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ASSESSMENTOFURBANHEATISLANDUHIUSINGREMOTESENSINGANDGIS

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## I. Background

Approximately 2% of the Earth's land surface is covered by urban regions, contains about half of the human population (UNDP, 2001). The increased urbanization trend has various environmental impacts and it seems to be never ending with a continuous and rapid increase throughout the last century and still projected to increase even faster. Developing and improving urban infrastructure is important for human welfare but it has somehow hindered the natural eco-system especially within the urban areas.

More and more people move from rural to urban areas in order to provide themselves with better opportunities for progress. This rural urban migration is inevitable and has implications on economic growth and development. But as population influx in the urban areas increases, it puts a burden on the localized urban environment and somehow this development is accompanied by environmental deterioration.

Consistent development of urban areas results in the formation of more and more impervious surfaces which has been considered as a predominant driving force towards the alteration of the natural eco-system (Zhou et al., 2004). These unreceptive surfaces seal soil surface that results in elimination of rain water penetration (infiltration) and ground water recharge. This enhances ground water runoff which ultimately plays a part in natural catastrophes like floods. When this heat is released, it increases temperature thus increasing energy consumption within urban areas to modify the environment.

Quality of urban life and energy cost are mainly affected by Urban Heat Island. With each degree temperature the power used for air conditioning is enhanced. The level of atmospheric temperature elevates due to the subsequent increased use of electricity for cooling. The earth's rising temperature are the hot issues today in the world. Since the industrial revolution the temperature of the planet has been increased. Today the main cause of $CO^2$ level rise is due to increased energy use. (Irfanet al, 2001).

The knowledge of urban heat island is important for a range of issues and themes in earth sciences and also in planning and management practices as the impact of urbanization is huge and affects the natural ecology.

## II. Objectives

The research analyses and verifies the spatial pattern of surface temperature with urban spatial information related with landuse/cover and NDVI using remotely sensed data and GIS.

The main objectives of the research are listed below:

- To estimate the urban heat Island Effect using remote sensing data.
- To analyze the relationship between LST and Vegetation Density in urban area.
- Evaluate the connection between LST and other urbanization parameters. (Population Density, Air Pollution, etc)

## III. Study Area

*Lahore District* is the Capital of Punjab province and is the second largest city of Pakistan. It is located within the geographic extents of 31°34' North latitude and 74°22' East longitude at the left bank of river Ravi, one of the five rivers of the Punjab province. The dimensions of the area are 31°15 and 31°45 latitude and

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74°01' and 74°39' longitude. Figure 1 highlights the study area location in Pakistan.

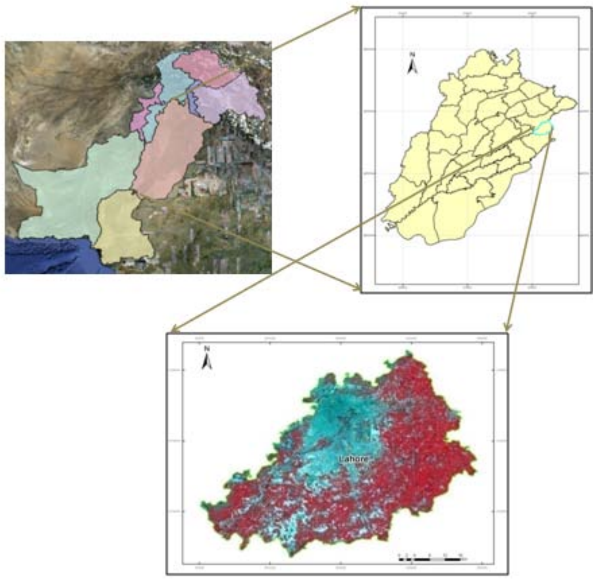

*Figure 1 :* Study area

## IV. Material and Methods

The adopted methodology for this research was dependent on the needs and demands of the researcher to achieve research objectives and does not follow any particular school of thought. However it consisted of the following steps:

- Data collection
- Data processing
- Data analysis

*a) Datasets Used*

The data collected for study was obtained from different sources. The boundary of the study area was obtained from The Urban Unit on request. The respective city boundary was then overlapped with the obtained satellite imagery to identify the study areas.

