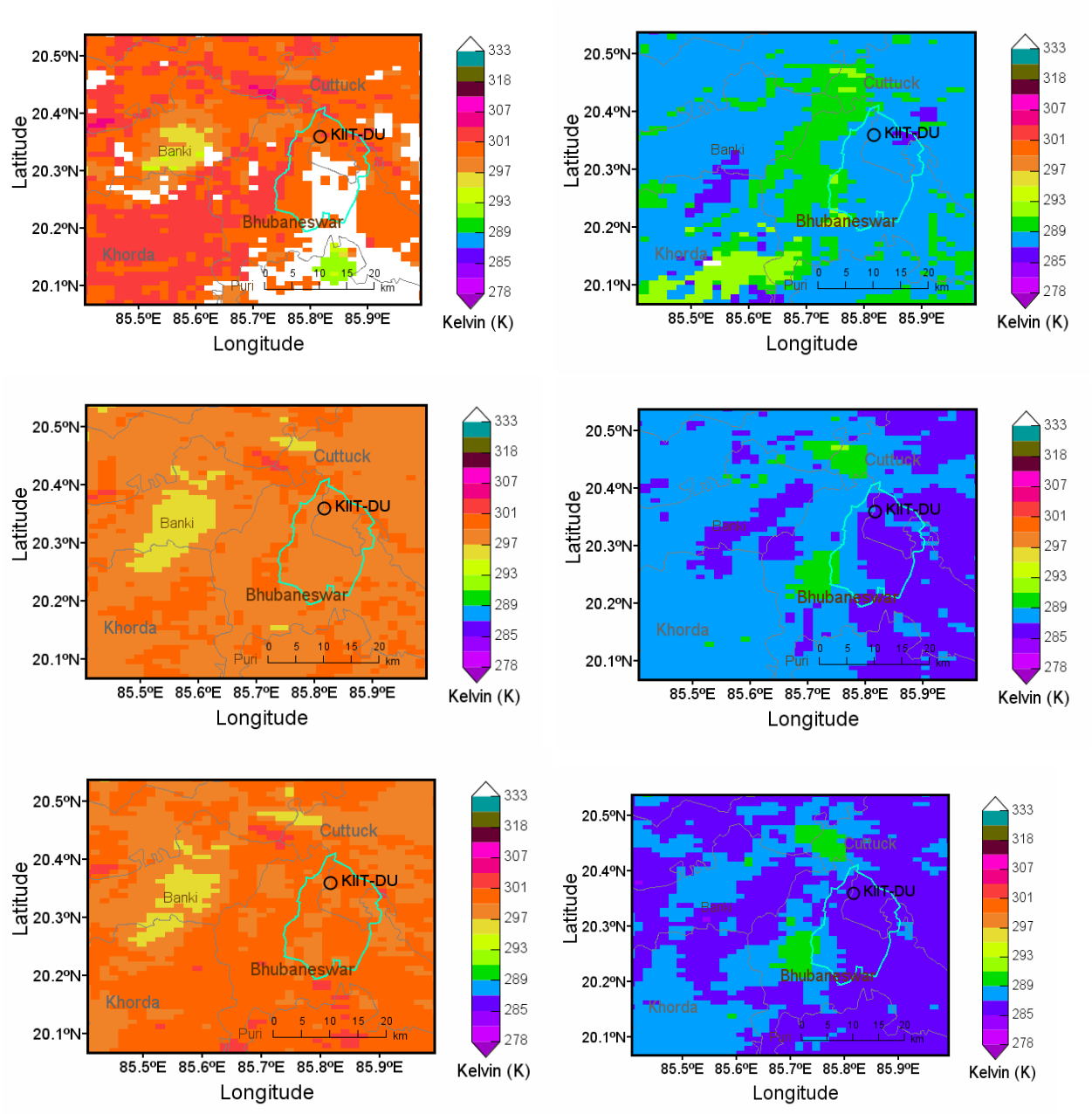
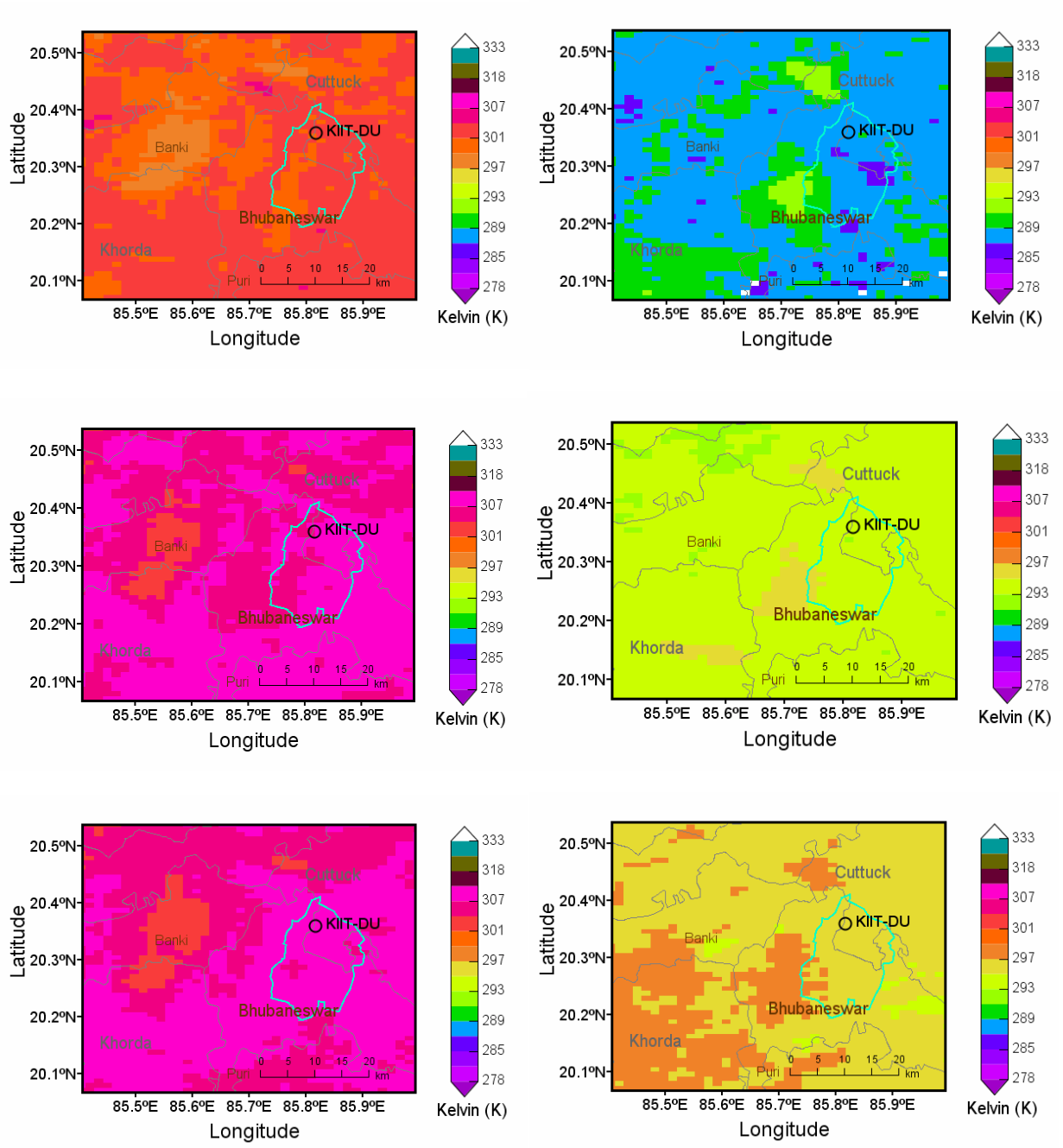


