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Fundamental LCZ Mapping with ArcGIS-Based Spatial and Correlational Analyses to Study the Impacts of Infrastructural Area-Maximum Volume (A-MV) Attributes on OTC – An Urban Aw Summer Case

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ABSTRACT

The aim of this study is to map the study location stretches into 100mx100m local climate zones (LCZs) on the basis of primary observations and secondary photographic data for spatial analysis of various urban infrastructural elements (grey(G)-built structures, blue(B)-water bodies and green (Gr)-natural vegetation) and impact assessment of their estimated area (EA) and maximum volume (EMV)) on the air temperature (Ta) that characterizes the outdoor thermal comfort (OTC). **Climate Modification by Urban Infrastructure, Fundamental Concepts of Urban Infrastructure Mensuration Parameters, Fundamental Concepts of Urban Grey Blue Green Infrastructure (UGBGI) and Concepts Of OTC, Koppen Classification and LCZs** are the linked areas. Study locations are based on socio-economic and geophysical attributes. Initial 200 pilot survey responses regarding thermal sensation votes and other subjective details were used. Preferred values of Physiological Equivalent Temperature (PET) and optimum Ta have been used. After the mapping in ArcGIS and polygonal delineation of the areas, EA values were compiled in tabular format. Based on primary measurements and secondary studies, a maximum height (hmax) value was assigned to each sub-category for EMV evaluation. Statistically, the EA and estimated perimeter (EP) values were analyzed using QQ, scatter plots, histogram and generate near table tools in ArcGIS. EA and EMV values were correlated with mean Ta values by linear regression. The R-square values generated gave a clear idea about the extent of their impacts on Ta. From the established relationships and preferred PET and optimum Ta values, optimum EA, EMV and hmax values of the broader categories(G,B,Gr) required for preferred OTC levels were finally evaluated.

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Introduction

Rapid urbanization, unorganized situation oriented planning techniques combined with extreme climatic conditions are exerting their resultant impacts upon the ever growing and expanding urban population. Urban areas occupy hardly 5% of the world's surface area and land cover. The major amount of global energy produced which is almost 70% is also consumed by them. Critical global environmental issues like global warming and depletion of ozone layer get their causing and driving forces from these urban micro and meso level climatological phenomena thereby making the urban inhabitants severely vulnerable to impacts like heat stress, urban heat island effects and urban floods [1].

There is a huge space for rehabilitation, resilience and damage control. Two very crucial steps that are supposed to be focused on are capacity building and community participation that mostly don't happen due to differences in awareness and consciousness of individuals among different communities. The unending population pressure, lack of adequate financial resources, administrative loopholes and failures and lack of basic level education in a major part of the population lead to an overall degraded air quality in urban areas that also result in an increased atmospheric temperature, humidity, air pollutants and suspended particulate matters (SPMs).

The cognitive needs of the urban population are addressed often whereas urban sustainability remains unattended. A parametric approach is recommended and preferred in developing a more comprehensive framework of guidelines that can help in enhancing the thermal comfort levels of the urban residents. The basic aspects of this research - urban sustainability, grey blue green infrastructure and ecosystem based services are connected. Ecosystem based services emerges as the most important medium in linking urban planning and sustainability and focus on 3 broad areas of functioning: (1) regulatory (2) provisioning and (3) cultural. Area (1) and its thermal aspects will be focused in details.

After the initial level literature studies, several broader areas that can possibly play a crucial role in the upcoming stages of our research have been listed and discussed under the following heads:

Climate Modification by Urban Infrastructure

It is clearly evident that by the year 2030 it is estimated that 80% of the world's population will live in cities. The study of urban climates becomes very important. Firstly, the formation of a pleasant and healthy environment for urban dwellers needs to be ensured and secondly, the effects of urbanization on large scale planetary climates need to be kept under check. Studies show that 60% to 80% of energy consumption are counted by cities in the form of human induced Green House Gases (GHG) emissions (approximately 70% as per the reports of UN-Habitat 2016). Anthropogenic heat is the amount of energy produced by processes related to mankind like the heat from vehicular traffic, the waste heat from buildings - mainly industrial activities and the heat released from human metabolic processes that result in comprehensive climatological and visuality impacts. Urban areas with their social and economic transformative responsibilities become forerunners of sustainable development. Increased urbanization has given rise to exponential rise in global carbon emissions especially from the combustion of fossil fuels [1].

CO and CO_2 are mainly generated due to the incomplete combustion of carbonaceous materials especially that of emissions of vehicles concentrated along major highways and near congested urban streets. Hydrocarbons mostly produced by the combustion of fossil fuels are very harmful to both vegetation and human beings because of their photochemical reactive nature. Other secondary pollutants like hydrogen fluoride, toluene, radioactive wastes and ammonia undergo biologically adverse chain photochemical reactions among themselves. Among the Sulphur compounds entering the atmosphere namely Sulphur dioxide (SO_2), Hydrogen Sulphide (H2S), Sulphurous (H_2SO_3) and Sulphuric (H_2SO_4) acids, SO_2 is the most vital one. It is majorly produced as a waste product by the combustion of fuels like coal and oil that are mainly used to heat up spaces during winter and generate electricity in power plants. Vegetation and water bodies act as natural CO_2 sinks. Vehicles, coal and natural gas consumption and factories manufacturing fertilizers and explosives act mostly as the principal sources of oxides of nitrogen - nitric oxide (NO), nitrous oxide (N_2O) and nitrogen dioxide (NO_2). After undergoing chemical reactions among themselves they may give rise to photochemical chain reactions producing products like ozone (O_3), peroxyacetyl nitrate (PAN) and aldehydes. Sufficient sunlight allow the formation of photochemical smog that exerts deeper climatological impacts [1].

Built up structures give rise to radiative, thermal, moisture and thermodynamic modification of the surrounding environment. The water balance around the same is disturbed due to spatial variability in precipitation receipt, soil drainage and evaporation. The average anthropogenic heat flux density depends upon the average use of energy by individuals and the urban population density. Huge amounts of water vapor are released when fossil fuels mainly natural gas, gasoline, fuel oil and coal are burnt. The utilization of water for absorbing heat waste from power plants and other industrial processes enhance vaporization from cooling towers, cooling ponds, rivers and lakes. Strong seasonal differences are observed mostly due to the use of water for lawns and gardens, swimming pools, washing and cleaning activities during the summer. Evapotranspiration gets reduced by loss of natural vegetation cover and their replacement by impervious materials most of which are grey infrastructural raw materials.

Urban Heat Island (UHI) is commonly defined as the scientific process or phenomenon in which urban areas experience higher temperatures compared to their relatively lesser developed surroundings. When isotherms are drawn connecting places with similar temperatures and associated thermal properties, it can be observed as an island like pattern of urban temperatures increasing from city's edge towards the densest areas. In the corresponding cross section of the city, it appears to start with a large gradient or cliff at its periphery continuing steadily across suburban areas and reaching the apex at the urban center [1].

The different types of UHI and the results of their formation are:

- BLUHI / Meso-scale - during the day, they are formed due to bottom up sensible heat flux through top of roughness sub-layer, top down heat entrainment into the Urban Boundary Layer (UBL) and radiative flux divergence due to polluted air. During the night, the same repeats itself but with reduced intensity and miscellaneous sources' anthropogenic heat.
- CLUHI / Local & Micro-Scales - during the day, they are formed due to strong positive sensible heat flux at surface and sensible heat flux convergence in canyon. During the night, it happens mostly due to positive sensible heat flux from the release of stored heat, longwave radiative flux convergence and anthropogenic heat.
- SUHI / Meso, local & micro-scales - during the day, it happens due to strong radiation absorption and heating by exposed dry and dark surfaces with surface energy balance. During the night, it happens due to larger cooling at roofs giving large sky view compared to canyon facets that give restricted skyview with surface energy balance.
- SSUHI Micro-Scale - happens by subsurface energy balance and heat diffusion into the ground.

As per the IPCC (Intergovernmental Panel on Climate Change), urban areas are expected to undergo an overall temperature rise by more than 1.5 degrees Celsius by the middle of the 21st century. Frequency of meteorological disasters like storms, floods, heat extremes and landslides is also expected to increase.

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Fundamental Concepts of Urban Infrastructure Mensuration Parameters

The fundamental elements of mensuration and calculation that have been focused upon here in terms of urban infrastructure (grey, blue and green elements) are:

Estimated Area (EA)

Estimated calculations are done on the basis of rough estimates and not exact figures. They are mostly utilized in making lump some estimates directly related to the rough measurements.

Estimated Area is defined by the extent covered by boundaries formed with roughly drawn polygonal surfaces enclosing and denoting various types of land uses and infrastructural footprints. They are mostly in the form of irregular shapes whose areas are auto-calculated by the tools used for area delineation. For the area delineations, alongside satellite images, primary and secondary photographic data are referred.

In this study, the ArcGIS tool has been utilized for area delineations using the polygon tool. Similarly, after using fishnet to demarcate the entire study area into 100 x 100 meters grids of local climate zones (LCZs), it has been used to delineate various grey (built up structures), blue (water bodies) and green (natural vegetation) urban infrastructural elements and their sub-categories.

Assumed Maximum Height (hmax)
This attribute is defined as the highest height of presence of any particular urban infrastructural element. It has been mostly fixed and assumed in this study on the basis of roughly taken measurements by means of distometer, eye estimated measurements and primary cum secondary photographic data. For example, any flyover spans over a large stretch from one end of a local climate zone (LCZ) to an end of another LCZ throughout varying heights but its highest height of ascent will be taken as the hmax. Same concept has been applied for all other categories and sub-categories of urban infrastructure.

As mentioned, roughly taken measurements by distometers, eye estimations and comprehensively taken photographic data have been utilized for assuming this attribute. The main objective behind this one is to provide the second attribute after determining EA for calculating the corresponding estimated maximum volumes (EMVs) whose significance and purpose have been mentioned later.

Estimated Length or Perimeter (EP)
First of all, the purpose of this attribute is majorly secondary with respect to this study. It can tentatively be utilized in the future stages of the research specially in the final stages of simulation where the relations in between estimated areas and lengths of various infrastructural elements in a ward-wise manner will be referred. This attribute is auto-calculated side by side along with the estimated areas in ArcGIS tool as per the area delineations performed. It denotes the perimeters enclosed by the boundaries of the polygons used for delineating the different categories of urban infrastructural elements.

As already mentioned, this attribute is majorly secondary with respect to this particular study except the fact that it will help in understanding how the estimated lengths and areas of various urban infrastructural elements and their categories are related in each ward contained in the study areas. Later, in the final simulation stage, it will be utilized for simulating the optimized outcomes.

Estimated Maximum Volume (EMV)
After the EA, this attribute is another primary one in terms of this study and the broader aspect of the research. **EMV** is calculated by virtue of the products of auto-calculated and summed EA values and corresponding assumed hmax values. It depicts the maximum 3-dimensional content covered by any particular infrastructural element on the basis of its maximum assumed height, width, elevated level above the ground or depth for water bodies. Its significance is quite crucial in terms of understanding their 3-dimensional impacts on the modification of urban outdoor thermal environments.

Later, the sets of average or mean estimated area and maximum volume values have been utilized for the required regressional analyses and establishment of relationships with the meteorological parameters. Based on the evaluated optimized values of meteorological parameters, these established relationships will help in determining the optimized values of estimated A-MV attributes.

Fundamental Concepts of Urban Grey Blue Green Infrastructure (UGBGI)
Integrated urban green and grey infrastructure combines "green" (natural, living) and "grey" (human-made, anthropogenic) infrastructure constituents to provide facilities in support of key (ecosystem) services and functions to urban communities. Integration may occur in the form of green infrastructure adding improved or additional services or functions to grey infrastructure or grey infrastructure increasing the functionality of green infrastructure. It may also occur along a green-grey continuum based on the proportional composition of green or grey constituents within integrated green and grey infrastructure systems.

Urban Blue-Green Infrastructure (UBGI) mainly defines the sustainable urban planning approach that characterizes the implementation of naturalistic or completely artificial infrastructures in the city to allow the whole water cycle to occur within its boundaries. It enhances the standards of delivery of natural vegetation and water related ecosystem services. These services include reduction of air pollution, mitigation and controlling of floods and similar others. BGI refers to a network that provides the "ingredients" for solving urban and climatic challenges by a combination of infrastructure, ecological restoration and urban design to connect people with nature. Blue indicates water bodies such as wetlands, ponds, lakes and river channels. Green indicates lawns, parks, orchards and gardens.

Green Infrastructure (GI) exclusively depicts trees, lawns, hedgerows, parks, fields, forests and similar features. Urban planners place a lot of emphasis on the formation of stepping stones and networks of blue and green infrastructures to allow animals, plants, water, clean air and other natural components to circulate in a balanced manner around the landscape. Water forms the basis for the BGI infrastructure services. It has a high heat capacity. It means that in comparison to most other natural materials it takes a huge amount of energy to cause a similar rise in the temperature.

Water is a good storer of energy thereby allowing itself to act as a conservative thermal influence. Precipitation happens in short, discreet spells whereas evapotranspiration from natural vegetation is a continuous and regular natural process. The thermal properties of soil are also adjusted by the addition of water by which the potential latent heat effects of soil moisture play a very crucial role. Biochemical energy storage changes are related to the rate of assimilation of Carbon dioxide (CO_2) by the plant community. Stomatal activities result in differing degrees of resistance to the exchange of water vapor through evapotranspiration and CO_2 between the plants and the atmosphere thereby making them vital components in modifying the climate at all scales [2].

UBGI comprises a conglomerate of natural and man-made components that are referred to as the 'core areas'. These core areas organize themselves in 'hubs' that provide the space for plants and animals species to develop further thereby acting as the ecological building blocks for the network. These hubs are connected and integrated to each other through 'corridors' that enable the interrelation and communication among species and the interchange of nutrients and information. Morphological composition and spatial configuration of natural systems have a profound influence on them [3].

The three basic principles underpinning the concept of UBGI are:
1. dynamic spatial and temporal heterogeneity
2. spatial interconnectivity or integration of blue and green components
3. multifunctionality

The ecosystem service categories to measure the effectiveness of blue-green infrastructure are discussed as follows:

Provisioning Services
- food supply (eg: agricultural land)
- water provision (eg: water storage capacity)

Supporting Services
- nutrient cycling (eg: nutrient retention in soil)
- provision of habitats (eg: species connectivity)

Regulating Services
- air quality regulation (eg: air purification)
- climate modification (eg: wind flow alteration)

Cultural Services
- landscape and amenity values (eg: cultural identity)
- recreation and cognitive development (eg: nature tourism)

The different measures to counter the formation of UHI implenting UBGI are:
- Increase green infrastructure - vegetation serves as a natural cooling system by providing evapotranspiration and vegetated open spaces and tree canopy provide cooling for downwind areas
- Use of green roofs or walls - green roofs or walls reduce heat transfers into buildings thereby encouraging evapotranspiration.
- Increased evaporative cooling - active systems like spray coolers and fans in public spaces and passive cooling systems like vegetation and water bodies increase evaporation.
- Water Sensitive Urban Design (WSUD) - it enhances evapotranspiration and heat dissipation by improving irrigation, water infiltration and retention.
- Increased shedding and reduced solar exposure - strategic location of vegetation and shading devices reduce solar exposure and heat storage of buildings specially in summer [3].

Concepts of Outdoor Thermal Comfort (OTC), Koppen Classification and Local Climate Zones (LCZs)

Thermal Comfort is that condition of human mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation. It is determined by physiological, psychological and environmental conditions. The environmental factors may be LST, Ta, RH, WS and cloud cover. The personal factors may be metabolic rate and clothing.

The general Energy Balance Equation of the human body is as follows:

M – W = C + R + E + Cres + Eres + S (all in measured in unit **W/sq. meters**)

[M ---> metabolic rate, W ---> mechanical power, C ---> convective heat loss from skin, R ---> Radiative heat loss from skin, E ---> Evaporative heat loss from skin, Eres ---> Evaporative heat loss due to respiration, Cres ---> Convective heat loss due to respiration, S ---> Rate of body heat storage]

The thermal comfort index that has been evaluated and focused upon in this study is:

Physiological Equivalent Temperature (PET)

Introduced and revised by Mayer and Hoppe in 1987 and 1999 respectively. It considers clothing and activity as variables in RayMan model application and considers the human body's thermo-regulations [4].

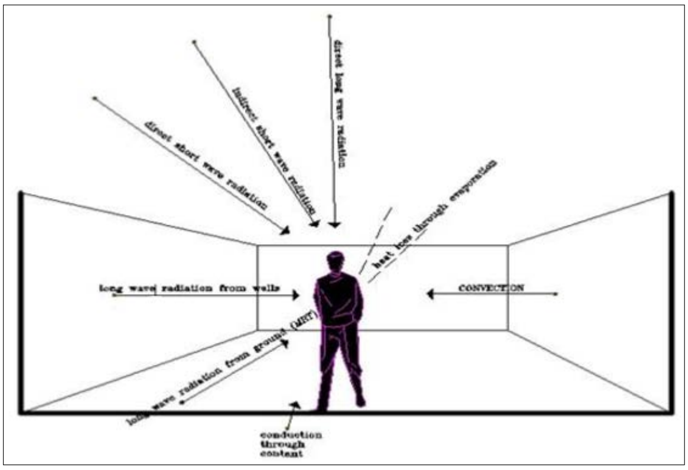


Figure 1: Energy Exchange Diagram of Human Body in Outdoor Environment

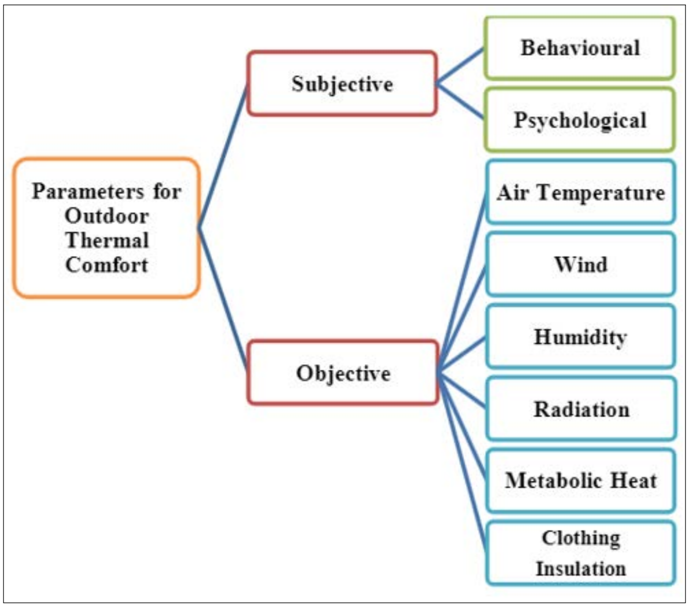


Figure 2: Outdoor Thermal Comfort Parameters

Activity	Metabolic rate (met)	Metabolic rate (W/m^2)
Reclining	0.8	46
Seated, relaxed	1.0	58
Standing, light activity	1.6	93
Standing, medium activity	2.0	116
Walking on level ground, 2 km/h	1.9	110
Walking on level ground, 3 km/h	2.4	140
Walking on level ground, 5 km/h	3.4	200

1 metabolic unit = 1 met = 58 W/m^2.

Table 1: Clo Value Chart for Males and Females (American Society of Heating, n.d.)