In general the data used for analysis comprises the following combined Satellite images and secondary data:

- Landsat 5 (Thematic Mapper) Image
- Population Density data
- Air Pollution data

i. *LANDSAT Thematic Mapper*

Landsat TM images dated June, 14, 2011 were acquired from the Earth Explorer to locate and analyze the Spatial distribution pattern of LULC types (classes and LST (Land Surface Temperature). For this purpose, the image was given a geographical reference by rectifying it to Universal Transverse Mercator (UTM) WGS84. Later on, the image was resampled to its spatial resolution with the help of the algorithm of nearest neighborhood.

The TM data is captured in seven spectral bands simultaneously. Band 6 is thermal band that senses infrared radiation. (NASA 2011)

Technical detail of the TM sensor is as follows:

- Spatial Resolution: 30m (120m - Thermal)
- Spectral Resolution: (0.45 – 12.5) $\mu$m
- Temporal Resolution: 16 days
- No. of Bands: 7
- Image Size: 185Km X 172Km
- Swath Width: 185 Km
- IFOV: 30m$^2$ & 120 m$^2$band 6

The TM band list is given in Table 1.

*Table 1 :* TM Bands List

| Wavelength Region | Band Number | Wavelength ($\mu$m) | Resolution |
|---|---|---|---|
| Visible | 1 | 0.45-0.515 | 30 m |
| | 2 | 0.525-0.605 | 30 m |
| | 3 | 0.63-0.69 | 30 m |
| NIR | 4 | 0.75-0.90 | 30 m |
| SWIR | 5 | 1.55-1.75 | 30 m |
| | 6 | 10.4-12.5 | 120 m |
| TIR | 7 | 2.09-2.35 | 30 m |
| Pan | 8 | 0.52-0.9 | 15 m |

*Source: NASA 2011*

Band 6 of TM is basically analyzed and examined for extracting the surface temperature, whereas all other bands helped in classification of landcover for Lahore.

The individuals images/bands are stacked using Erdas Imagine software and then clipped based on the area of interest. (Figure 2).

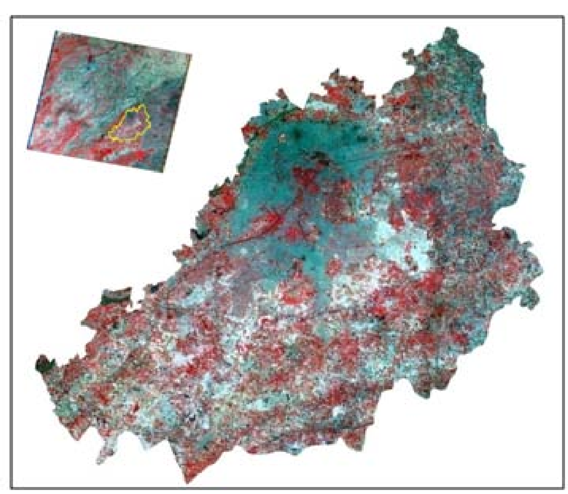

*Figure 2 :* Clipped Image of Lahore with Band Combination (4,3,2)

*b) Land Surface Temperature Estimation*

An algorithm adopted from (Saleh S, 2002 & Zhao-ming et al) has been used to retrieve LST. The flow chart (Figure 3) below shows the major steps of algorithm for obtaining LST and the calculated land surface temperature of Lahore, using band 6 of Landsat has been shown in Figure 4.

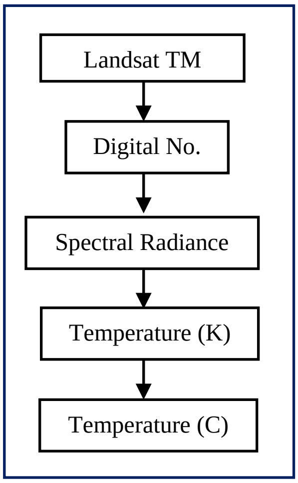


*Figure 3 :* Major steps obtaining LST

i. *Conversion of the Digital Number (DN) to Spectral Radiance (L)*

LANDSAT 5(TM) data are acquired as the 8-bit grey scale imagery in Level 1G product. The equation and constants (see in Table 2 below) for converting the 8 bits digital number of the image data into the spectral radiance is as follows:

$$L = L_{MIN} + (L_{MAX} - L_{MIN}) * DN/255$$

Where

L = Satellite Spectral radiance

$L_{MIN}$= 1.238 (Spectral radiance of DN value 1)

$L_{MAX}$= 15.600 (Spectral radiance of DN value 255)

DN= Digital Number

Group scaling parameters' which shows what the upper/lower bounds for radiance are in each band. $L_{MIN}$ and $L_{MAX}$ values for each thermal scene can find in the satellite header file.