Figure 2(a). Ilustration of land surface temperature (LST, in Kelvin (K)) from MODIS satellite observations over Bhubaneswar Municipal corporation (BMC) as highlighted as a dotted hatch over the map approximately occupied area between 20.19-20.41˚N, 85.65-85.90˚E. Left panel depicts LST of daytime while right panel depicts nighttime LST for 345, 353 Julian day of 2018 and 001 Julian day of 2019.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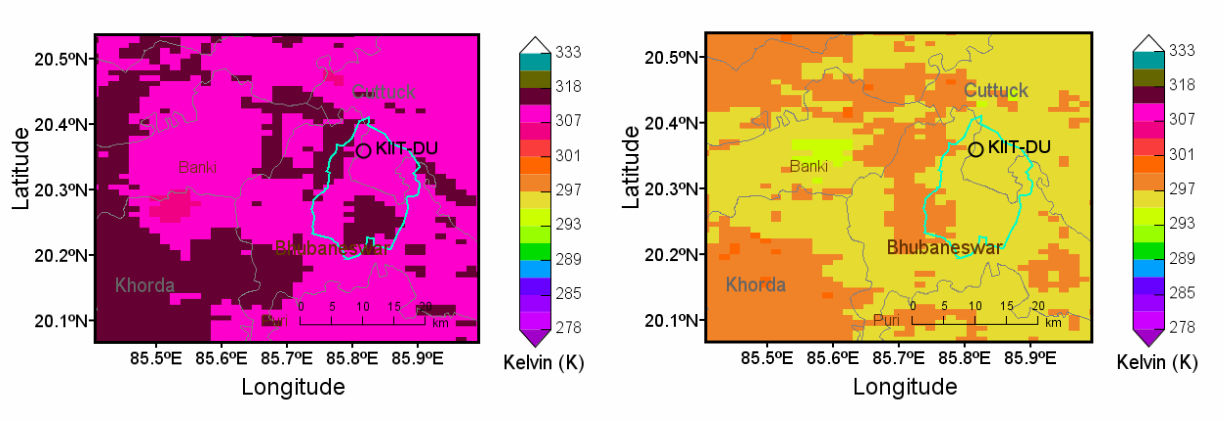