Clothing Types (Female)	**Clo** Values
Undergarments	0.05
Salwar + Kurta	0.55
T-Shirt (thin cloth)	0.25
T-Shirt (thick cloth)	0.29
Shorts	0.15
Saree	0.50
Blouse	0.20
Jeans	0.30
Slippers	0.02
Clothing Types (Male)	**Clo** Values
Shirt	0.22
T-Shirt	0.25
Jeans trousers	0.30
Non-jeans trousers (thin)	0.26
Non-jeans trousers (thick)	0.32
Undergarments	0.20
Slippers	0.02
Sports shoes	0.08
Shoes	0.04

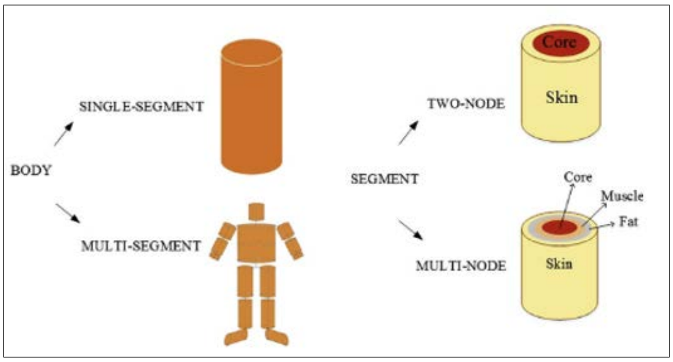


Figure 4: Comparison of 2-Node and Muti-Node Thermo-Physiological Model

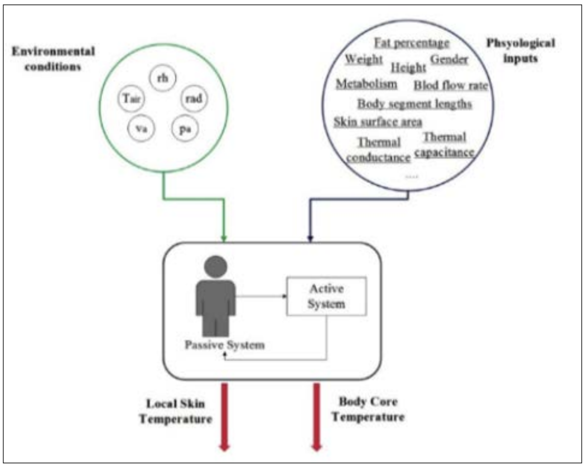


Figure 5: Typical 2-Node Thermophysiological Model

Table 2: Comparative Analysis of The Three Standard Thermal Comfort Indices [4]

INDICES / FACTORS	**PMV**	**PET**	**SET**
Introduced	Fanger in 1972	Mayer and Hoppe in 1987,1999	Pickup and DeDear in 1999
Parameters considered	Clothing and activity levels as variables	Clothing and activity levels as variables	Clothing and activity levels as variables
Range	Limitations in the range of upper and lower limits (Ta range of 10°C - 30°C) and not suitable for extreme tropical climates	RH = 50% assumed for reference indoor situations and varies with Ta in outdoor conditions	Vapour Pressure (VP) = 12hPa assumed for reference conditions both indoor and outdoor irrespective of Ta
Applicability	Thermo-regulations of a human body not taken into account due to which not very accurate for extreme typical outdoor conditions	Thermo-regulations of a human body are taken into account due to which more accurate for assessment of outdoor environments and better than PMV	Thermo-regulations of a human body are taken into account due to which more accurate for assessment of outdoor environments and better than PMV

The Köppen climate classification scheme divides climates into five main climate groups: A (tropical), B (arid), C (temperate), D (continental), and E (polar). The second letter indicates the seasonal precipitation type, while the third letter indicates the level of heat. Summers are defined as the 6-month period that is warmer either from April–September and/or October–March while winter is the 6-month period that is cooler.

Group A: Tropical Climates - This type of climate has an average temperature of 18°C (64.4 °F) or higher every month of the year, with significant precipitation. The sub-groups are:

Af = Tropical rainforest climate; average precipitation of at least 60 mm (2.4 in) in every month
Am = Tropical monsoon climate; driest month (which nearly always occurs at or soon after the "winter" solstice for that side of the equator) with precipitation less than 60 mm (2.4 in), but at least 100 - (Total Annual Precipitation (mm) / 25)

Aw or *As* = Tropical wet and dry or savanna climate; with the driest month having precipitation less than 60 mm (2.4 in) and less than (Total Annual Precipitation (mm) / 25)

The study site chosen for this particular research broadly falls within the Aw Koppen climate classification category. Specifically, considering the climatic profile of Indian sub-continent, it falls within the warm and humid climatic zone.

Table 3: Koppen Climate Classification

1st	2nd	3rd
A (Tropical)	f (Rainforest) m (Monsoon) w (Savanna, dry winter) s (Savanna, dry summer)	
B (Dry)	W (Arid Desert) S (Semi-Arid or steppe)	h (Hot) k (Cold)
C (Temperate)	w (Dry winter) f (No dry season) s (Dry summer)	a (Hot summer) b (Warm summer) c (Cold summer)
D (Continental)	w (Dry winter) f (No dry season) s (Dry summer)	a (Hot summer) b (Warm summer) c (Cold summer) d (Very cold winter)
E (Polar)		T (Tundra) F (Ice cap)

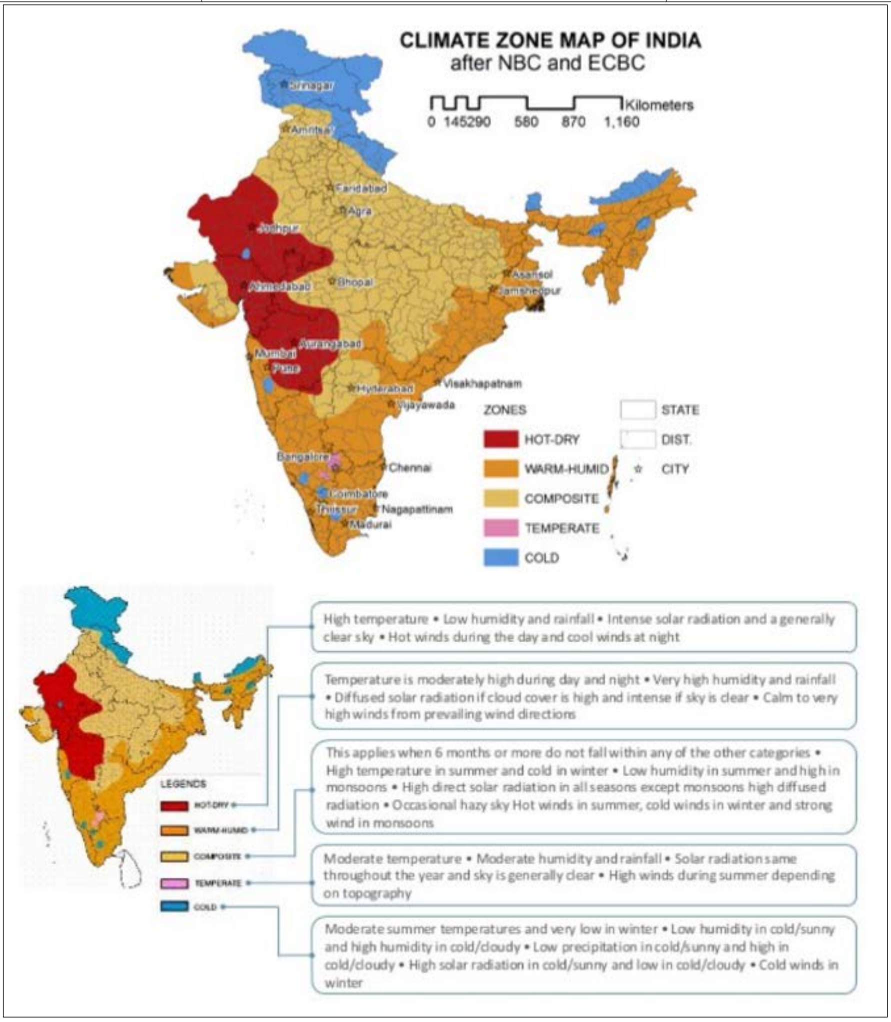
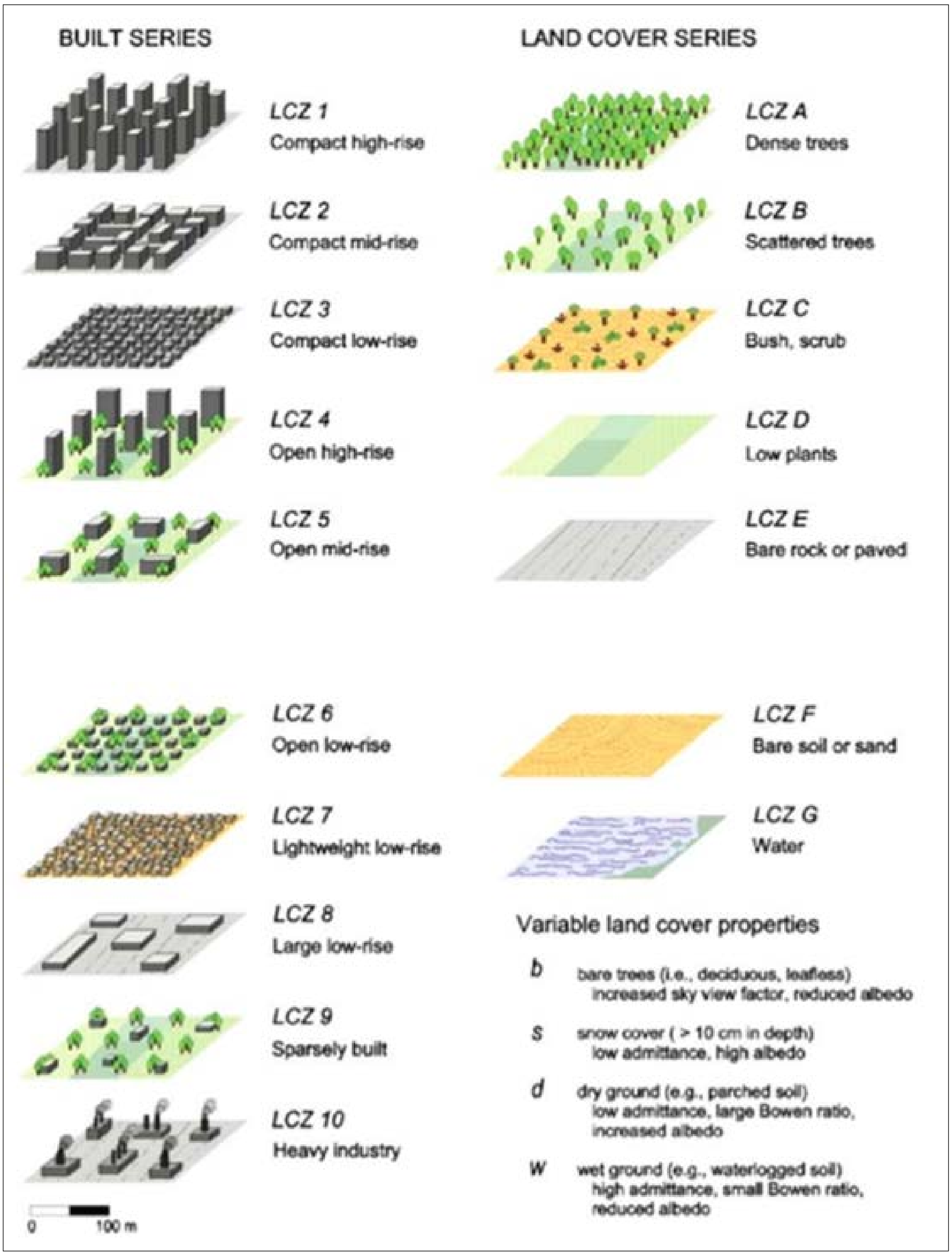


Figure 6: Climate Zone Maps of Indian sub-continent

The land classification system called 'Local Climate Zone' (LCZ) developed by Stewart and Oke (2012) deals with the physical properties like surface cover and surface structure of the city which introduces a logical approach in studying urban heat islands. Indian cities are characterized by the heterogeneous type of built forms. The primary task of mapping LCZ in such cities poses difficulty due to their complex urban form and data insufficiency [5].



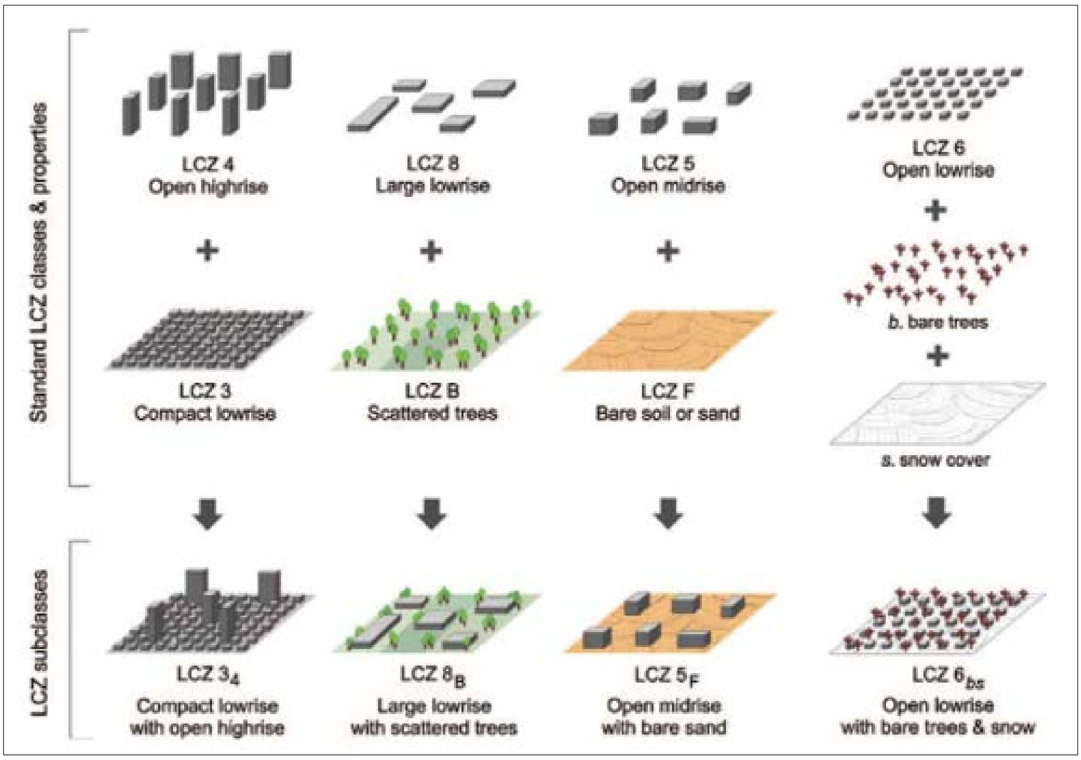


Figure 7: LCZ Classification and Subclasses Representing Combination of "Built" and "Natural Land Cover" Types

The urban microclimate refers to the exclusive climatic conditions of a given location considerably influenced by the highly heterogeneous nature of urban environments specially the physical structure of the urban form like height and shape of buildings, presence of vegetation, water bodies and orientation of streets. There are two broad zones – Urban Canopy Layer (UCL) and Urban Boundary Layer (UBL). Urban Boundary Layer corresponds with the 'meso' scale where 'Region' and 'City' act as the urban units. Built-up features are mostly present in the form of large urban areas and districts with extents spreading up to 100 kilometers. Urban Canopy Layer corresponds with the 'local' and 'micro' scales. In the 'local' scale, 'Neighborhoods', 'Local Climatic Zones (LCZs)' and 'Precincts' act as the urban units. BGI features are mostly in the form of greenbelts, forests, lakes, swamps and oceans. City centers, residential areas and suburban zones act as the built-up features with extents spanning up to 10 kilometers. On the other hand, in the 'block' level of the same, storage ponds, parks, woods and streams act as the BGI structures with city blocks and open spaces spanning up to 1000 meters acting as the built features. In the 'micro' scale, street canyon, building and facets act as the different levels with extents spanning at the most to 100 meters [5].

Study Site – Fundamental Local Climate Zones (LCZ) Mapping and Categorization

Some of the factors speculated while fixing this up for our initial stages are:

- The climatic zones of the world and Indian subcontinent
- The heat stress and thermal comfort level variations experienced
- The prominent climatological, socio-economic and cultural preferences
- The factor of footfall considering increased urban sprawl

The socio-economic and other geophysical points or features that have been considered here are:

- Varied density of population in the different segments or patches with varied income groups
- Obvious variations in micro-climate due to diverse grey physical structures (buildings, roadways, bridges and flyovers and similar others)
- Varied flow and frequency in terms of footfall at places
- Majority grey infrastructure done through wetland reclamation
- Degraded and poor stormwater management (SWM) and rainwater harvesting (RH) techniques
- Presence of large scale fallow lands that are no longer being irrigated or cultivated and ultimately converted for grey infrastructure development

Figure 8: Red Borders Denote the Boundaries within Which the Study Locations are Situated

Accordingly, using the fishnet tool of ArcGIS, all the stretches were separately demarcated into 100 m x 100 m grids for local climate zone (LCZ)-based micro-climate analysis. Thereafter, all these grids were separately analyzed and studied on a fundamental preliminary scale on the basis of primary and secondary photographic data. Its main objective was to designate and categorize each and every gridded 100 m x 100 m squares into separate local climate zones (LCZs) as per the classification and categorization system introduced by Stewart and Oke, 2012. The following were the major types of categories of LCZs designated by particular colour codes found among the study locations (stretches):

a. LCZ A (Dense Trees) - ■
b. LCZ B (Scattered Trees) - ■
c. LCZ F (Bare Soil or Sand) - ■
d. LCZ G (Water) - ■
e. LCZ 1 (Compact High-Rise) - ■
f. LCZ 2 (Compact Mid-Rise) - ■
g. LCZ 3 (Compact Low-Rise) - ■
h. LCZ 7 (Lightweight Low-Rise) - ■
i. LCZ 8 (Large Low-Rise) - ■

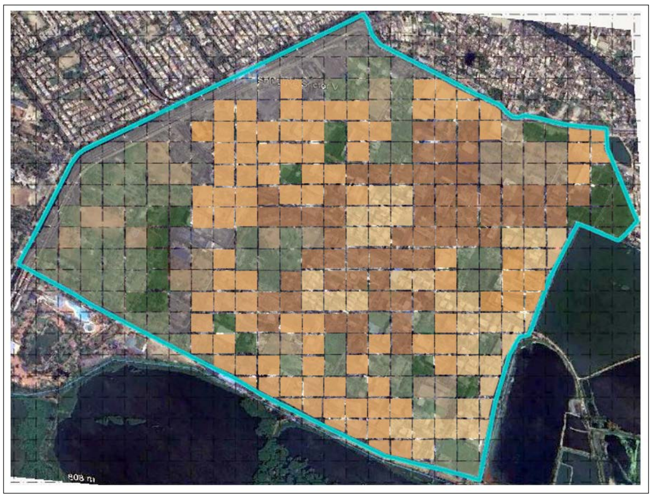


Figure 9: LCZ Demarcated Map of Stretch-1 (Salt Lake Sector-5 Area under the Jurisdiction of NDITA)

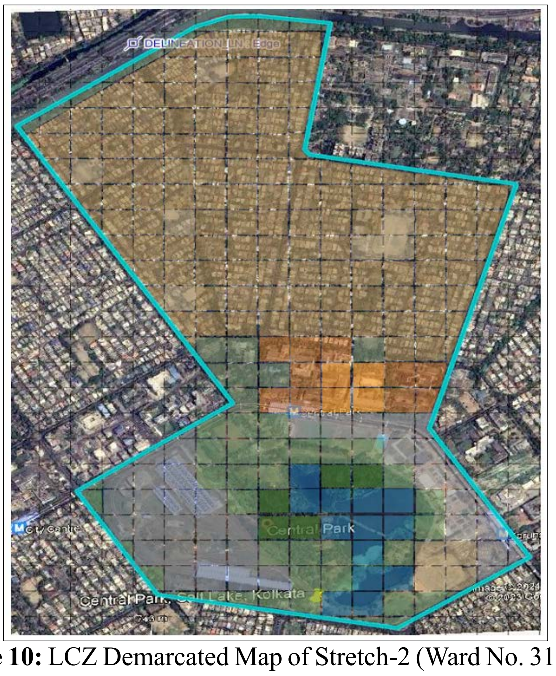


Figure 10: LCZ Demarcated Map of Stretch-2 (Ward No. 31 Area under the Jurisdiction of BMC)

Figure 11: LCZ Demarcated Map of Stretch-4 (Ward No. 39 Area under the Jurisdiction of BMC)

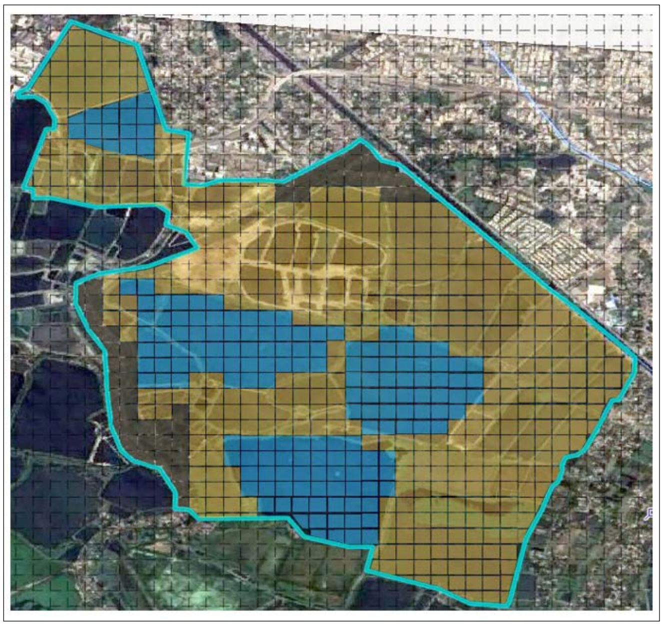


Figure 12: LCZ Demarcated Map of Stretch-3 (Ward No. 36 Area under the Jurisdiction of BMC)

Figure 13: LCZ demarcated map of Stretch-5 (Ward No. 41 Area under the jurisdiction of BMC) [5-9]

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Methodology
In this study, the pilot stage considering 200 initial responses from our study locations has been utilized for carrying out the required steps and understanding their scientific relevance in terms of the broader research perspective. Key need of this study with formulated aims and objectives are being discussed here as follows:

Need of the Study / Research
To achieve a systematic parametric framework that can have the potential of proper monitoring, assessment and implementation of adaptive and climate-responsive strategies. Comprehensive emphasis required on meteorological parameters and OTC indices. User-specific empirical data and site-specific spatial estimates to be given emphasis upon [6-9].