*Table 2 :* TM Spectral Radiance

| TM Spectral Radiance Range in ($Wm^{-2}sr^{-1}\mu m^{-1}$) | | |
|---|---|---|
| Band Number | Lmin | Lmax |
| Band 1 | -1.52 | 193.0 |
| Band 2 | -2.84 | 365.0 |
| Band 3 | -1.17 | 264.0 |
| Band 4 | -1.51 | 221.0 |
| Band 5 | -0.37 | 30.2 |
| Band 6 | 1.238 | 15.303 |
| Band 7 | -0.15 | 16.5 |

ii. *Conversion of Spectral Radiance to Temperature in Kelvin*

The radiance is converted to the temperature in Kelvin using following formula:

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)}$$

Where

$K_1$= Calibration constant 1 (607.76) for TM

$K_2$= Calibration constant 2 (1260.56)

$T_B$= Surface Temperature

$L_\lambda$ = Spectral Radiance in $Wm^{-2}sr^{-1}\mu m^{-1}$

| | *TM* | *ETM+* |
|---|---|---|
| $K_1$ | 607.76 | 666.09 |
| $K_2$ | 1260.56 | 1282.71 |

For Landsat-5 TM,

$K_2$ = 1260.56, and $K_1$ = 607.76mW cm_ 2 sr_ 1 Am_ 1.

Landsat TM Spectral Radiance $L_{MIN}$ and $L_{MAX}$ offset gains range for band 6 is:

| Band | Lmin | Lmax |
|---|---|---|
| 6 | 1.238 | 15.303 |

iii. *Conversion of Kelvin to Celsius*

$T_B$= $T_B$-273

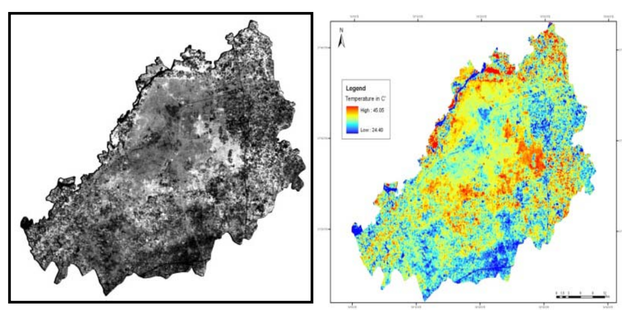

*Figure 4 :* Surface Temperature Images

*c) Normalized Difference Vegetation Index (NDVI)*

The derivation of Normalized Difference Vegetation Index (NDVI) is a standard procedure and has already been enlightened in the literature. The study adopted this standard mathematical formula for NDVI as below:

$$\frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}}$$

where

$R_{NIR}$ = Reflectance in near infrared band

$R_{RED}$ = Reflectance in red band

The 5 shows the NDVI images retrieved using above formula.

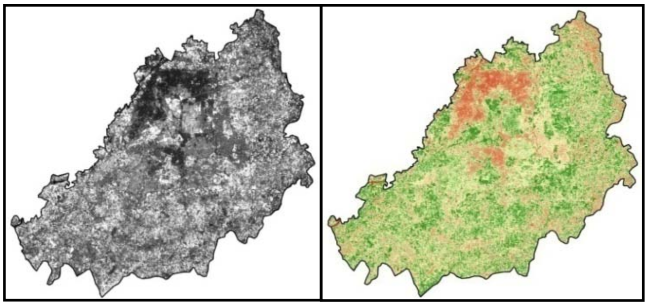

*Figure 5 :* NDVI Images

*d) Definition of Urban and Non Urban Spaces*

In order to understand the relationship between temperature and typical land cover types, correlation was performed between temperature and NDVI images on a pixel to pixel basis. Supervised image classification was also performed to get landuse categorizations.

## V. Results and Conclusions

In case of Lahore, after examining the temperature distribution maps, it was found that maximum temperature values mostly existed with in the central part of the urban area also called the old city typically characterized by densely built-up commercial areas with deep street canyons.

The urban and suburban areas have experienced maximum temperatures ranging between within 30°C and 44°C. In addition due to the building geometry, wind circulation in urban areas is limited. So a human body experiences discomfort and requires air cooling with these temperatures. More heat is released and temperatures increase further because more air conditioners are used for cooling purpose. On the contrary, the LSTs are usually lower in suburban and rural areas where there is agricultural land.