Figure 2(b). Same as figure 1(a), but for 017, 049, 073 and 107 Julian day of 2019.

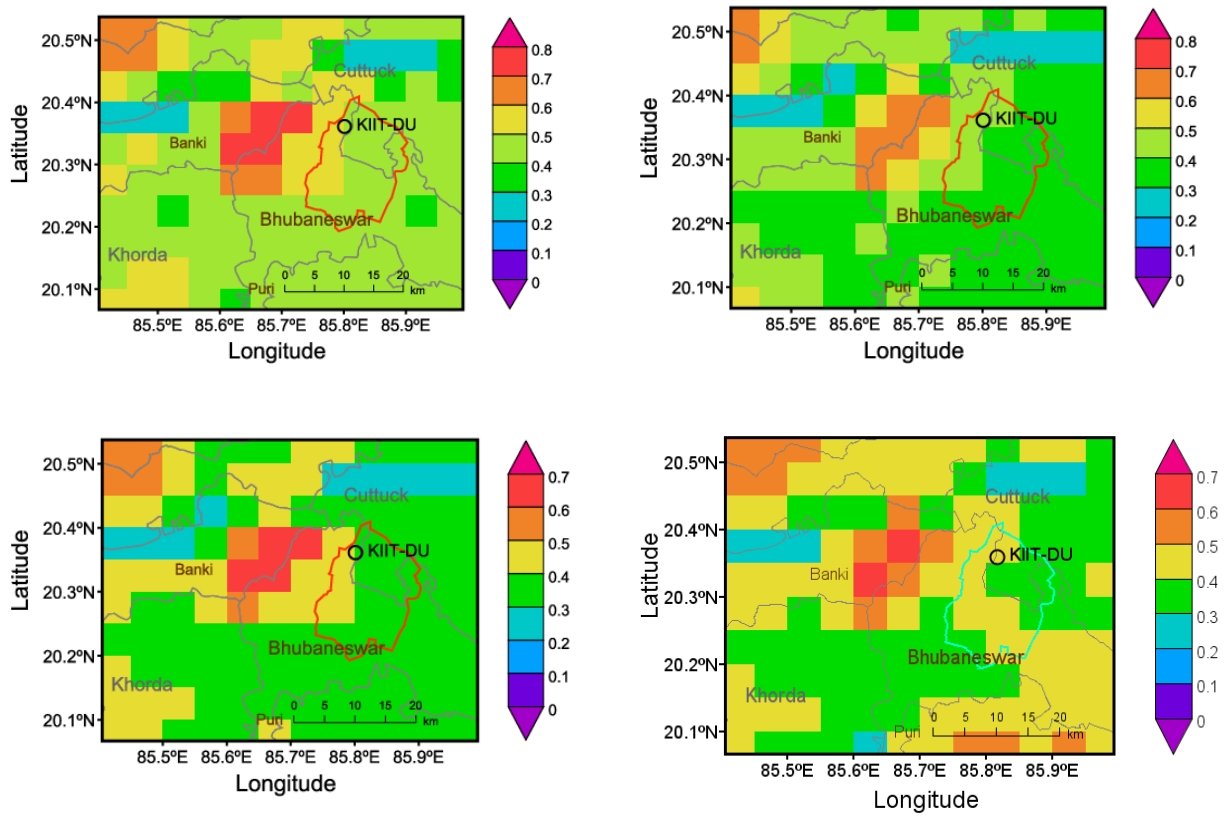

Figure 3. Normalized Deviation of Vegetation Index (NDVI, Unit less) for the corresponding months of winter monsoon season including November (Left-upper), December (Right-upper), January (Left-lower) and February (Right-lower) panels of the year 2018-19 over Bhubaneswar Municipal Corporation (BMC) (marker in red boundary).