Aim
To assess and pre-model necessary scientific relationships among the required meteorological parameters and OTC indices and chosen spatial parameters or attributes.

Objectives
- To perform comprehensive literature studies for understanding climate modification by urban infrastructure, mensuration parameters and attributes related to urban infrastructure, urban grey blue green infrastructure (UGBGI), OTC, Koppen classification and LCZs
- To identify meteorological and spatial parameters and OTC indices for preliminary assessment of outdoor thermal stress, make fundamental LCZ mapping and area delineation of built environment components to evaluate their EAs and assume hmax for evaluating EMVs
- To statistically analyze by linear regression and establish relations in between air temperature (Ta) and EAs and EMVs and thereafter form the correlation between EAs and EMVs of grey and blue-green urban infrastructure components for tentative required measures in the following modelling stage

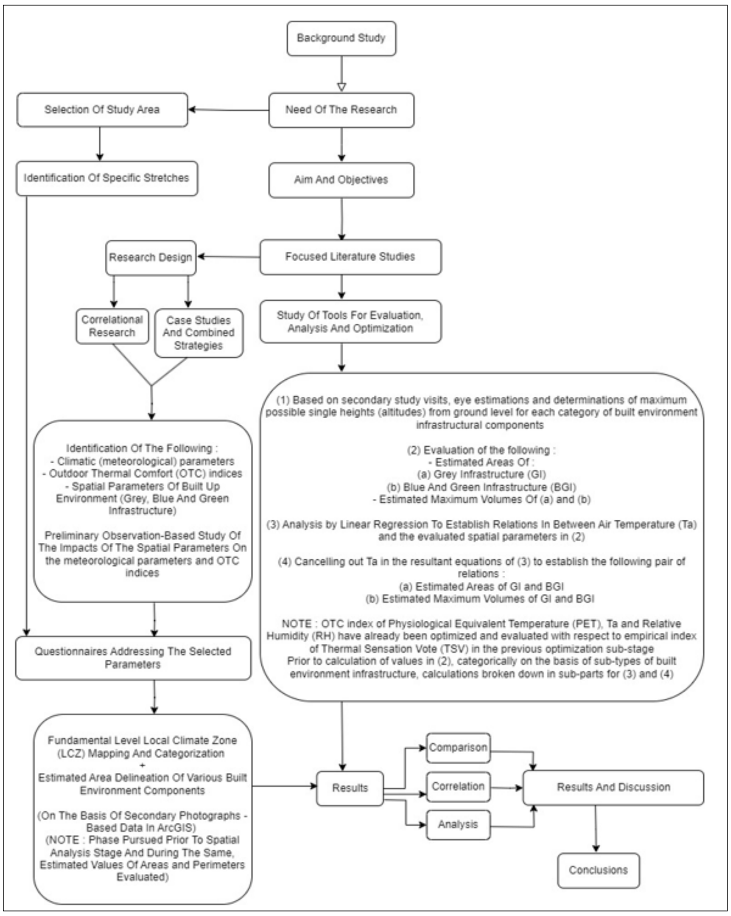


Figure 14: Methodology of Research for Current Sub-Stage of Optimization and Pre-Modelling

Instruments and Tools for Measurements and Evaluations
Infrared Thermometer (59 MAX+), **Thermo-anemometer** and **Thermo-hygrometer** (405i and 605i) were used to measure the surface temperature and air temperature, wind velocity, relative humidity respectively during the surveys at the different locations.

Figure 15: Infrared Thermometer, Thermo-Anemometer and Thermo-Hygrometer (405i and 605i)

Infrared thermometer works by switching mechanism in which the green switch is pressed by holding its optical infrared screen faced towards the surface whose temperature is required. It is given by the corresponding reading on the screen. Thermo-anemometer (405i) and thermo-hygrometer (605i) work by bluetooth mechanism for which the application of 'SmartProbes' is installed in the mobile phone and the orange coloured switches need to be put on. After that, when the application window is opened on the phone and the lamp starts glowing from red to green, the readings (air temperature, relative humidity, wind speed) immediately start showing on the window [4].

RayMan tool has been used to evaluate and generate the individual 200 corresponding values of Predicted Mean Vote (PMV), Physiological Equivalent Temperature (PET) and Standard Effective Temperature (SET) based on the following entered details:

- Weather Data – values of measured **air temperature** (Ta), **relative humidity** (RH), **wind speed** (WS) and **cloud cover okta value**
- Subjective Data – values of recorded **height** (in meters), **weight** (in kg), **age** (in years), **sex** (M/F), **clothing insulation value** (clo), **activity level value based on activity during survey** (in W/sq. Meters)

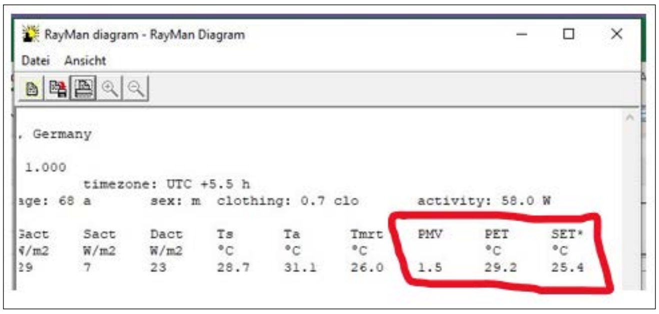


Figure 16: Appearance of the RayMan 1.2 Window Showing Generated Values of Thermal Indices After Running

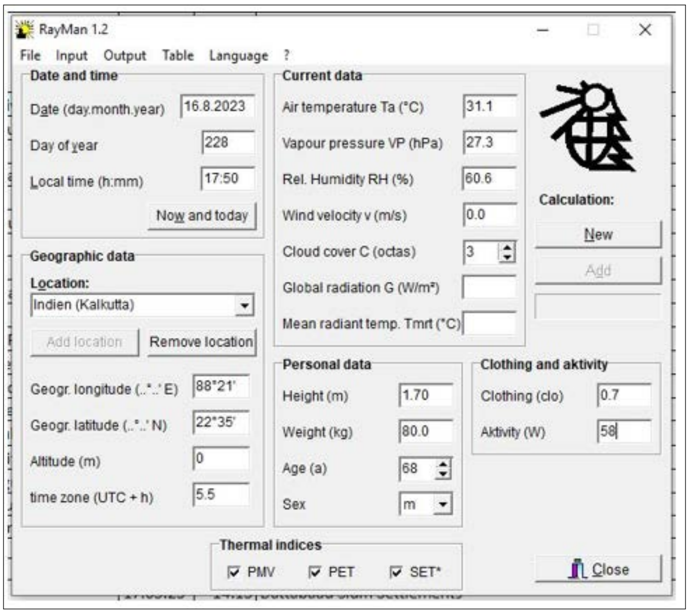


Figure 17: Appearance of the RayMan 1.2 Window Showing Places for Entering Respective Measured and Recorded Weather and Subjective / Personal Data Prior To Calculation of Otc Indices and Running

At the beginning, depending on our broader study location, the 'Location' was changed to Indien (Kalkutta). The latitudes and longitudes are set by the tool system itself in a default manner. The measured weather data are entered under the 'Current data' with vapour pressure value in hectaPascal (hPa) being auto-calculated by the system. The values of recorded personal or subjective data are entered along with the standardized values of 'Clothing and activity'. The New tab under Calculation is clicked finally after which the generated values of thermal indices show in a fresh run-time window.

The same process was repeated for 200 respondents and accordingly, the generated values along with the names of the respondents were compiled in a particular columnar sequence in MS Excel.

Pilot Stage Responses And Analysis						Climate				Personal						Comfort Index				
																Calculated Results			Survey Results	
Sl. No	Name	Date	Time	Location	Site (Index No.)	Air Temperature (deg. Celsius)	RH (%)	WS (m/s)	Cloud Cover (oktas)	Height (m)	Weight (kg)	Age (years)	Sex	Clothing (clo)	Activity (W)	PMV	PET (deg. Celsius)	SET (deg. Celsius)	TCV	TSV
1	Anil Manpuriya	13.05.23	14:30	Ward-31 Community Ground Area	2	31.1	60.6	0	3	1.7	80	68	M	0.73	58	6.5	51.4	43.6	3	2
2	Kamla Manpuriya	13.05.23	14:30	Ward-31 Community Ground Area	2	31.1	60.6	0	3	1.6	75	60	F	0.62	58	9.6	51.4	44.5	3	2
3	Rishika Rai	13.05.23	14:40	Ward-31 Community Ground Area	2	31.1	60.6	0	3	1.6	45	21	F	0.47	58	8.3	51.5	43.8	3	2
4	Ashwini Lama	13.05.23	14:40	Ward-31 Community Ground Area	2	31.1	60.6	0	3	1.6	40	21	F	0.47	58	8.0	51.5	43.4	4	2

Figure 18: A typical MS Excel Snippet Showing the Same

This approach was implemented in a systematic manner as follows using available formulae and XL Stat plug-in tool of MS Excel:
a. A separate page / worksheet in Excel created for the further works related to the statistical modelling that are going to define the fundamental steps of the optimization and pre-modelling
b. These steps if carried out in a very accurate and precise manner will pave convenient framework for us in the following further stages of statistical analysis:

- Understanding the ranges by generating bell-curves and the distributions by generating bar-graphs and pie-charts, establishing the relationships using linear regression of the mean values (calculated in a stretch-wise location-specific manner) and evaluating the optimized values of neutral and preferred values of PET by probit regression and resultant equivalent values of Ta

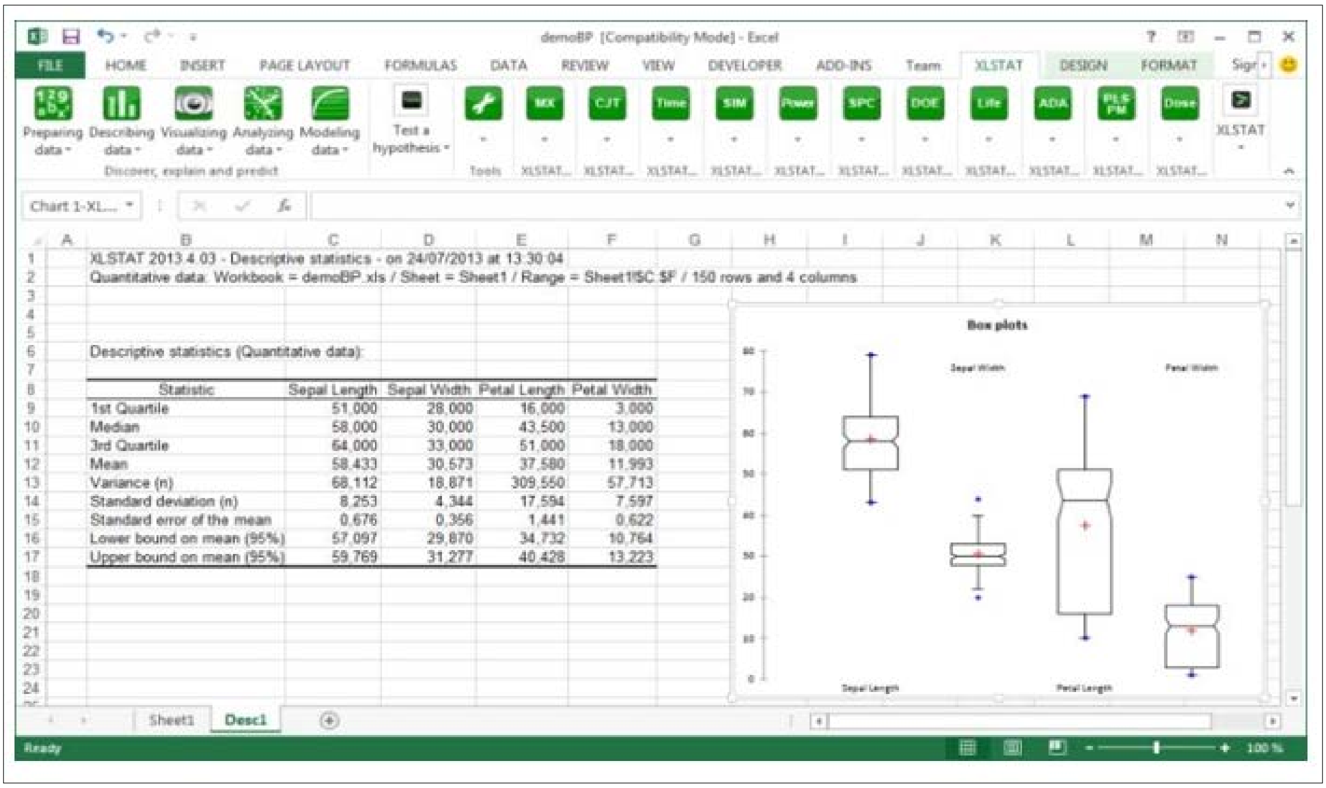


Figure 19: Sample MS Excel XL Stat Snippet

The ArcGIS tool was used extensively for the following tasks:

a. Initial georeferencing of the locations (5 different stretches) with different layers maintained for different urban infrastructure components and their various sub-categories (natural vegetation – bushes and shrubs, less and more dense deciduous trees; water bodies; grey infrastructure – roadways and pavements, railway tracks, flyovers, built up structures of different heights)
b. Using fishnets, dividing each of the stretches into 100 x 100 meters grids to prepare them for local climate zones (LCZs) mapping and categorization as per the standards set by Stewart and Oke
c. Assigning color codes to each category and generating the resultant LCZ map using Photoshop software applied on the gridded base map taken from ArcGIS
d. Using the following self-assigned layers applied along with particular color codes to prepare the base map for estimated area rastering and delineation using polygon raster tool in ArcGIS:

-WATER_BODIES- RAIL_TRACKS- ROADWAYS - NV_1 (for groundcover, bushes and shrubs)- NV_2 (for less dense deciduous trees) - NV_3 (for denser deciduous trees)

BLDGS_1 (for compact informal settlements)- BLDGS_1A (for large extent informal settlements)- BLDGS_2 (for low rise settlements) -BLDGS_3 (for mid-rise settlements) -BLDGS_4 (for high-rise settlements) - FLYOVER - OTH_CIRCULATION (for other miscellaneous circulation spaces eg: bottlenecks)

e. From the attributes table feature, copying the system calculated estimated areas and perimeters and separately maintaining them in an Excel worksheet
f. Using the 'Generate Near Table' feature to preliminarily analyze the various features and their inter-connectedness with each other
g. Using the following statistical features in ArcGIS for particular analytical purposes:
    - QQ Plots (comparisons of the various features' estimated areas and perimeters with perimeters on X-axis and areas on Y-axis)
    - Scatter Plots (same as QQ Plots with area and perimeter values correlated by linear regression-based equations and R-square values generated) and Box Plots (with both estimated areas and perimeters as numeric fields on the basis of generated z-scores in A-Z x-axis ascending mode)
    - Histograms (with both estimated areas and perimeters as variables, mean, median and mode values along with normal distribution turned on)

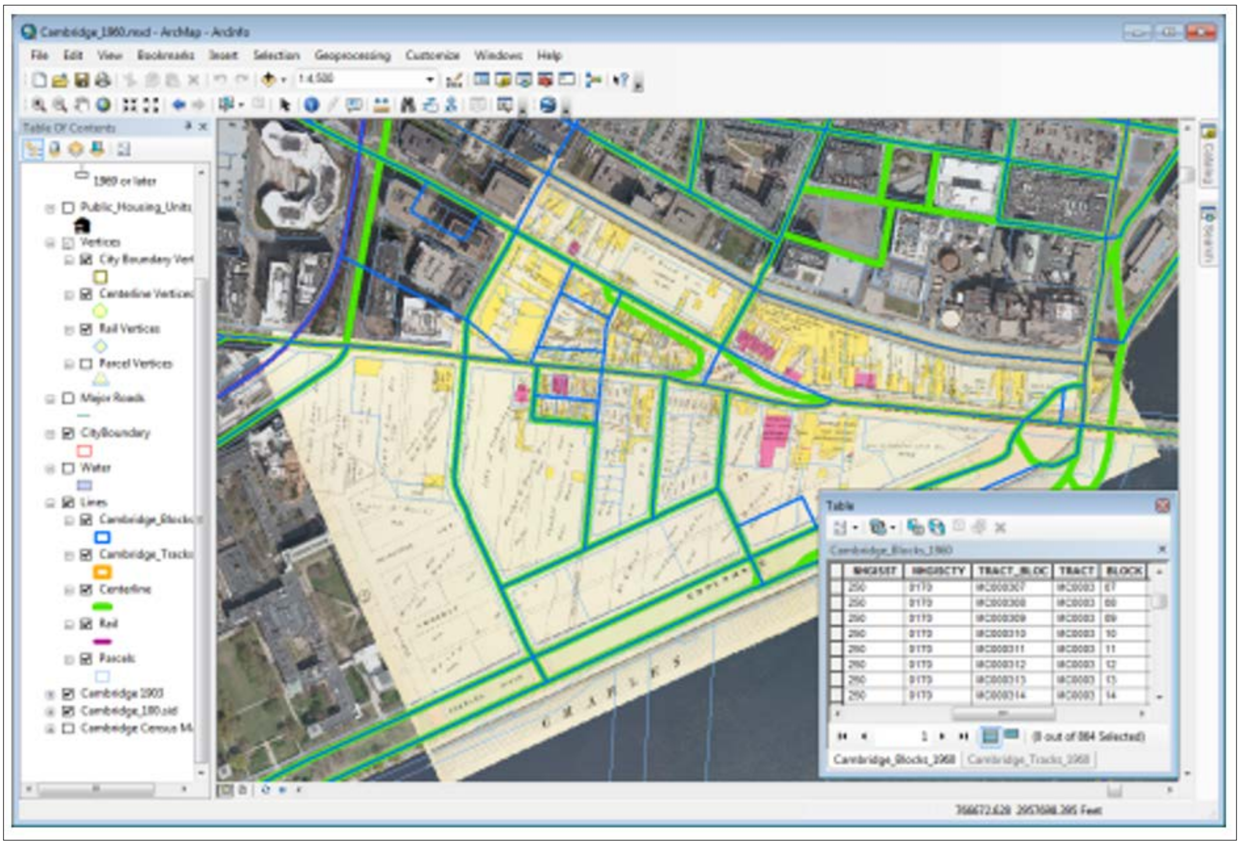


Figure 20: Sample ArcGIS Snippet [10-19]

Fundamental Statistical Sampling with Questionnaire on OTC
Accordingly, a questionnaire has been framed up with the following questions broadly sorted into **4** major segments and statistical calculations helping us in deciding the relevant and valid number of respondents required for our baseline data collection. **Personal Details** - (1) Name, (2) Gender, (3) Date, (4) Time, (5) Original Residence, (6) Measuring Site, (7) Job/Occupation, (8) Age, (9) Weight, (10) State of Activity, (11) Clo Thermal Resistance Value, (12) Sky Condition, (13) Duration in Outdoor on Working Days and Holidays, (14) Income / Expenditure (approx. assumptive values based on (7))

Thermal Stress Survey - (1) Current Level Of Thermal Comfort Rating (TCV) (**Likert 5-point scale**), (2) Current Thermal Sensation Rating (TSV) (**Bedford 7-point scale**), (3) Evaluation Of Environmental Parameters (Temperature, Wind Speed, Humidity and Sunlight – **same scale as** (2)),(4) Measured Parameters (Surface Temperature, Air Temperature, Relative Humidity, Wind Speed – at the time of conducting the surveys)

User Data - (1) Frequency of visiting parks and similar other open spaces, (2) Preferences of space types for relaxation / recreation, (3) Leisure time outdoor activities, (4) Preferences of space types for outdoor activities

Public Awareness – Blue Green Infrastructure - (1) Time (since how many years) of residing and commuting at current place, (2) Perception of change (increase / decrease) of blue and green spaces in the surroundings from before (on a scale of 5),(3) Opinion – whether re-establishment of blue and green spaces can help in mitigating the concerned issues,(4)Presence of blue and green spaces on familiar routes (brief narration),(5)Probable reasons behind the change in surrounding blue and green space (brief narration),(6)Preference of proximity from current location in terms of the referred re-establishment

The statistical calculations related to the representative sample size were done as follows:

No. of Residents (app.) in **Salt Lake Sector V = 100000** (taken for calculation)

Source: https://ndita.org/

No. Of Residents (app.) in **BMC** including Wards No. 31, 36, 39 and 41 = **61500**
Source: http://www.bmcwbgov.in/index.php/about-us/bmc-profile

Total size (N) in our areas of study = 100000 + 13500 + 19000 + 14000 + 15000 = **161500**

As N > 1000, applying **scenario-2 of Slovin's formula:**

Sample Size (n) = {z*z*d*(1-d)}/(e*e) [z ---> z-score, d ---> standard deviation, e ---> margin of error]

Assuming a confidence level of 90% in our case, corresponding z-score = 1.65

By trial and error, taking a **margin of error** e = 3.35% = 0.0335

Like any other typical similar case, considering **standard deviation** d = 50% = 0.5

n = (1.65 * 1.65 * 0.5 * 0.5) / (0.0335 * 0.0335) = 610 = **600** (Take for our study)

Therefore, n = **600**

No. of surveys considered for pilot survey = 1/3rd of n = **200**

The results obtained in this pilot survey stage were analyzed and cross-examined first to judge the scientific relevance and reliability of the questionnaire tool before the main survey stage commences.