*a) Analysis of Land use/ Land cover*

The land use classified image of Landsat-5 TM is shown in Figure 6. The image is classified using Maximum likelihood classification that used the nearest neighbor algorithm to resample the pixels in order to make different classes. The classification helped to study the relationship between land cover change and temperature. The accuracy of the classification images was gauged by comparison against the actual LST and NDVI images and it was clear that higher temperature values corresponded to more developed areas while lower values exhibited the rural areas.

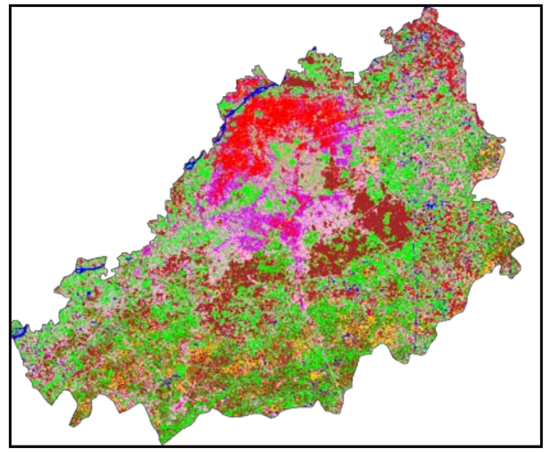

*Figure 6 :* Land use Classification of Lahore

*Table 3 :* Supervised land use Classification statistics

| Class No. | Class Name | No. of Pixels | Percentage (%) |
|---|---|---|---|
| 1 | Vegetation | 963102 | 48.03 |
| 2 | Built-up High | 155560 | 7.75 |
| 3 | Built-up Medium | 55822 | 4.78 |
| 4 | Built-up Low | 181778 | 9.06 |
| 5 | Bare Soil | 256811 | 12.80 |
| 6 | Water | 14179 | 0.70 |
| 7 | Sand | 377704 | 18.83 |

*b) Analysis of Surface Temperature*

NASA model is used to estimated the surface temperature.

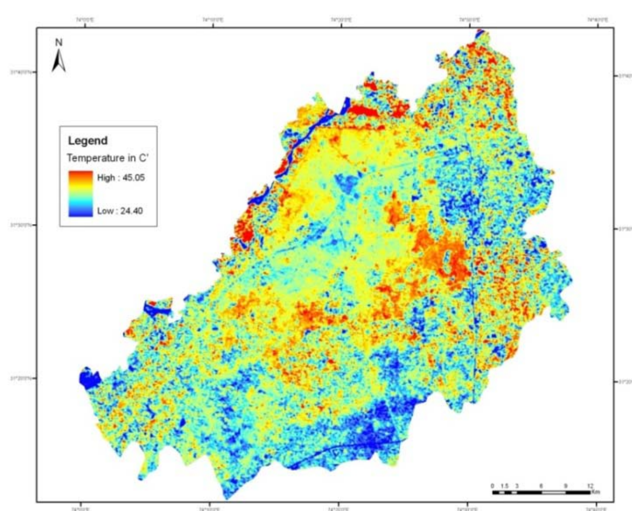


*Figure 7 :* Spatial Distribution of Temperature in Lahore

The estimated surface temperature ranges (figure 7) from 23.16 to 43.58°C (mean temp. 33.37°C). It is observed that the upper left part shows maximum surface temperature range that corresponds to high built-up areas (30.73 to 43.58°C). Whereas the low dense built-up ranges from 29.91 to 38.11°C. Water bodies exhibit minimum surface temperature compared to other land use/land cover features (23.16 to 33.32°C). Table 4 shows the surface temperature statistics, followed by vegetation (27.30 to 37.21°C). Hence Water bodies and sparse vegetation is cooler as compared to other land use/land cover features.

*Table 4 :* Temperature statistics per land cover/ land use classes

| Class No. | Class Name | Temperature | | |
|---|---|---|---|---|
| | | Mean | Min | Max |
| 1 | Vegetation | 32.00 | 27.30 | 37.21 |
| 2 | Water | 28.08 | 23.16 | 33.32 |
| 3 | Built-up High | 37.15 | 30.73 | 43.58 |
| 4 | Built-up Medium | 35.30 | 31.95 | 38.66 |
| 5 | Built-up Low | 33.95 | 29.91 | 38.11 |

*c) Analysis of Normalized Difference Vegetation Index (NDVI)*

A NDVI image was computed (see figure 8) from red and near infrared (NIR) bands of landsat 7 ETM+, using the formula:

NDVI= TM 4 – TM 3/ TM 4 + TM 3

The NDVI image has been transformed into image of 8bit (0-255) value from the original values ranges between -1 to +1. The land use/cover change and surface temperature map extracted from landsat image was correlated with the resultant NDVI image to study how all these changes have interacted.