3.3 Surface mass concentration

Seasonal variability of PM10 and total suspended particulate matter (TSP) in Bhubaneswar city during December 2018-April 2019 in terms of 24-hourly, daily and seasonal mean quantities are

as shown in Figure 4. Spring months (14 February, 14 March and 15 April, 2019)show high difference of concentration between TSP-PM_{10} compared to that of other months. It signifies the presence of dust in the atmosphere, though there is no prominent dust emission sources near the station. This is likely due to the inter-continental transport of dust from adjoining continental source regions.

Surface PM_{10} concentration exhibits relatively high during winter (11 and 19 December 2018, 1 and 17 January 2019) followed by spring season (Figure 4). Coarser size aerosols are predominantly present in the spring airmass, this was reasoned by the long range transport of dust (from desert or plain regions) originating from regional to continental region level. Fine aerosols dominates the airmass in winter due to the prevailing meteorology favors the emissions to accumulate in the lower boundary layer, particularly, at the surface level. In spring, slight increase of PM_{10} is observed as the biomass burning activities due to the action of crop-field burning emanating carbonaceous emissions escalates the pollution -burden and -transport in IGP and its adjoining outflow regions (e.g. Eastern India).

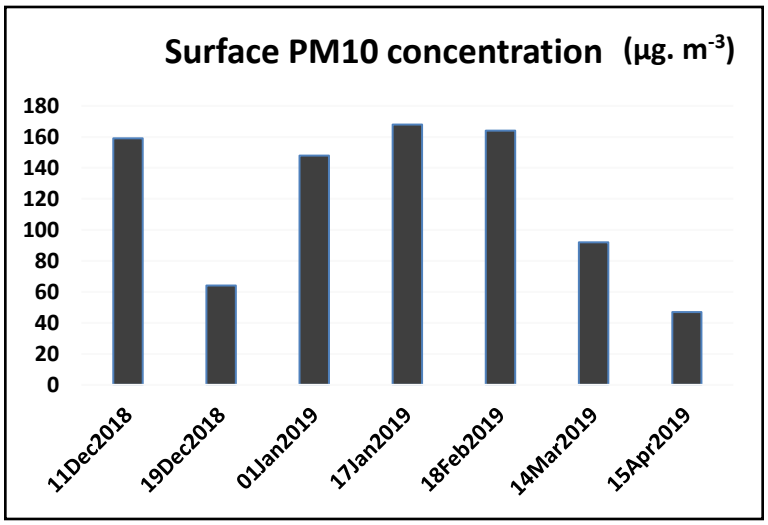

Figure 4. Bar plot of PM10 concentration (in µg. m^{-3}) for the days of ground-based observations over [85.81E, 20.35N] Kalinga Institute of Industrial Technology-Deemed to be University (KIIT-DU), Bhubaneswar in winter (December 2018-January 2019) and Spring (February-April 2019).

4. Conclusions

We conclude that difference of surface UHI (SUHI) between winter and spring days are well addressed by the land surface temperature of satellite data. The temperature data from satellite observations show consistent results as it exhibited a good correlation (R^2 =0.78) of land surface temperature (LST) and surface temperature over the surface level atmosphere over KIIT-DU station. The following conclusions were drawn from the present study are listed as below:

(i) The surface urban heat island (SUHI) was found over Khandagiri region as the LST over this region has 2-3 K higher than that from adjoining regions of Bhubaneswar. This was reasoned by high built-up area and low NDVI results.

(ii) Over the KIIT-DU region the SUHI shows low compared to that over Khandagiri region. Pollution measurements over KIIT-DU shows relatively high for the days of winter compared to that for spring days. Low boundary layer height followed by low convective transport of pollution air mass vertically in the atmosphere brings down temperature to lowest in winter at surface level. Though production of air pollution emissions from vehicular activities and resuspended dust in urban areas, high convective transport of pollution from surface to the elevated layers of atmosphere was noticed on the days of spring season (14 February and 14 March, 2019) results to have less cooling at the surface level. As a result, the LST in spring season is considerable compared to that in winter.

(iii) The normalized deviation of vegetation index (NDVI) analysis highlighted more on green cover, which represents the changes of land use and land cover over a landscape. Many of urban-settlements in Bhubaneswar were identified as built-up areas as per the land-use and land-cover change data. Relative difference of NDVI exhibits 0.2 to 0.4 between built-up area and forest green covered regions. However, the NDVI correlates well with the LST over Khandagiri and Chandaka region.

As a summary, present study highlighted about surface urban heat island (SUHI) identification on consistency of the LST, correlation of the NDVI with the LST and emissivity over two distinct land-scapes of Bhubaneswar region during winter and summer 2018-19. More studies on the UHI at canopy level, boundary layer level and surface level are needed to be carried out to evaluate significance of pollution, land-use and land-cover change and meteorolody on escalating heat over urban locations at local level and Earth's radiation budget at global level.

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