As per proportion of population in different stretches, number of respondents varied from each. The pilot survey stage has been completed and the main stages of survey for baseline data collection is expected to be completed within the months of April -July this year (2024).

Evaluation of OTC Indices and Spatial Parameters
For the entire stage, the OTC index of Physiological Equivalent Temperature (PET) was chosen considering its applicability in outdoor environments and better usability in comparison to Predicted Mean Vote (PMV) and Outdoor Standard Effective Temperature (OUTSET). Its neutral and optimized preferred values were determined by probit analysis. The evaluated values of the meteorological parameters, chosen OTC indices and empirical indices (TCV votes and TSV votes) are as follows:

a. Ta: Mean =**37.5°C**, Standard Deviation = **4.2°C**, Lowest = (37.5 - 3*4.2) °C = **24.9°C**, Highest = (37.5 + 3*4.2) °C = **50.1°C**
b. RH: Mean =**58%**, Standard Deviation = **8%**, Lowest = (58 - 3*8)% = **34%**, Highest = (58 + 3*8)% = **82%**
c. PET: Mean =**55.8°C**, Standard Deviation = **4.4°C**, Lowest = (55.8 - 3*4.4) °C = **42.6°C**, Highest = (55.8 + 3*4.4) °C = **69°C**
d. TSV: Mean =**2.7**, Standard Deviation = **0.5**, Lowest = 2.7 - 3*0.5 = **1.2**, Highest = 2.7 + 3*0.5 = **4.2**

The mean values considered for establishing the required relationships are being shown in the form of the following tabular data:

Table 4: Mean Values of Grouped Data Considered for Linear Regression

Mean Values / Group or Stretch No.	Ta (in °C)	PET (in °C)	TSV
1	32.9	53.1	2.2
2	34.4	52.0	2.1
3	33.6	51.0	2.7
4	33.4	51.9	2.8
5	33.3	51.9	2.8
6	32.4	49.2	2.7
7	34.4	53.2	2.5
8	41.1	60.2	3.0
9	40.3	57.8	2.4
10	44.4	63.4	3.0
11	40.9	58.9	3.0
12	40.2	59.2	3.0
13	36.9	55.1	3.0
14	38.9	55.5	3.0
15	37.4	56.0	3.0

The linear regression graphs and corresponding required established relationships or equations have been shown as follows:

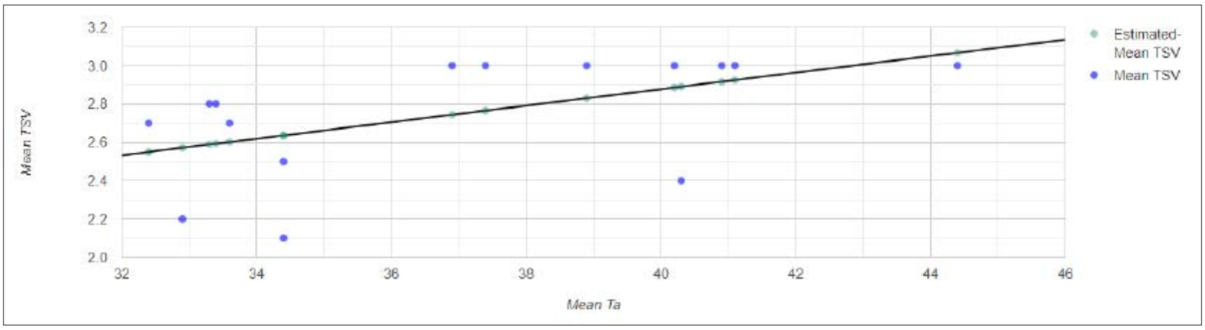


Figure 21(a): Linear Regression Graph for Mean Value Pairs of Ta and TSV

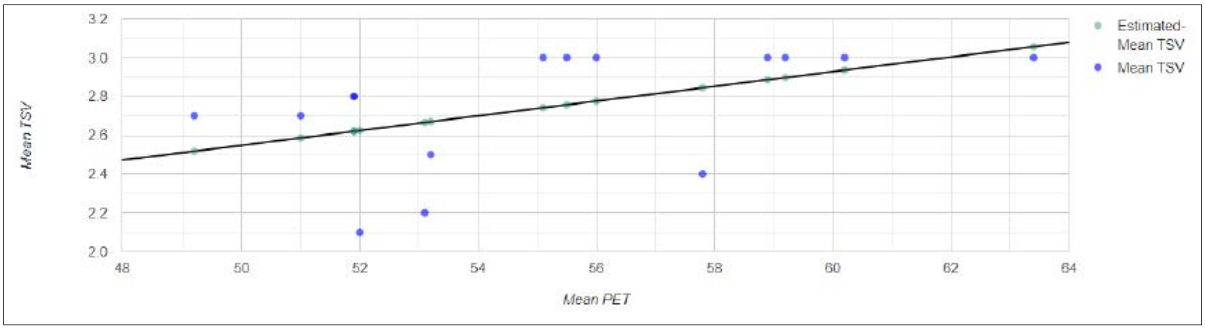


Figure 21(b): Linear Regression Graph for Mean Value Pairs of PET and TSV

Equation (a):
$TSV = 1.1545 + 0.04307\ Ta$ (1)
$R^2 = .28$, $F(1,13) = 4.94$, $p = .045$.
$\beta = .043$, $p = .045$, $\alpha = 1.15$, $p = .133$.

Equation (b):
$TSV = 0.6508 + 0.03795\ PET$ (2)
$R^2 = .24$, $F(1,13) = 4.04$, $p = .066$.
$\beta = .038$, $p = .066$, $\alpha = 0.65$, $p = .544$.

The low R-square scores obtained while generating the above equations can be overlooked because they are not going to affect the current pre-modelling and optimization stages due to:

a. The empirical index TSV is psycho-sociological in nature and is not going to get affected strongly due to the variations in Ta and PET
b. This pre-modelling and optimization are being done mainly for assessment purposes and not future predictions of outcomes with minor variations being easily overlooked
c. The following scales and assumptions were considered:
d. On x-axis, the independent variable PET was taken as 1 cm = 2.5°C with values starting from 30°C and calculated starting lowest value of PET during generation of standard deviation values and bell-curves was 42.6°C with the mean value being 55.8°C
e. On y-axis, the dependent variable TSV was taken as 1 cm = 0.15 with values starting from 1.2 and calculated starting lowest value of TSV during generation of standard deviation values and bell-curves was 1.2 with the mean value being 2.7
f. Blue dots denote places having respondents with average TSV responses ranging above 0.15
g. Grey dots denote places having respondents with average TSV responses ranging below 0.15

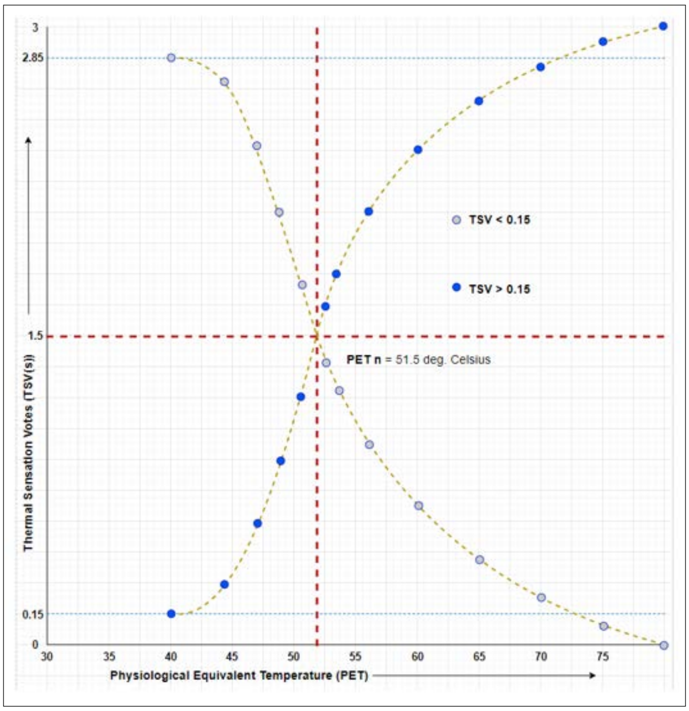


Figure 22(a): 2-Probit Regression for Determining PET n Value

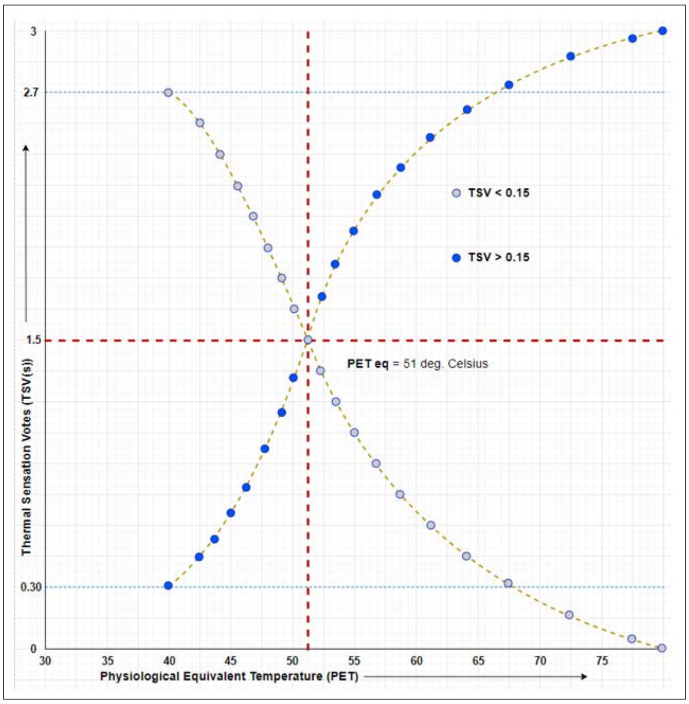


Figure 22(b): Probit Regression for Determining PET eq Value

The optimized calculated values are as follows:

a. Neutral Physiological Equivalent Temperature (PET n) = **<u>51.5°C</u>**
b. Preferred Equivalent or Acceptable Physiological Equivalent temperature (PET eq) = **<u>51°C</u>**
c. Using the Equation (g) established in the previous part, putting the following values:

TSV = 0.6508 + 0.03795 PET = 0.6508 + (0.03795 x 51.5) = **2.605225 = 2.6 (app.)**

Now putting the equivalent value of PET in the same equation:

TSV = 0.6508 + 0.03795 PET = 0.6508 + (0.03795 x 51) = 2.58625

Putting the above equivalent value of TSV in Equation (e) established in the previous part:

TSV = 1.1545 + 0.04307 Ta=> 2.58625 = 1.1545 + 0.04307 Ta=> Ta = 33.2423960994

Preferred Equivalent or Acceptable Air Temperature (Ta eq) = **<u>33.2°C</u>**

For the following shown data, the values are depicted by the following numerals or symbolizations along with other scientific considerations: (i ranges from 1 to 15 for the 15 stretches studied and assessed and maximum heights have been fixed on the basis of lump some optically adjusted measurements and primary cum secondary photographic data taken during the measurements and evaluation)

EAb1i depicts estimated areas of compact small low-rise buildings for which the maximum height (**h**b1max) has been taken as 5 meters for evaluation of estimated maximum volumes depicted by **EMV**b1i

EAb2i depicts estimated areas of large low-rise buildings for which the maximum height (hb2max) has been taken as 10 meters for evaluation of corresponding estimated maximum volumes depicted by **EMV**b2i

EAb3i depicts estimated areas of compact low-rise buildings for which the maximum height (**h**b3max) has been taken as 15 meters for evaluation of estimated maximum volumes depicted by **EMV**b3i

EAb4i depicts estimated areas of compact mid-rise buildings for which the maximum height (**h**b4max) has been taken as 30 meters for evaluation of estimated maximum volumes depicted by **EMV**b4i

EAb5i depicts estimated areas of compact high-rise buildings for which the maximum height (**h**b5max) has been taken as 100 meters for evaluation of estimated maximum volumes depicted by **EMV**b5i

EArpi depicts estimated areas of roads and pavements for which the maximum width (**w**rpmax) has been taken as 0.3 meters for evaluation of estimated maximum volumes depicted by **EMV**rpi

EArti depicts estimated areas of railway tracks for which the maximum elevated height (**h**rtmax) has been taken as 25 meters for evaluation of estimated maximum volumes depicted by **EMV**rti

EAfoi depicts estimated areas of flyovers for which the maximum elevated height (hfomax) has been taken as 20 meters for evaluation of estimated maximum volumes depicted by **EMV**foi

EAoci depicts estimated areas of other circulation types (eg: bottlenecks) for which the maximum width (**w**ocmax) has been taken as 0.9 meters for evaluation of estimated maximum volumes depicted by **EMV**oci

EAnv1i depicts estimated areas of type-1 natural vegetation (bushes, shrubs and groundcovers) for which the maximum height (**h**nv1max) has been taken as 1.5 meters for evaluation of estimated maximum volumes depicted by **EMV**nv1i

EAnv2i depicts estimated areas of type-2 natural vegetation (light deciduous cover) for which the maximum height (**h**nv2max) has been taken as 20 meters for evaluation of estimated maximum volumes depicted by **EMV**nv2i

EAnv3i depicts estimated areas of type-3 natural vegetation (dense deciduous cover) for which the maximum height (**h**nv3max) has been taken as 40 meters for evaluation of estimated maximum volumes depicted by **EMV**nv3i

EAwbi depicts estimated areas of water bodies for which the maximum depth (**d**wbmax) has been taken as 2 meters for evaluation of estimated maximum volumes depicted by **EMV**wbi

(https://www.vembanad.org/post/a-study-of-east-kolkata-wetlands)

The mean values considered for establishing the required relationships are being shown in the form of the following tabular data: (Note: All estimated values rounded off to nearest whole number integer)

Table 5: Mean values of grouped data
(Estimated Areas of Buildings of Varying Height Categories)
considered for linear regression

Mean Values / Sl No.	Tai (in °C)	EAb1i (in sq.m)	EAb2i (in sq.m)	EAb3i (in sq.m)	EAb4i (in sq.m)	EAb5i (in sq.m)
1	32.9	43658	5378	120567	21468	37589
2	34.4	43010	5445	120813	21534	37384
3	33.6	43786	5624	120954	21948	37437
4	33.4	43125	5535	120850	21396	37469
5	33.3	43028	5526	121123	21876	37142
6	32.4	43597	5438	121532	20976	36993
7	34.4	43040	5475	120438	20989	37658
8	41.1	42765	5488	120389	21436	37547
9	40.3	43838	5645	120279	21385	37756
10	44.4	42385	5469	120634	21547	37979
11	40.9	42265	5515	120856	21482	37571
12	40.2	41380	5785	120672	21367	37765
13	36.9	42378	5645	121138	21845	37587
14	38.9	43745	5575	120698	21974	37946
15	37.4	43830	5560	121802	21566	37443

Table 6: Mean values of grouped data
(Estimated Areas of Roadways and Pavements,
Rail Tracks, Flyovers and Other Circulation Spaces)
considered for linear regression

Mean Values /Sl No.	Tai (in °C)	EArpi (in sq.m)	EArti (in sq.m)	EAfoi (in sq.m)	EAoci (in sq.m)
1	32.9	21587	3648	918	11688
2	34.4	21789	3469	907	11785
3	33.6	21387	3546	948	11649
4	33.4	21098	3647	937	11748
5	33.3	22674	3329	934	11695
6	32.4	21784	3561	915	11723
7	34.4	22458	3642	932	11763
8	41.1	21872	3546	914	11287
9	40.3	21885	3543	912	12038
10	44.4	21175	3549	943	11475
11	40.9	21496	3784	906	11287
12	40.2	21870	3477	941	12084
13	36.9	22341	3694	909	12116
14	38.9	22474	3548	906	12238
15	37.4	22154	3444	954	12198

Table 7: Mean values of grouped data
(Estimated Areas of Natural Vegetation and Water Bodies)
considered for linear regression

Mean Values /Sl No.	Tai (in °C)	EAnv1i (in sq.m)	EAnv2i (in sq.m)	EAnv3i (in sq.m)	EAwbi (in sq.m)
1	32.9	402435	123516	38187	116876
2	34.4	401578	124125	38586	117009
3	33.6	402469	123597	38064	117019
4	33.4	402128	124166	38088	117035
5	33.3	401564	123477	38095	116785
6	32.4	401892	123695	37679	116894
7	34.4	402259	123586	35694	116888
8	41.1	401587	123182	37844	116976
9	40.3	401588	123116	38067	116892
10	44.4	402316	123169	38048	117081
11	40.9	401876	124167	37644	117052
12	40.2	401755	123891	38452	117231
13	36.9	401566	123886	37479	117009
14	38.9	402364	123782	38960	117265
15	37.4	402491	123818	37602	117176

Table 8: Mean values of grouped data
(Estimated Maximum Volumes of Buildings of Varying Height Categories)
considered for linear regression

Mean Values / Sl No.	Tai (in °C)	EMVb1i (in cu.m)	EMVb2i (in cu.m)	EMVb3i (in cu.m)	EMVb4i (in cu.m)	EMVb5i (in cu.m)
1	32.9	402435	123516	38187	116876	3758900
2	34.4	401578	124125	38586	117009	3738400
3	33.6	402469	123597	38064	117019	3743700
4	33.4	402128	124166	38088	117035	3746900
5	33.3	401564	123477	38095	116785	3714200
6	32.4	401892	123695	37679	116894	3699300
7	34.4	402259	123586	35694	116888	3765800
8	41.1	401587	123182	37844	116976	3754700
9	40.3	401588	123116	38067	116892	3775600
10	44.4	402316	123169	38048	117081	3797900
11	40.9	401876	124167	37644	117052	3757100
12	40.2	401755	123891	38452	117231	3776500
13	36.9	401566	123886	37479	117009	3758700
14	38.9	402364	123782	38960	117265	3794600
15	37.4	402491	123818	37602	117176	3744300

Table 9: Mean values of grouped data
(Estimated Maximum Volumes of Roadways and Pavements,
Rail Tracks, Flyovers and Other Circulation Spaces)
considered for linear regression

Mean Values /Sl No.	Tai (in °C)	EMVrpi (in cu.m)	EMVrti (in cu.m)	EMVfoi (in cu.m)	EMVoci (in cu.m)
1	32.9	6476	91200	18360	10519
2	34.4	6537	86725	18140	10607
3	33.6	6416	88650	18960	10484
4	33.4	6329	91175	18740	10573
5	33.3	6802	83225	18680	10526
6	32.4	6535	89025	18300	10551
7	34.4	6737	91050	18640	10587
8	41.1	6562	88650	18280	10158
9	40.3	6566	88575	18240	10834
10	44.4	6353	88725	18860	10328
11	40.9	6449	94600	18120	10158
12	40.2	6561	86925	18820	10876
13	36.9	6702	92350	18180	10904
14	38.9	6742	88700	18120	11014
15	37.4	6646	86100	19080	10978

Table 10: Mean values of grouped data
(Estimated Maximum Volumes of Natural Vegetation and Water Bodies)
considered for linear regression

Mean Values /Sl No.	Tai (in °C)	EMVnv1i (in cu.m)	EMVnv2i (in cu.m)	EMVnv3i (in cu.m)	EMVwbi (in cu.m)
1	32.9	602895	2470320	1515775	233752
2	34.4	603086	2482500	1515969	234018
3	33.6	602795	2471940	1515868	234038
4	33.4	602990	2483320	1516082	234070
5	33.3	603362	2469540	1516016	233570
6	32.4	602974	2473900	1516066	233788
7	34.4	602992	2471720	1515988	233776
8	41.1	602968	2463640	1515992	233952
9	40.3	602995	2462320	1516042	233784
10	44.4	602976	2463380	1516057	234162
11	40.9	602882	2483340	1516021	234104
12	40.2	602990	2477820	1515780	234462
13	36.9	602861	2477720	1515894	234018
14	38.9	602668	2475640	1515982	234530
15	37.4	603368	2476360	1516042	234352

Statistical Analysis of Spatial Parameters
In this section, all the evaluated estimated spatial parameters and attributes (areas and lengths) have been statistically analyzed by means of the following tools in ArcGIS on a stretch wise basis in five different sub-parts depicting five respective study locations or stretches:

QQ Plots
This tool helped in comparing the distributions of estimated areas and lengths (perimeters) of the different infrastructural components on the basis of the features of the polygons delineating them. The areas have been plotted on the y-axes and lengths or perimeters on the x-axes thereby showing the stretch wise variation of the former with the latter.