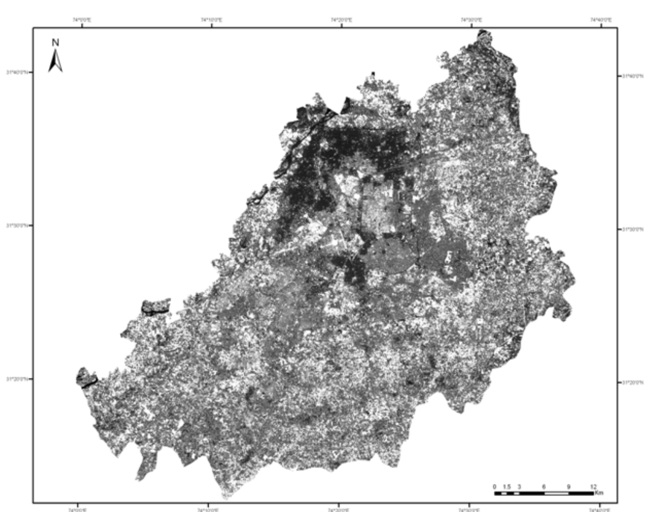

*Figure 8 :* NDVI image for Lahore District

*Table 5 :* Average NDVI per land cover/ land use classes

| Class No. | Class Name | Mean NDVI Value | STD. |
|---|---|---|---|
| 1 | Vegetation | 139.31154 | 28.134737 |
| 2 | Water | 63.036182 | 16.571907 |
| 3 | Built-up High | 55.151108 | 8.636002 |
| 4 | Built-up Medium | 69.333649 | 10.100005 |
| 5 | Built-up Low | 86.761292 | 14.734277 |

As shown in the table 5vegetated area has the highest NDVI value 139.31, while High Built-up area has the lowest NDVI value (55.15) Medium and Sparse residential areas have comparatively low NDVI value of 69.33 and 86.76 respectively, because these areas have few green spaces.

*d) Relationship between Surface Temperature and NDVI*

For each land cover type the relationship between surface radiance temperature and NDVI was investigated through correlation analysis. Table 6shows the analysis between surface temperature and NDVI with respect to land cover/use type.

From the table it is apparent that surface temperature values negatively correlate with NDVI values for all land cover types. This relationship can be visualized by the plot 1 which shows the relation between mean surface temperature values for all land cover types with NDVI.

*Table 6 :* Surface temperature, NDVI per land use classes

| Class No. | Class Name | Mean NDVI Value | Average Temp |
|---|---|---|---|
| 1 | Vegetation | 139.311 | 32.00 |
| 2 | Water | 63.036 | 28.08 |
| 3 | Built-up High | 55.151 | 37.15 |
| 4 | Built-up Medium | 69.333 | 35.30 |
| 5 | Built-up Low | 86.761 | 33.95 |

Strong negative correlation has been observed between surface temperature and NDVI which implies that a land cover that has higher biomass exhibits lower surface temperature. Because of this relationship between surface radiance temperature and NDVI, land use/cover changes have an indirect impact on surface temperatures through NDVI.

*e) Population Density Vs Surface Temperature*

The Figure 9 shows the Population density (persons/acres) distribution for Lahore.

It is obvious from the map that urban areas have high population density which lowers towards the south side towards rural areas.

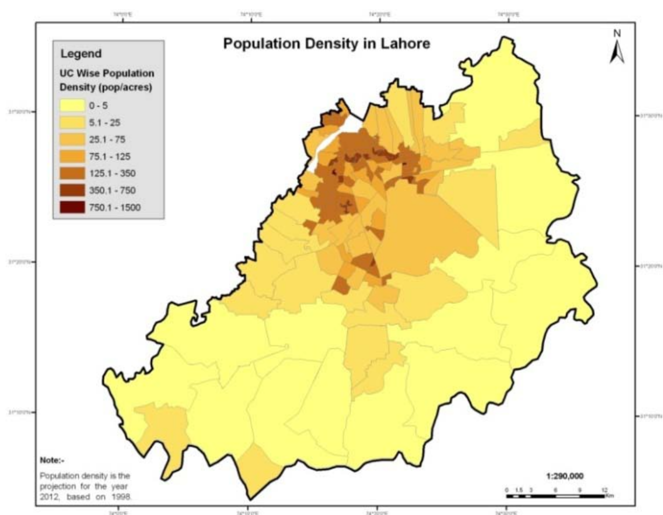


*Figure 9 :* Population density distribution in Lahore

*f) Analysis of Air Quality*

There is positive relationship between air pollutants, urban density and increased temperatures in urban areas as showed from results (Figure 10, 11). The air quality points are taken at different location in urban areas of Lahore as urban areas are associated with high temperatures and population density (obvious from table 7 and figure 11).