Scatter Plots
This tool helped in understanding the numerical correlation of the estimated areas and lengths (perimeters) of the various infrastructural components on a stretch wise basis. The equations relating the two were generated for each stretch with R-square correlation coefficient values depicting their relational extent determined for each.

Box Plots
This tool helped in understanding the sorted ordered comparison of these two spatial attributes (estimated areas and lengths) of the different infrastructural components by considering them as the two numeric fields. Then, their sorted order was evaluated on the basis of the generated z-score standardized values in the A – Z x-axis ascending order.

Histograms
This tool helped in understanding the normal distributions of the two spatial attributes (estimated areas and lengths) of the various infrastructural components in a stretch wise manner. Meanwhile, when these values were being generated, the mean, median and standard deviation options were turned on to generate the corresponding values.

Generate Near Table
This tool helped in understanding the proximity of the different infrastructural components with each other in the form of a table evaluated on the basis of near and input features in planar method. The layers depicting the built-up structures were considered as input features individually. The layers depicting the water bodies and natural vegetation were considered as near features on a grouped basis. The location, angle and find only closest feature options were kept turned on [6-8,14,20-23].

The analysis for the stretch-1 comprising the Salt Lake Sector-5 area under the jurisdiction of Nabadiganta Industrial Township Authority (NDITA) in Kolkata is being done as follows:

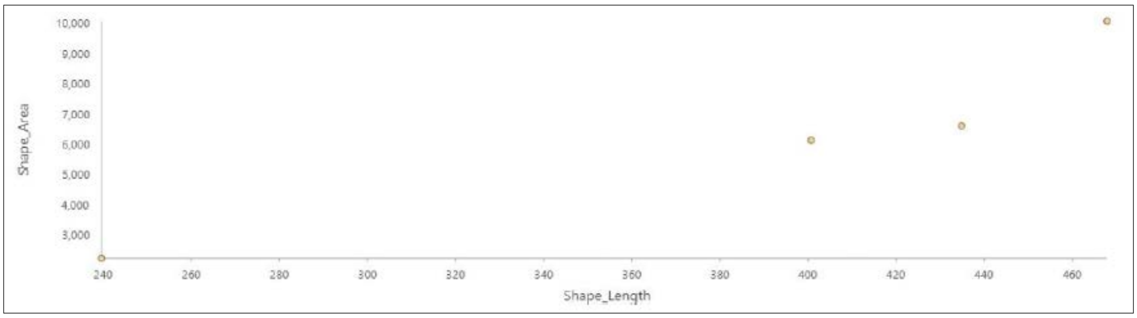


Figure 23(a): QQ plot representing BLDGS_1A (large extent informal settlements)

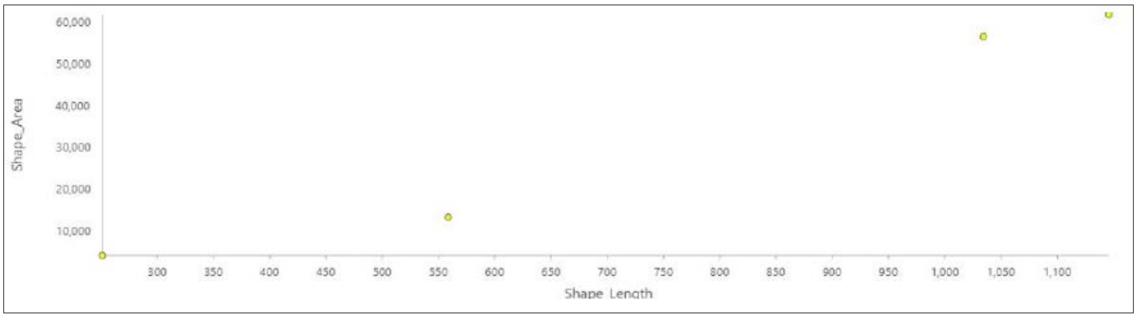


Figure 23(b): QQ plot representing BLDGS_2 (low rise settlements)

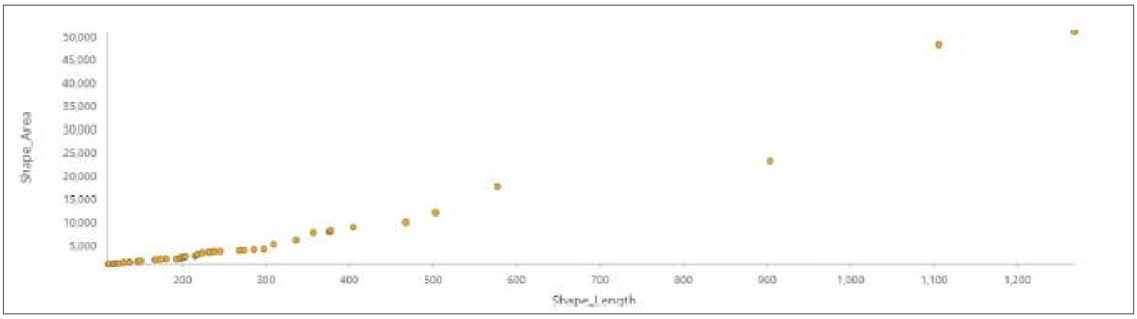


Figure 23(c): QQ plot representing BLDGS_3 (mid-rise settlements)

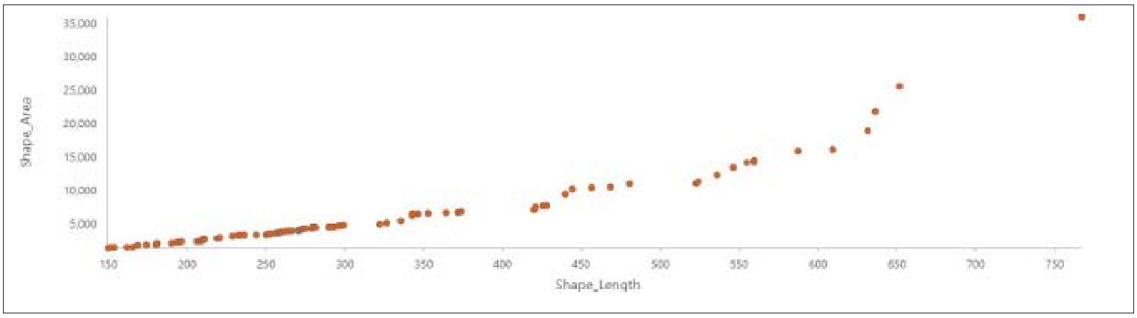


Figure 23(d): QQ plot representing BLDGS_4 (high-rise settlements)

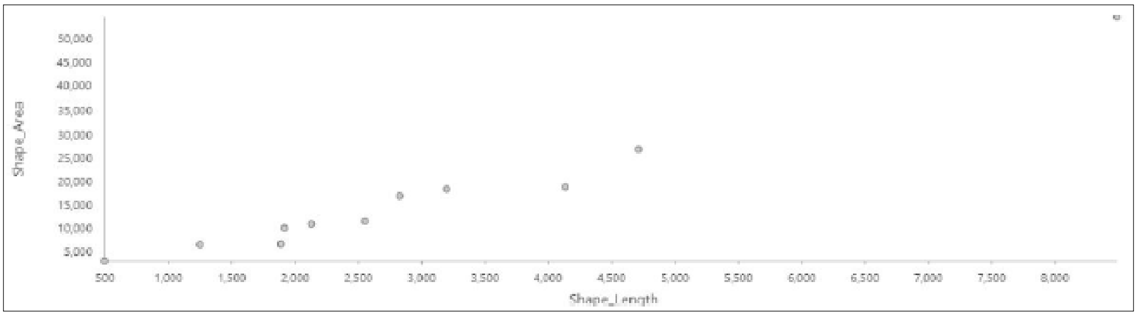


Figure 23(e): QQ plot representing ROADWAYS (vehicular roads and pedestrian pavements)

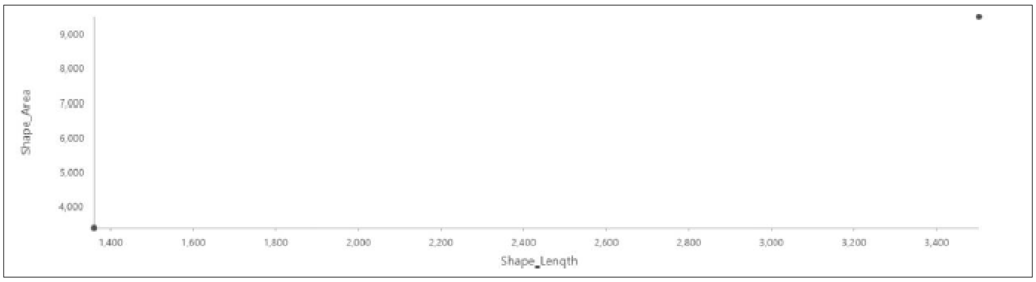


Figure 23(f): QQ plot representing RAILTRACKS (railway tracks)

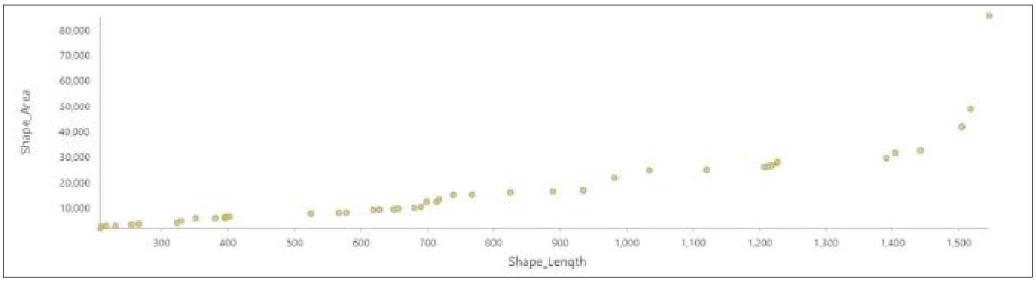


Figure 23(g): QQ plot representing NV_1 (groundcover, bushes and shrubs)

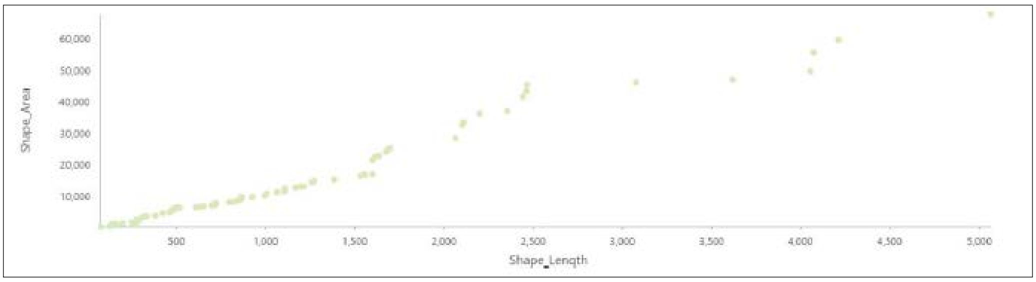


Figure 23(h): QQ plot representing NV_2 (less dense deciduous trees)

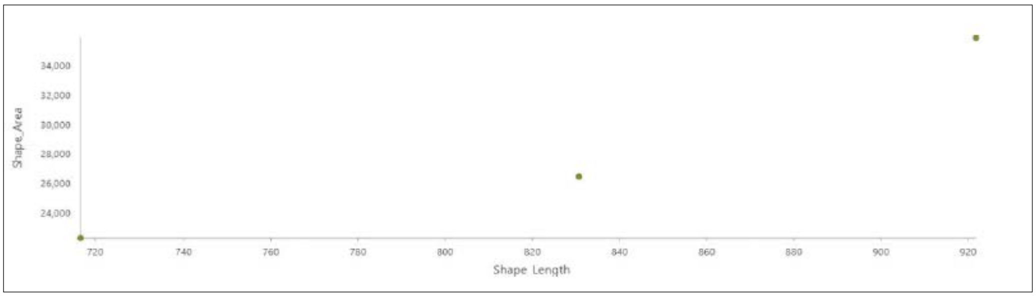


Figure 23(i): QQ plot representing NV_3 (dense deciduous trees)

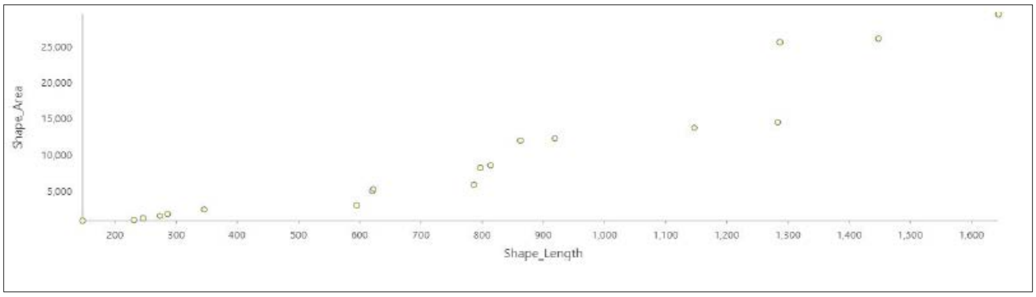
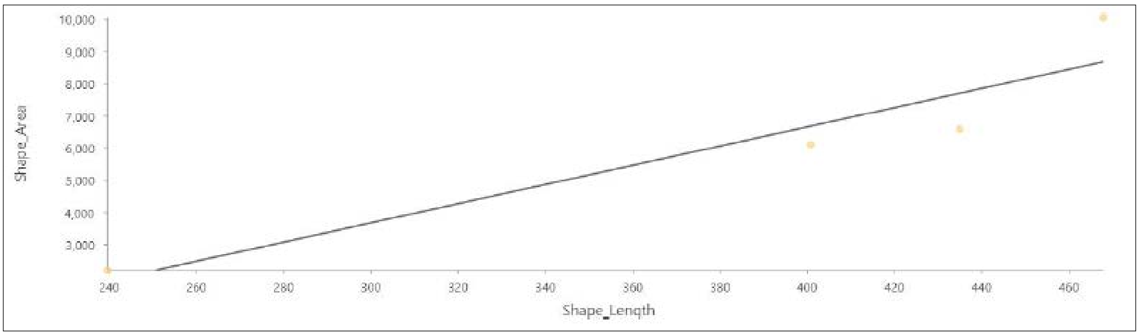
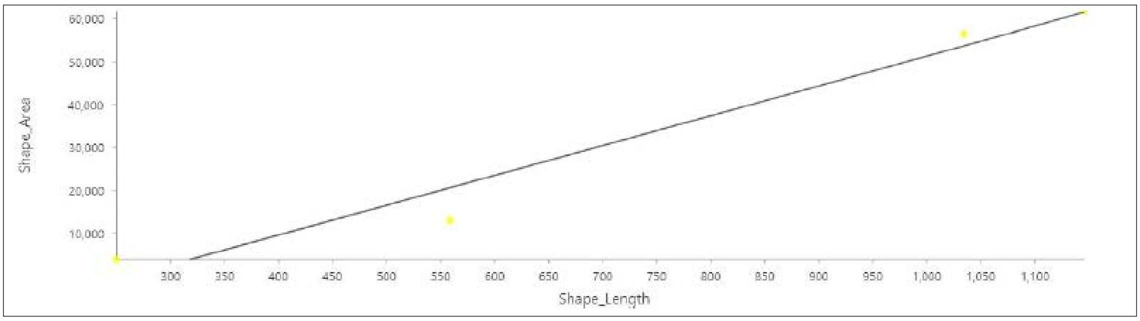


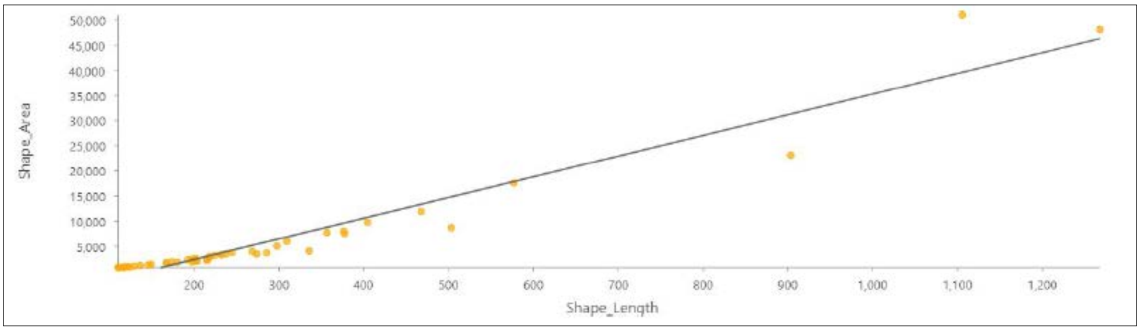
Figure 23(j): QQ plot representing OTH_CIRCULATION (miscellaneous circulation spaces eg: bottlenecks)



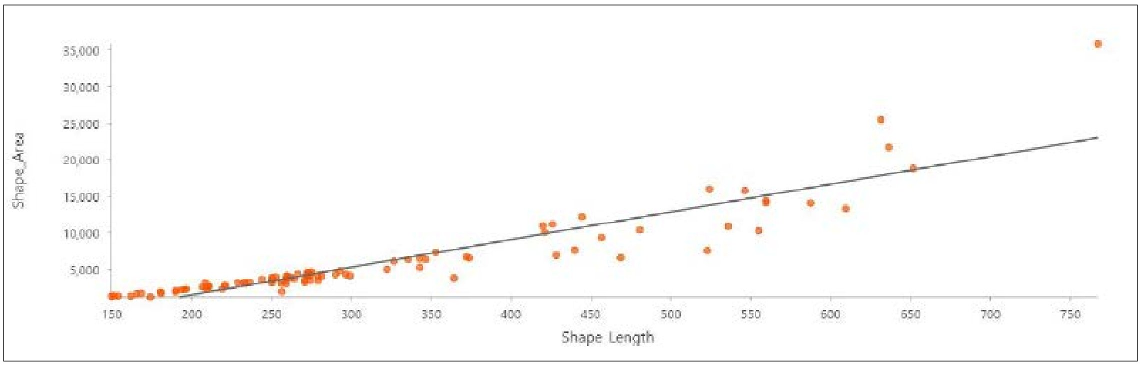
Resultant equation: y = -5289.3 + 29.9*x* (R-square value = 0.89)
Figure 24(a): Scatter plot and resultant equation representing BLDGS_1A (large extent informal settlements)



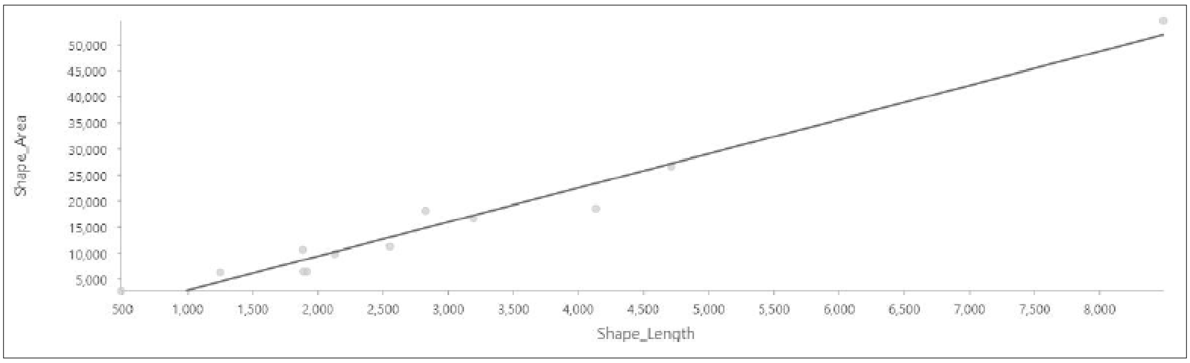
Resultant equation: y = -18327.2 + 69.6x (R-square value = 0.97)
Figure 24(b): Scatter plot and resultant equation representing BLDGS_2 (low rise settlements)



Resultant equation: y = -5879.2 + 41.2*x* (R-square value = 0.93)
Figure 24(c): Scatter plot and resultant equation representing BLDGS_3 (mid-rise settlements)

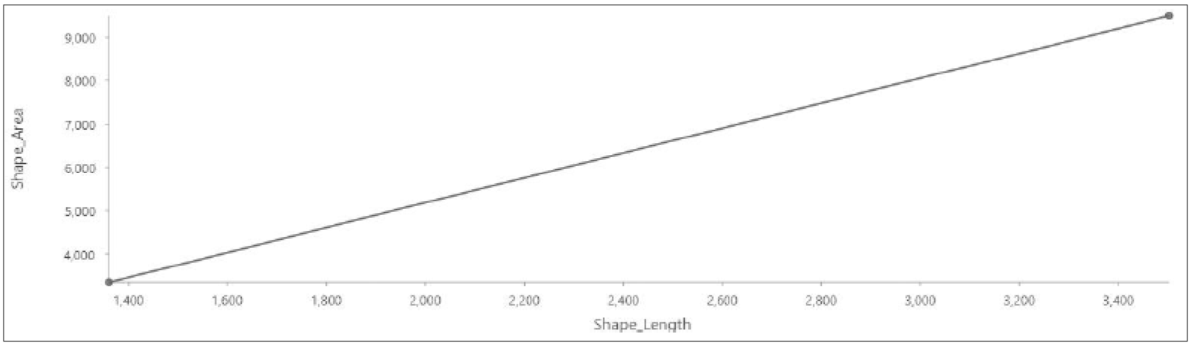


Resultant equation: y = -5992.1 + 37.8*x* (R-square value = 0.84)
Figure 24(d): Scatter plot and resultant equation representing BLDGS_4 (high-rise settlements)



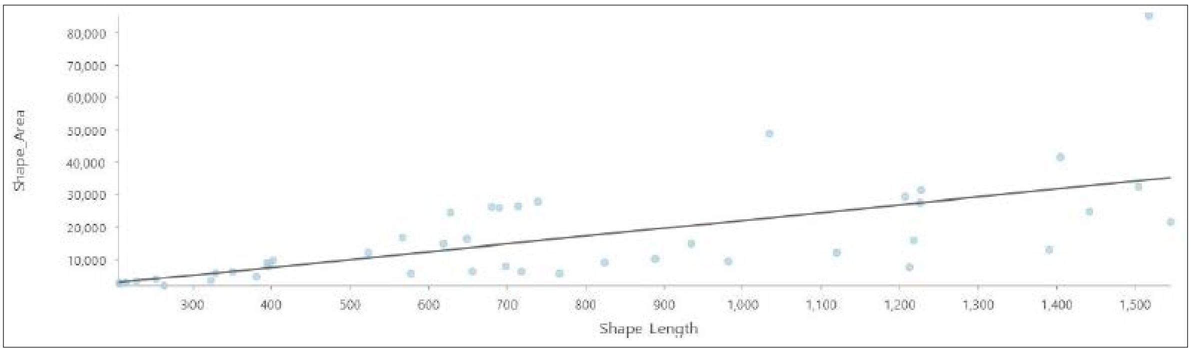
Resultant equation: y = -3685.2 + 6.6*x* (R-square value = 0.97)

Figure 24(e): Scatter plot and resultant equation representing ROADWAYS (roads and pedestrian pavements)



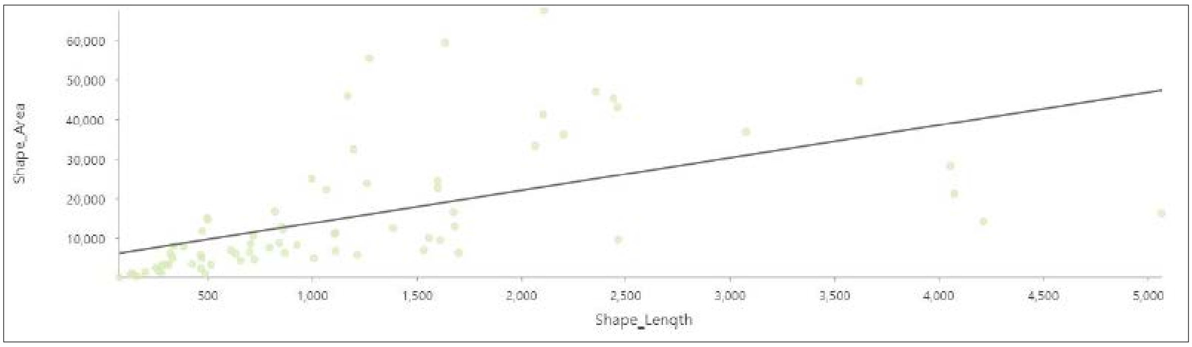
Resultant equation: y = -574.1 + 2.9*x* (R-square value = 1)

Figure 24(f): Scatter plot and resultant equation representing RAILTRACKS (railway tracks)



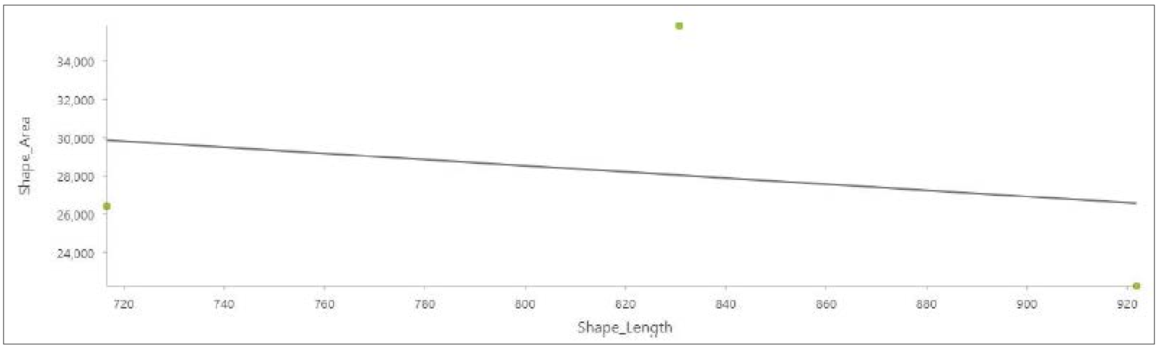
Resultant equation: y = -2205.7 + 24.2*x* (R-square value = 0.42)

Figure 24(g): Scatter plot and resultant equation representing NV_1 (groundcover, bushes and shrubs)



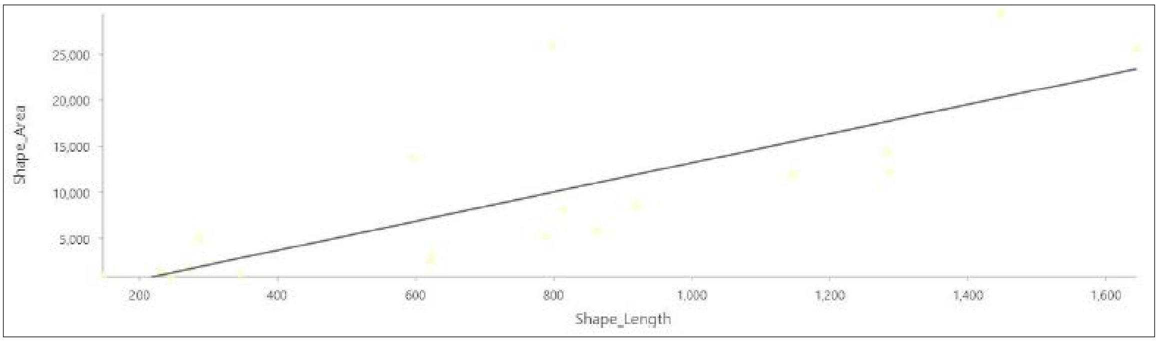
Resultant equation: y = 5661.4 + 8.2*x* (R-square value = 0.304)

Figure 24(h): Scatter plot and resultant equation representing NV_2 (less dense deciduous trees)



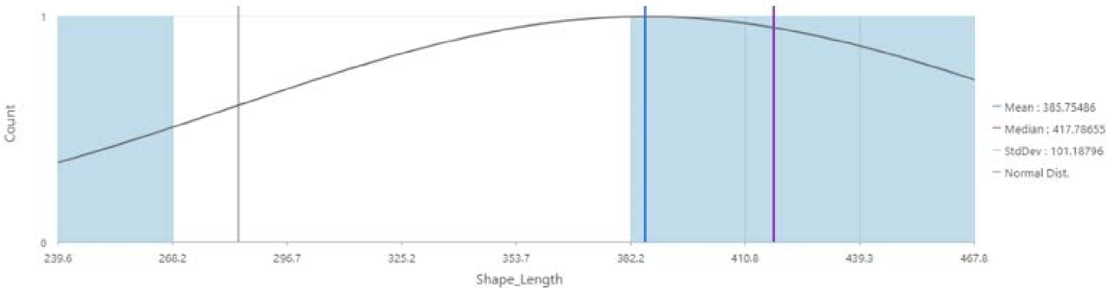
Resultant equation: y = 41402.7 + 16.1*x* (R-square value = 0.056)

Figure 24(i): Scatter plot and resultant equation representing NV_3 (dense deciduous trees)

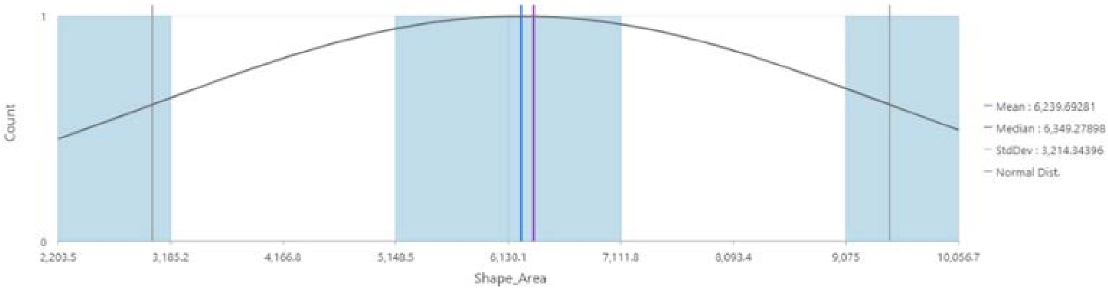


Resultant equation: y = -2698.3 + 15.9*x* (R-square value = 0.62)

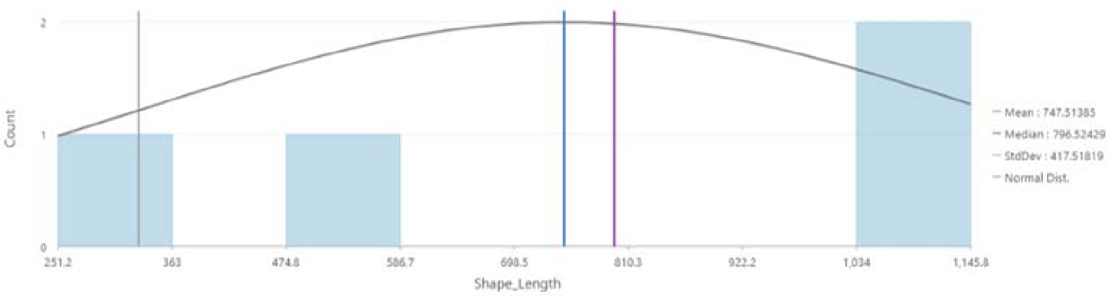
Figure 24(j): Scatter plot and resultant equation representing OTH_CIRCULATION (miscellaneous circulation spaces eg: bottlenecks)



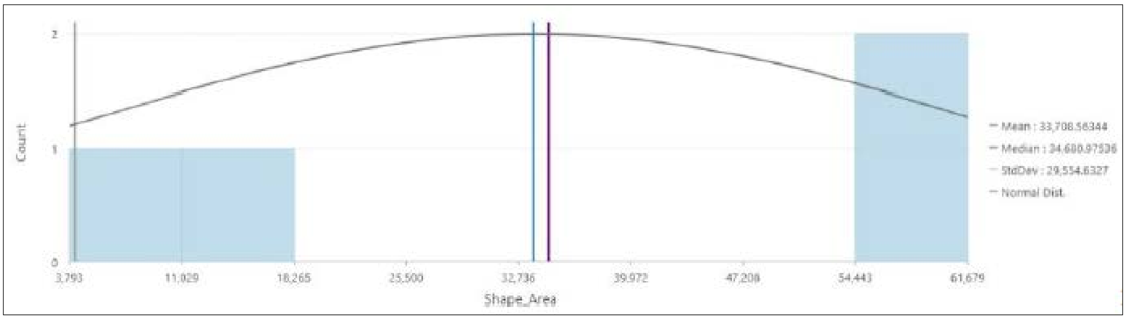
1(a)



1(b)



2(a)


Count
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Mean : 33,708.56344
Median : 34,600.97536
StdDev : 29,554.6327
Normal Dist.
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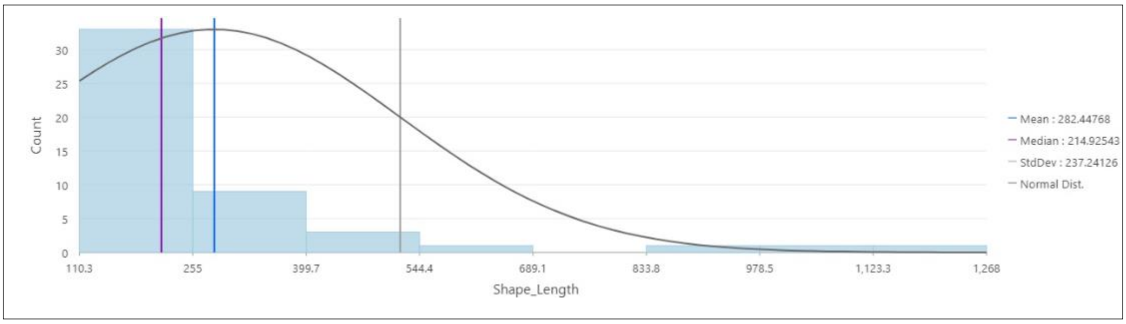
11,029
18,265
25,500
32,736
39,972
47,208
54,443
61,679

2(b)


Count
Shape_Length
Mean : 282.44768
Median : 214.92543
StdDev : 237.24126
Normal Dist.
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399.7
544.4
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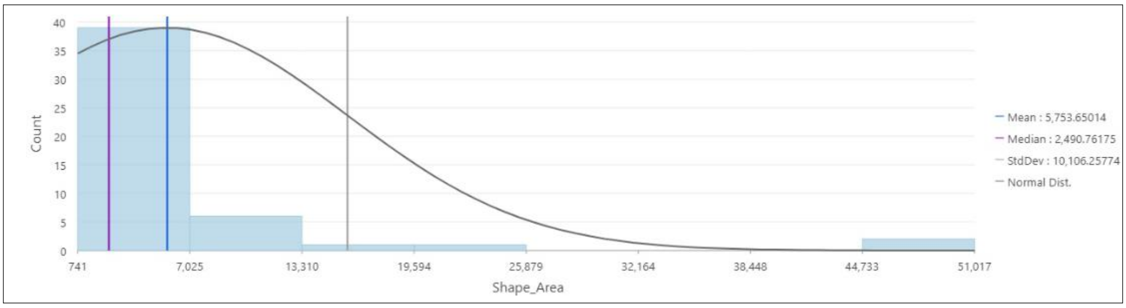
1,268

3(a)


Count
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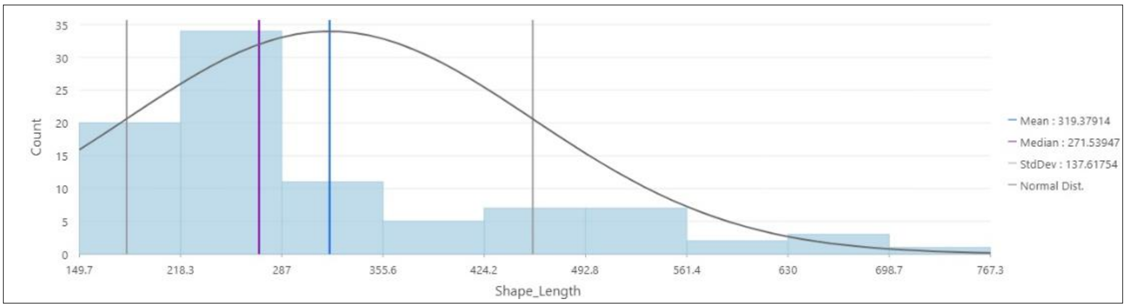
Median : 2,490.76175
StdDev : 10,106.25774
Normal Dist.
741
7,025
13,310
19,594
25,879
32,164
38,448
44,733
51,017

3(b)


Count
Shape_Length
Mean : 319.37914
Median : 271.53947
StdDev : 137.61754
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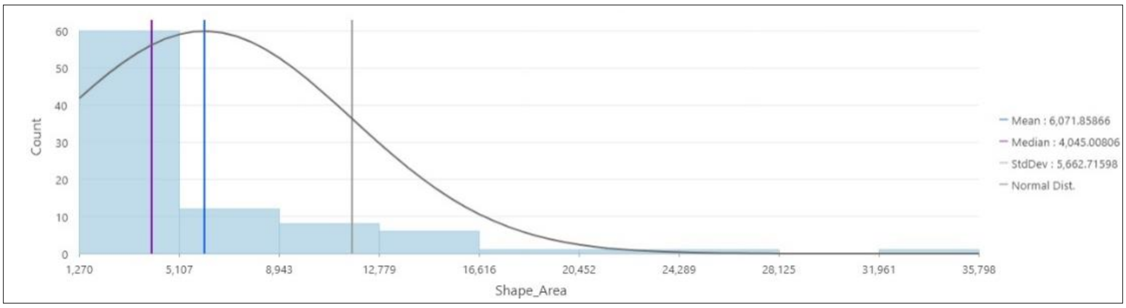
287
355.6
424.2
492.8
561.4
630
698.7
767.3

4(a)


Count
Shape_Area
Mean : 6,071.85866
Median : 4,045.00806
StdDev : 5,662.71598
Normal Dist.
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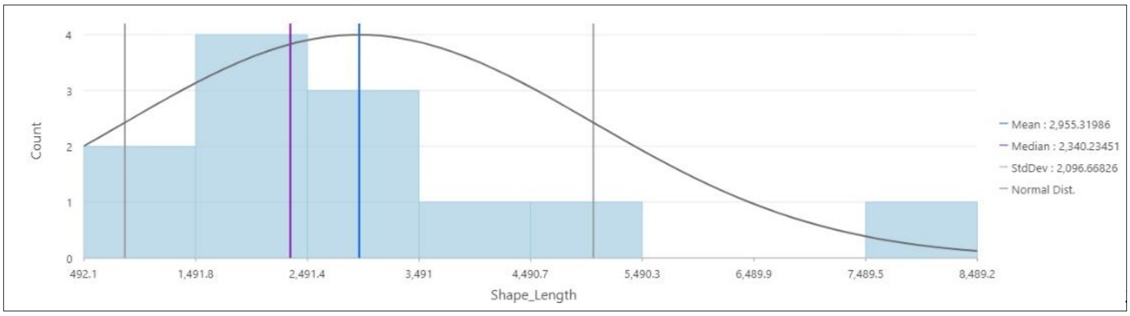
8,943
12,779
16,616
20,452
24,289
28,125
31,961
35,798

4(b)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Shape_Length
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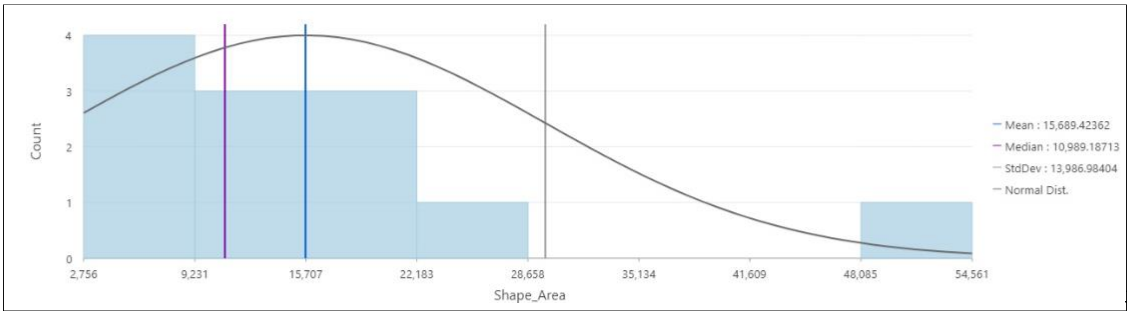
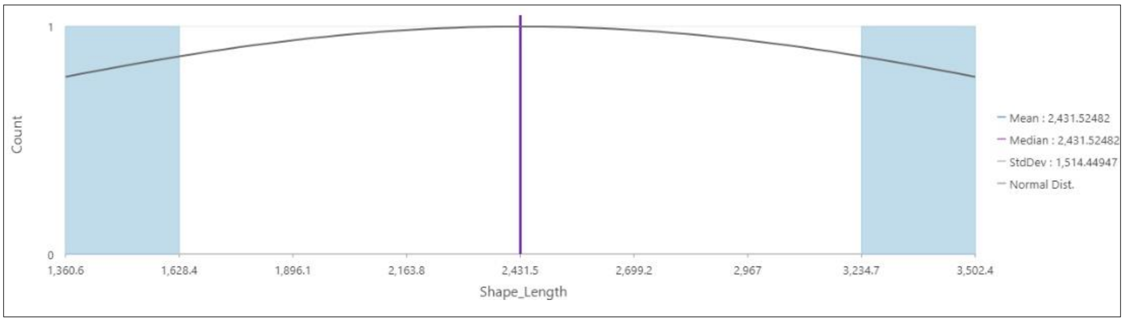
1,491.8
2,491.4
3,491
4,490.7
5,490.3
6,489.9
7,489.5
8,489.2
Mean : 2,955.31986
Median : 2,340.23451
StdDev : 2,096.66826
Normal Dist.