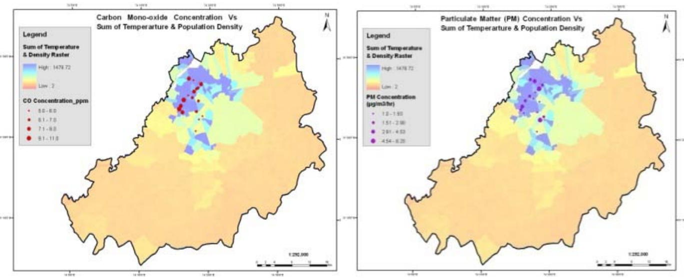


*Figure 10 :* Concentration of CO & $NO_2$

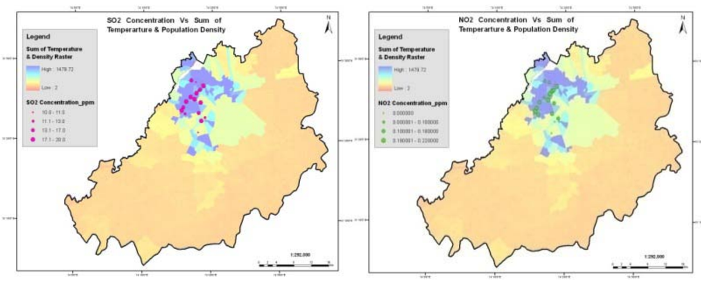


*Figure 11 :* Concentration of $SO_2$ & PMs

*Table 7 :* Statistics for Air Quality parameters vs Population density & Temperature

| Stop # | Population Density (Pop/acre) | Temp ‘C | Air Quality | | | |
|---|---|---|---|---|---|---|
| | | | CO (ppm) | $SO_2$ (ppm) | PMs ($\mu g/m^3/hr$) | $NO_2$ (ppm) |
| 1 | 159 | 35.544 | 5 | 20 | 2.76 | 0.1 |
| 2 | 307 | 35.937 | 8 | 16 | 2.365 | 0.08 |
| 3 | 62 | 35.544 | 5 | 20 | 8.17 | - |
| 4 | 277 | 36.330 | 7 | 17 | 7.6 | 0.17 |
| 5 | 277 | 35.937 | 7 | 12 | 1.111 | 0.2 |
| 6 | 34 | 35.544 | 6 | 12 | 2.208 | 0.15 |
| 7 | 274 | 36.330 | 5 | 10 | 4.532 | 0.1 |
| 8 | 197 | 35.544 | 7 | 15 | 1.428 | 0.15 |
| 9 | 112 | 35.937 | 9 | 18 | 1.385 | 0.2 |
| 10 | 347 | 36.330 | 10 | 20 | 1.93 | 0.18 |
| 11 | 223 | 37.111 | 11 | 18 | 2.381 | 0.22 |
| 12 | 43 | 35.544 | 7 | 18 | 1.04 | 0.15 |
| 13 | 335 | 36.330 | 9 | 15 | 3.607 | 0.17 |

*Source : Lahore urban transport master plan 2011, Volume II*

Table 7 describes the values of CO, $SO_2$, $NO_2$, Particulate matter and corresponding statistics of surface temperature and population density for each stop.

## VI. Recommendations

The methodology applied in this study gives an alternative, easy and most updated way against the traditional empirical analysis using the available updated data for environmental studies. This methodology should be applied to other regions in Pakistan that undergo a rapid urbanization.

Much Higher resolution imagery should be used for the classification and quantification of land use/land cover type, so that different classes could be easily distinguished and pixel based analysis would give more accurate and precise results. More improvement in temperature estimation will occur by using Landsat 7 with resolution of 60m thermal sensor.

Several atmospheric effects (e.g., partial water vapor absorption), variable surface emissivity, sub-pixel variation of surface temperature and urban geometry affects the measurement of Land surface temperature. Therefore, these factors should be considered in computing actual LST in future.