5 (a)


Count
Shape_Area
2,756
9,231
15,707
22,183
28,658
35,134
41,609
48,085
54,561
Mean : 15,689.42362
Median : 10,989.18713
StdDev : 13,986.98404
Normal Dist.

5 (b)


Count
Shape_Length
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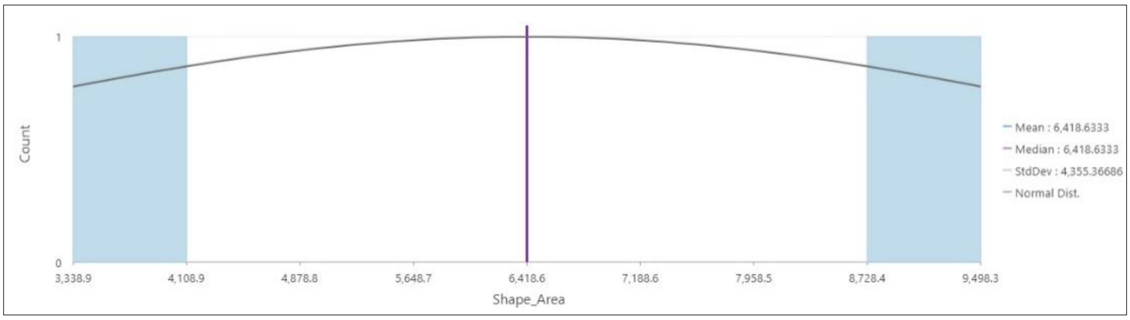
1,628.4
1,896.1
2,163.8
2,431.5
2,699.2
2,967
3,234.7
3,502.4
Mean : 2,431.52482
Median : 2,431.52482
StdDev : 1,514.44947
Normal Dist.

6 (a)


Count
Shape_Area
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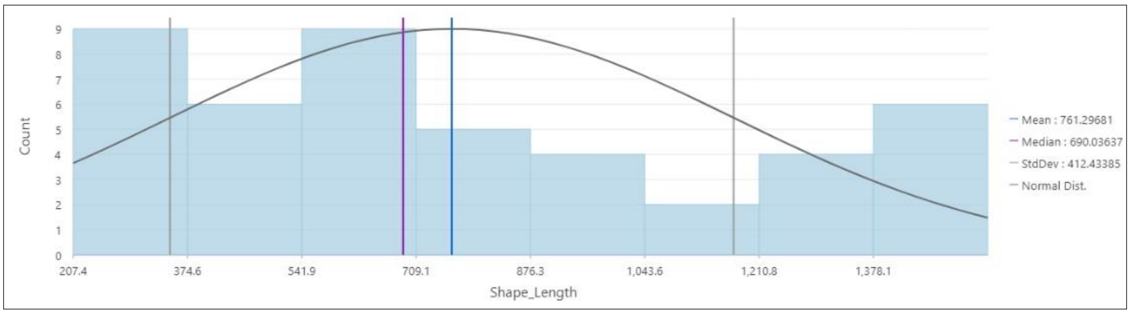
4,108.9
4,878.8
5,648.7
6,418.6
7,188.6
7,958.5
8,728.4
9,498.3
Mean : 6,418.6333
Median : 6,418.6333
StdDev : 4,355.36686
Normal Dist.

6 (b)


Count
Shape_Length
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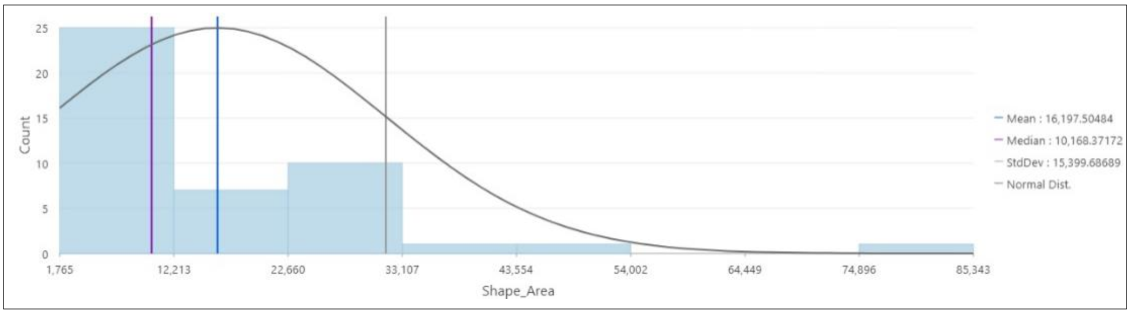
374.6
541.9
709.1
876.3
1,043.6
1,210.8
1,378.1
Mean : 761.29681
Median : 690.03637
StdDev : 412.43385
Normal Dist.

7 (a)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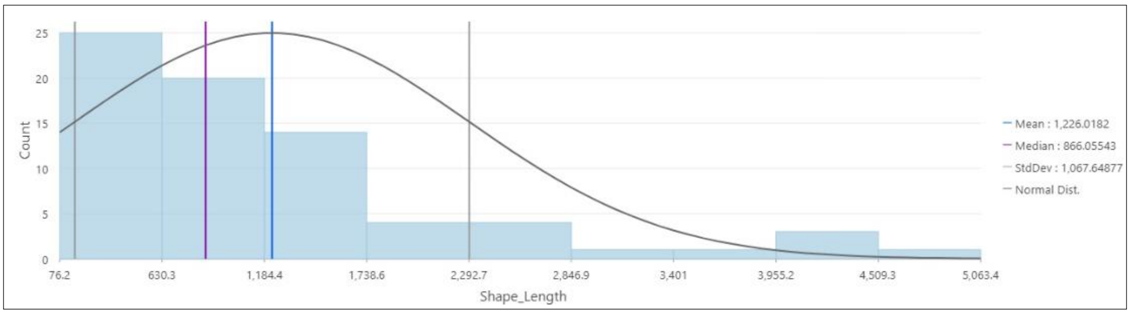
10
15
20
25
1,765
12,213
22,660
33,107
43,554
54,002
64,449
74,896
85,343
Shape_Area
Mean : 16,197.50484
Median : 10,168.37172
StdDev : 15,399.68689
Normal Dist.

7 (b)


Count
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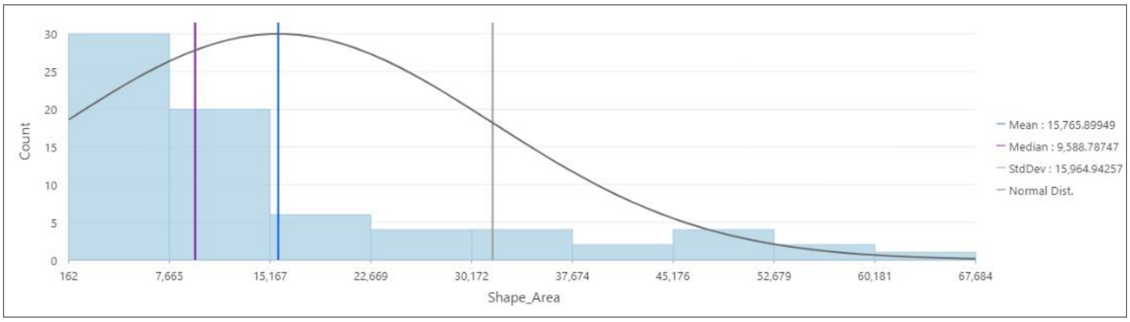
5
10
15
20
25
76.2
630.3
1,184.4
1,738.6
2,292.7
2,846.9
3,401
3,955.2
4,509.3
5,063.4
Shape_Length
Mean : 1,226.0182
Median : 866.05543
StdDev : 1,067.64877
Normal Dist.

8 (a)


Count
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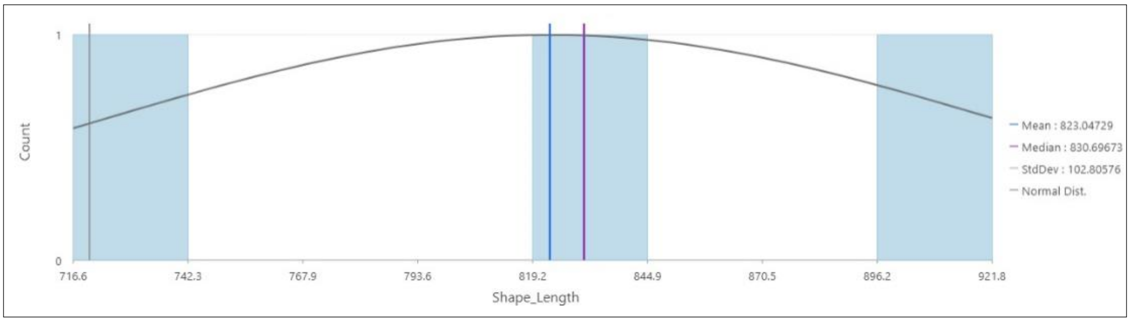
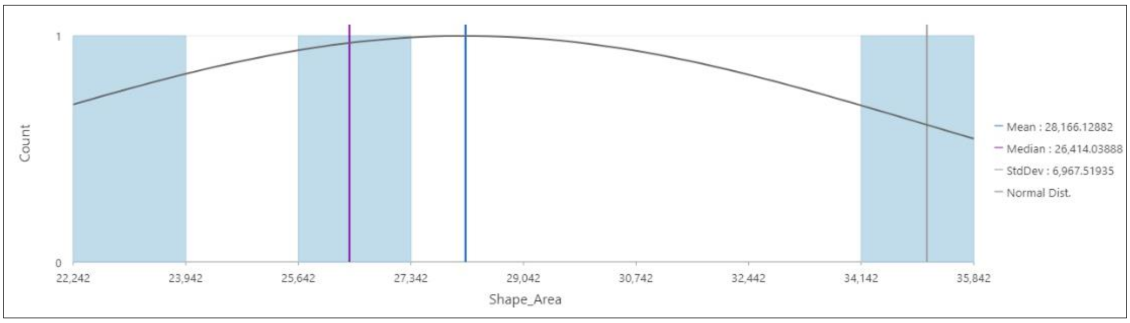
5
10
15
20
25
30
162
7,665
15,167
22,669
30,172
37,674
45,176
52,679
60,181
67,684
Shape_Area
Mean : 15,765.89949
Median : 9,588.78747
StdDev : 15,964.94257
Normal Dist.

8 (b)


Count
0
1
716.6
742.3
767.9
793.6
819.2
844.9
870.5
896.2
921.8
Shape_Length
Mean : 823.04729
Median : 830.69673
StdDev : 102.80576
Normal Dist.

9 (a)


Count
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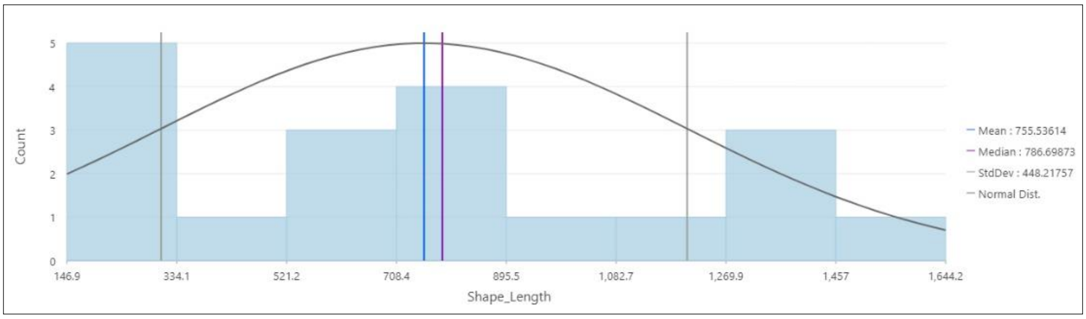
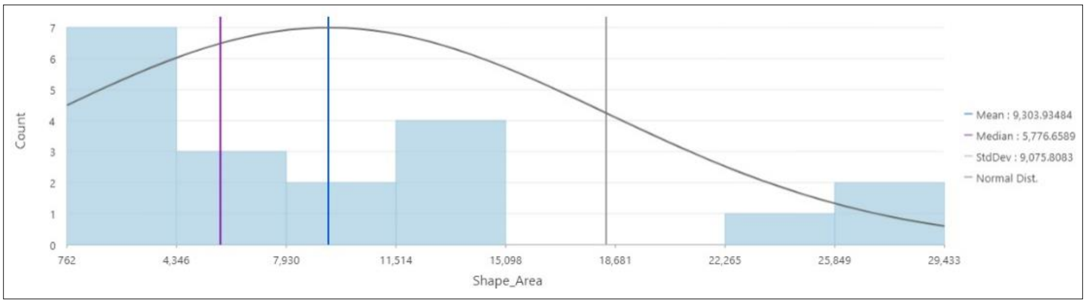
1
22,242
23,942
25,642
27,342
29,042
30,742
32,442
34,142
35,842
Shape_Area
Mean : 28,166.12882
Median : 26,414.03888
StdDev : 6,967.51935
Normal Dist.

9 (b)



10 (a)



10 (b)

Figure 25: Histograms (a) representing estimated areas and (b) representing estimated lengths or perimeters for (1) BLDGS_1A (large extent informal settlements), (2) BLDGS_2 (low rise settlements),(3) BLDGS_3 (midrise settlements), (4) BLDGS_4 (high rise settlements),(5) ROADWAYS (roads and pedestrian pavements),(6) RAILTRACKS (railway tracks), (7) NV_1 (groundcover, bushes and shrubs), (8) NV_2 (less dense deciduous trees), (9) NV_3 (dense deciduous trees), (10) OTH_CIRCULATION (miscellaneous circulation spaces eg: bottlenecks)

file:///C:/Users/Student/Downloads/SV_GNT1.pdf
Link for accessing Near Table generated

The analysis for the stretch-2 comprising the Ward No. 31 area (mostly public spaces and residences) under the jurisdiction of Bidhannagar Municipal Corporation (BMC) in Kolkata is being done as follows:

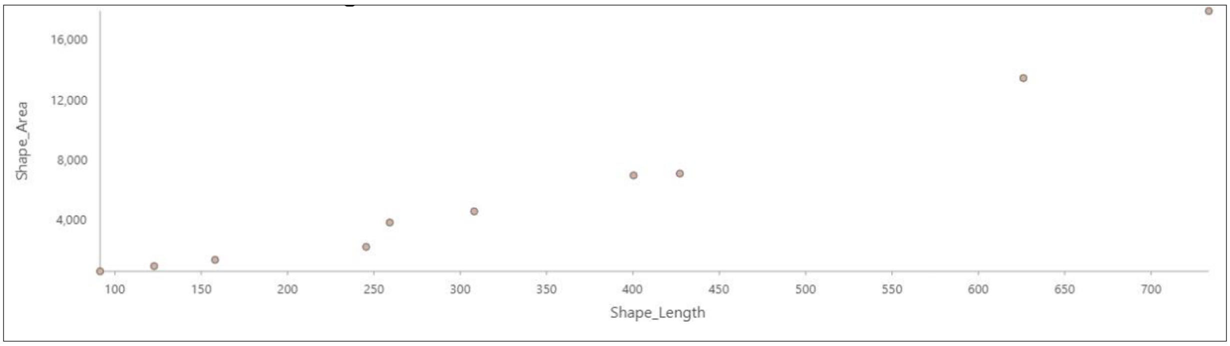


Figure 26(a): QQ plot representing BLDGS_1A (for large extent informal settlements)

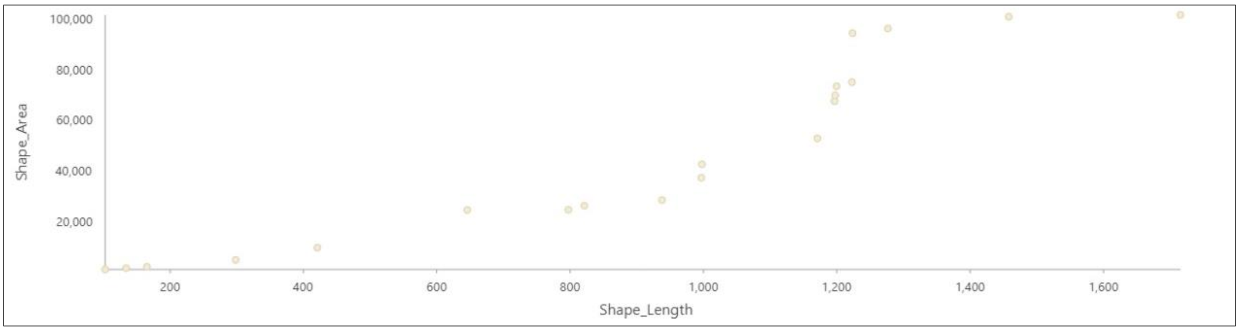


Figure 26(b): QQ plot representing BLDGS_2 (for low rise settlements)

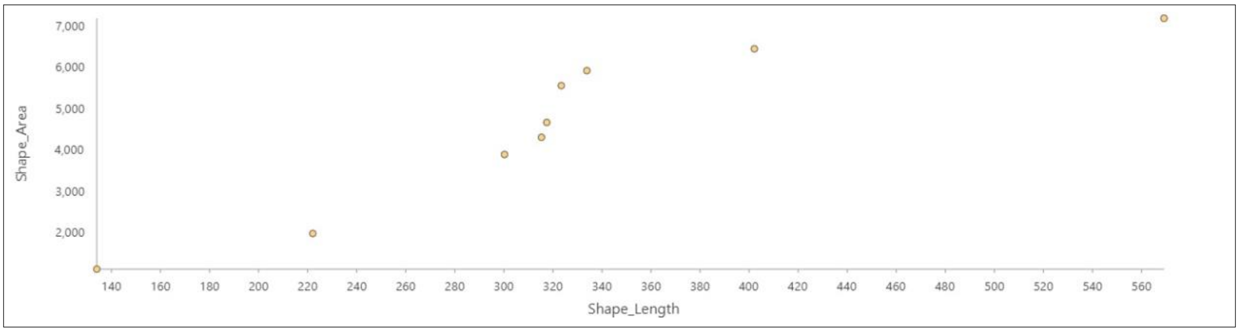


Figure 26(c): QQ plot representing BLDGS_3 (for mid rise settlements)

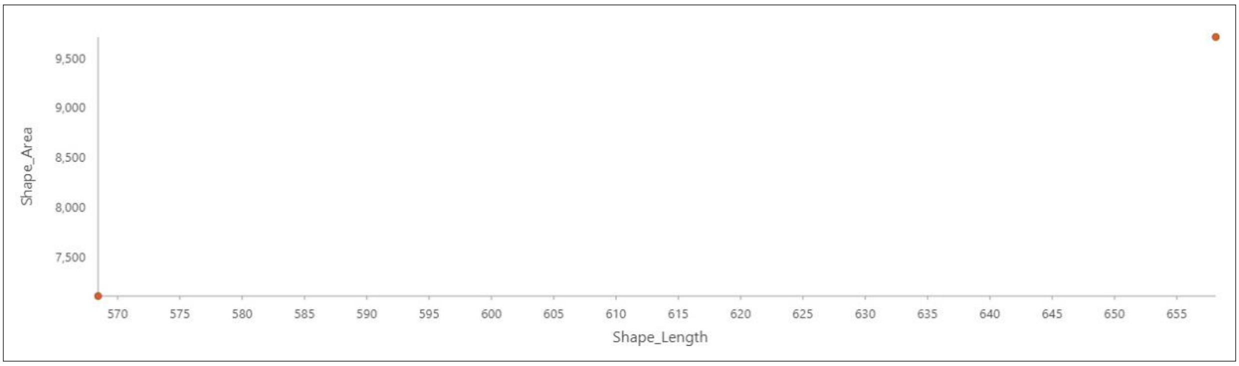


Figure 26(d): QQ plot representing BLDGS_4 (for high rise settlements)

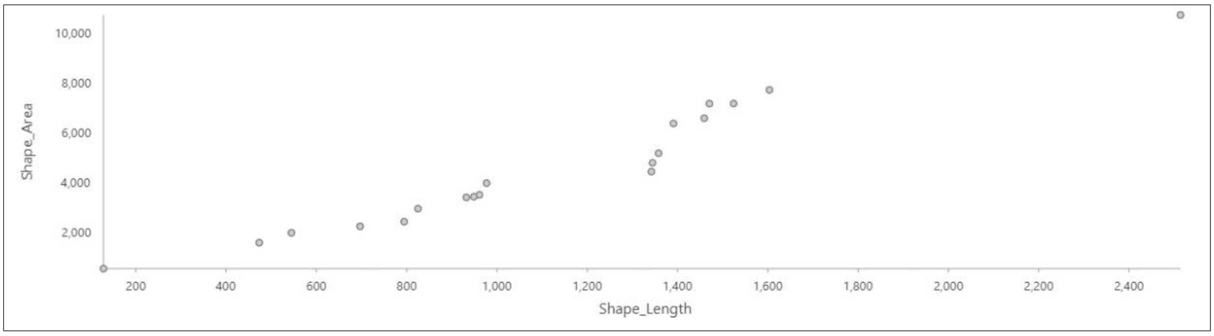


Figure 26(e): QQ plot representing ROADWAYS (for roads and pedestrian pavements)

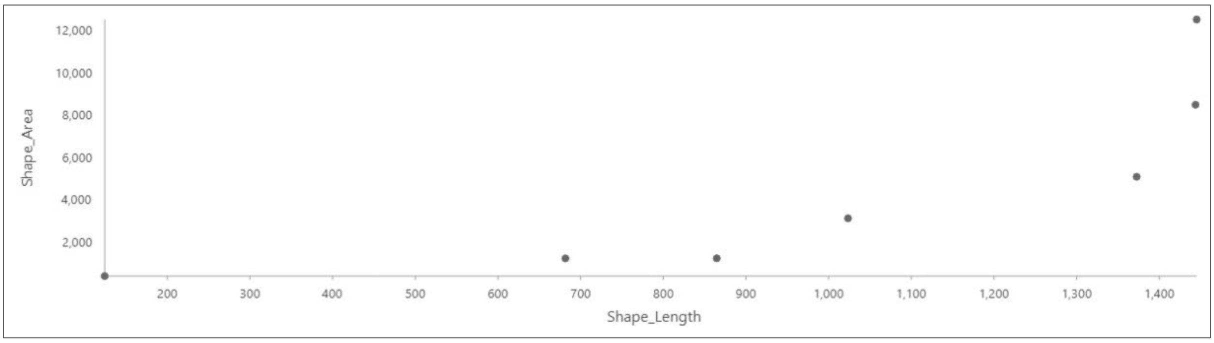


Figure 26(f): QQ plot representing RAILTRACKS (for railway tracks)

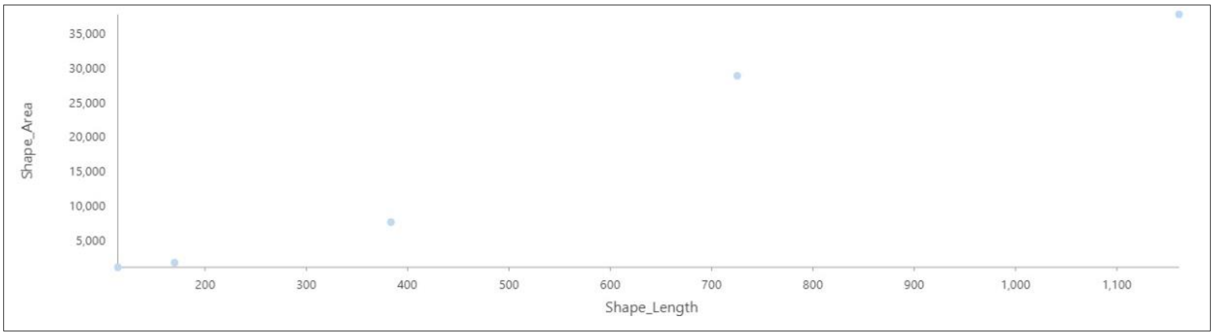


Figure 26(g): QQ plot representing WATER_BODIES (water bodies)

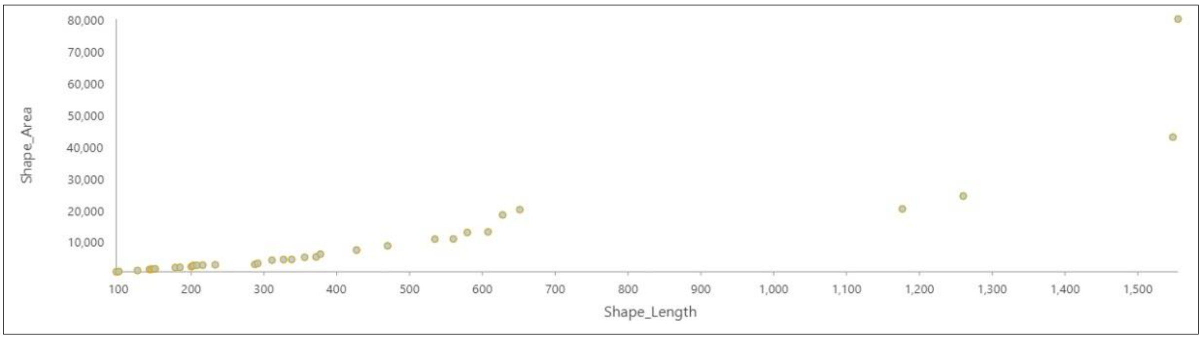


Figure 26(h): QQ plot representing NV_1 (groundcover, bushes and shrubs)

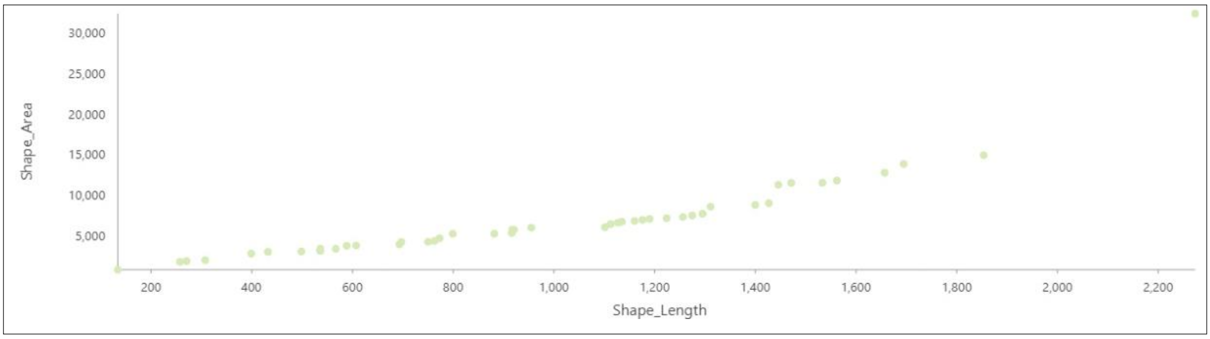


Figure 26(i): QQ plot representing NV_2 (less dense deciduous trees)

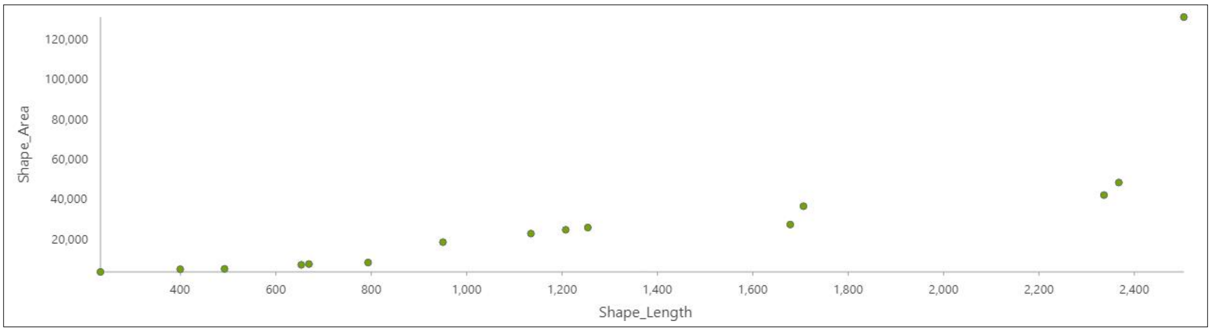
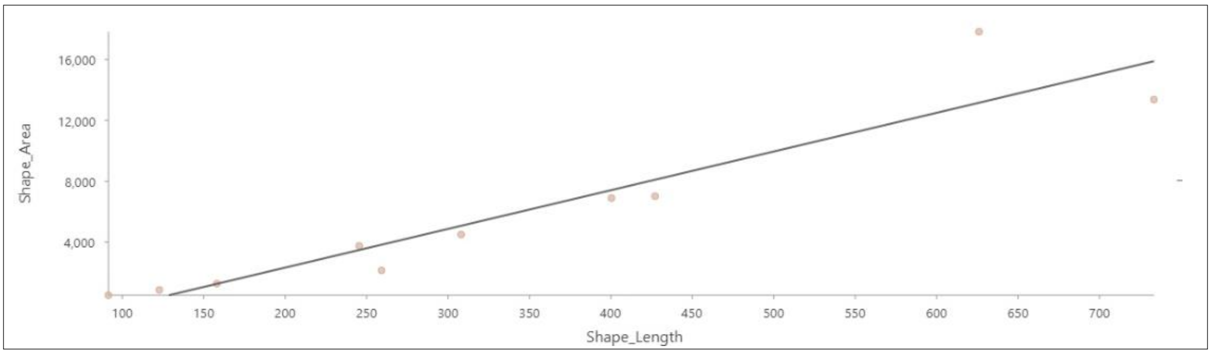
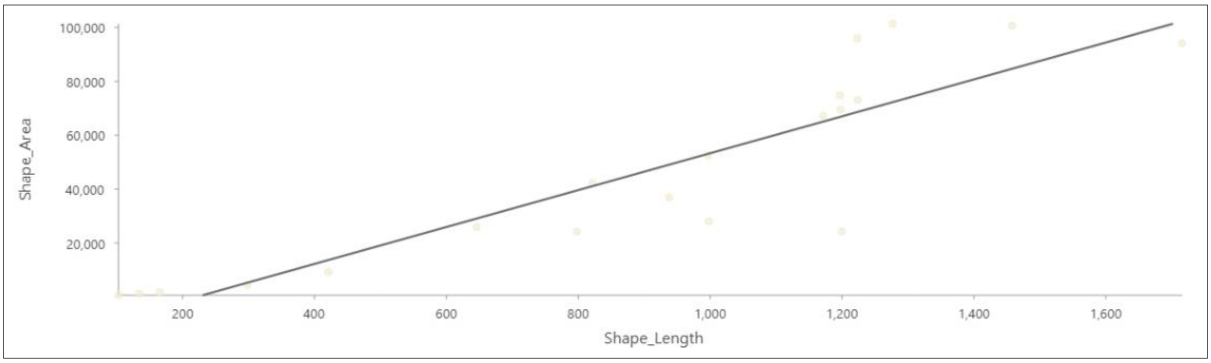


Figure 26(j): QQ plot representing NV_3 (dense deciduous trees)



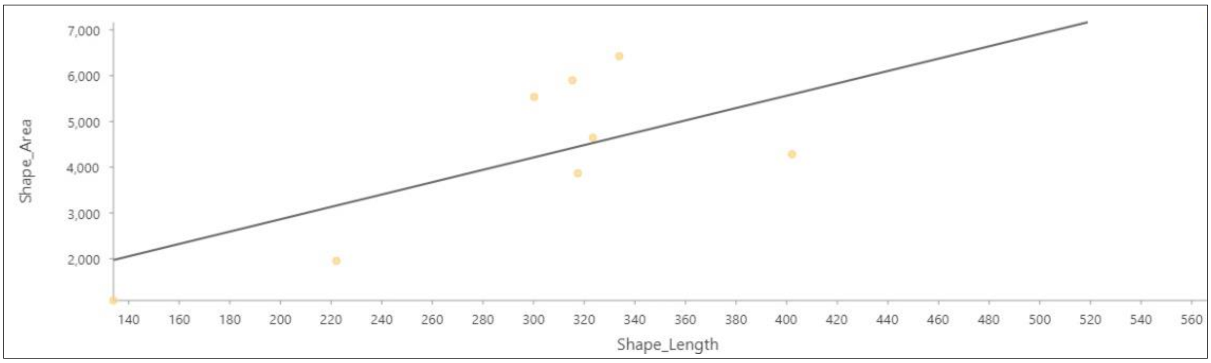
Resultant equation: **y = -2768.1 + 25.5*x*** (R-square value = 0.89)

Figure 27(a): Scatter plot and resultant equation representing BLDGS_1A (for large extent informal settlements)



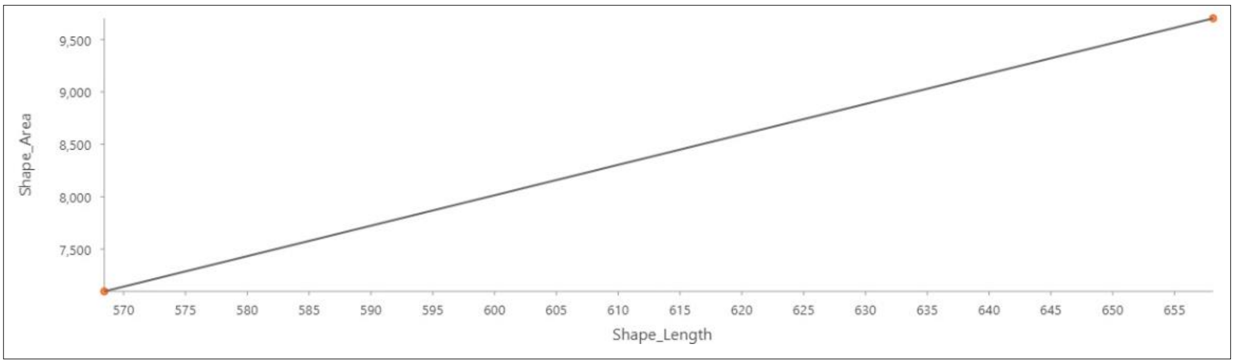
Resultant equation: **y = -15166.0 + 68.5*x*** (R-square value = 0.8)

Figure 27(b): Scatter plot and resultant equation representing BLDGS_2 (for low rise settlements)



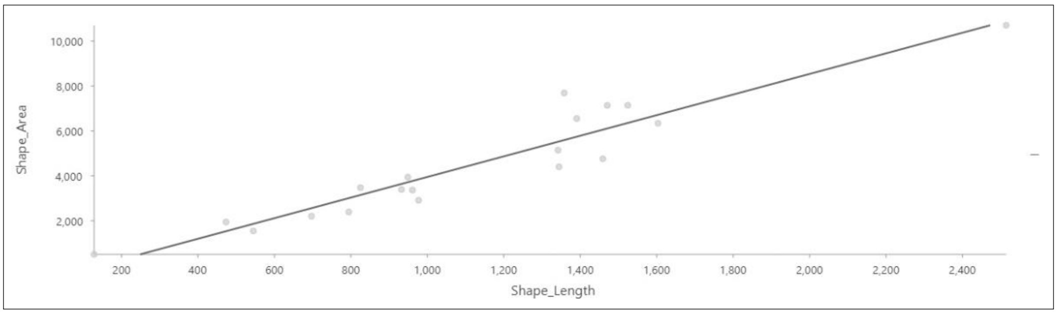
Resultant equation: **y = 165.9 + 13.5*x*** (R-square value = 0.64)

Figure 27(c): Scatter plot and resultant equation representing BLDGS_3 (for mid rise settlements)



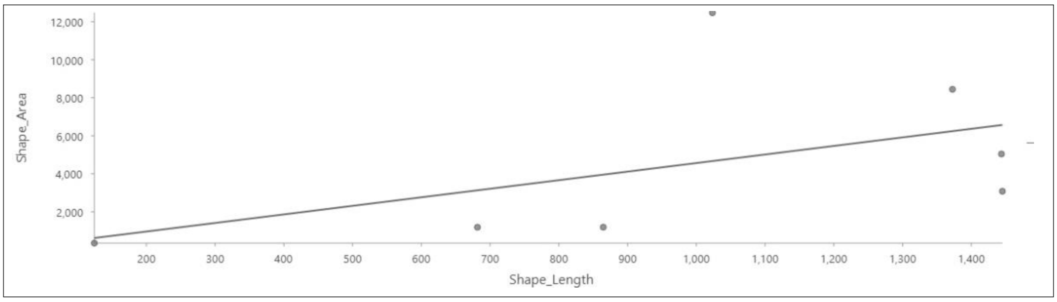
Resultant equation: **y = -9427.5 + 29.1*x*** (R-square value = 1)

Figure 27(d): Scatter plot and resultant equation representing BLDGS_4 (for high rise settlements)



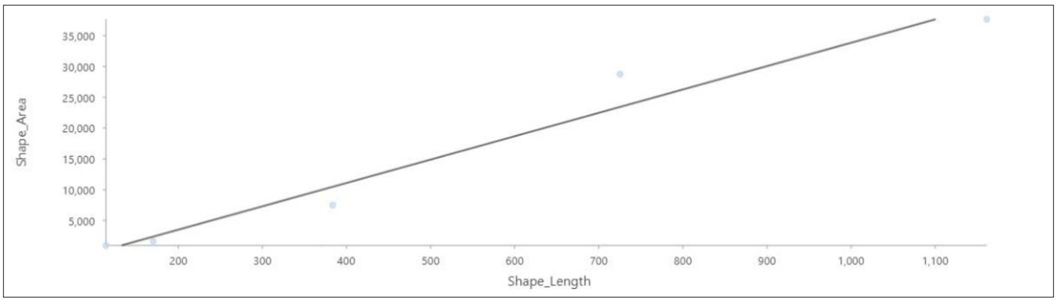
Resultant equation: **y = -640.1 + 4.6*x*** (R-square value = 0.9)

Figure 27(e): Scatter plot and resultant equation representing ROADWAYS (for roads and pedestrian pavements)



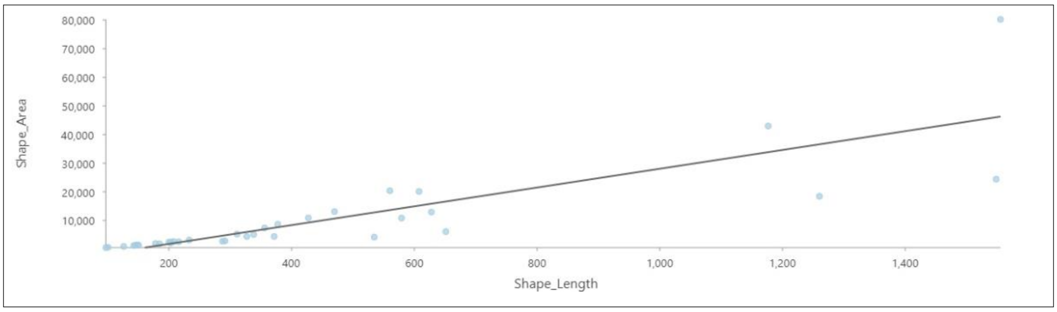
Resultant equation: **y = 62.2 + 4.5*x*** (R-square value = 0.24)

Figure 27(f): Scatter plot and resultant equation representing RAILTRACKS (for railway tracks)



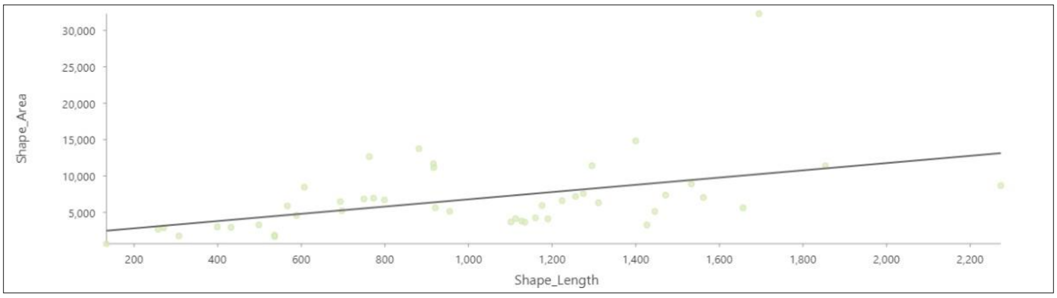
Resultant equation: **y = -4068.3 + 37.9*x*** (R-square value = 0.96)

Figure 27(g): Scatter plot and resultant equation representing WATER_BODIES (water bodies)



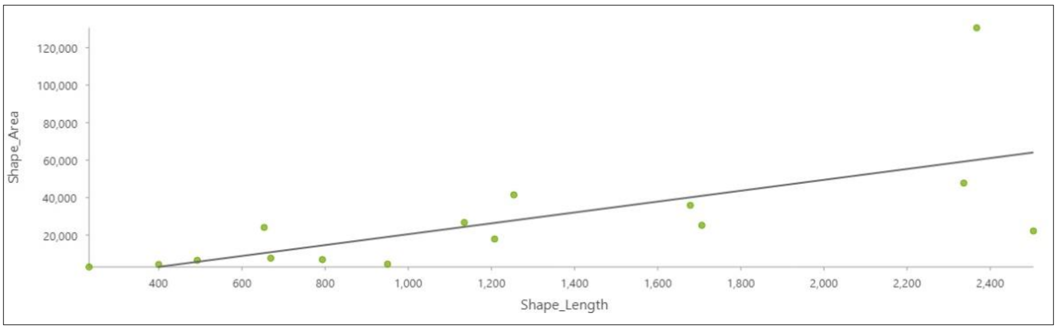
Resultant equation: **y = -4752.1 + 32.8*x*** (R-square value = 0.7)

Figure 27(h): Scatter plot and resultant equation representing NV_1 (groundcover, bushes and shrubs)



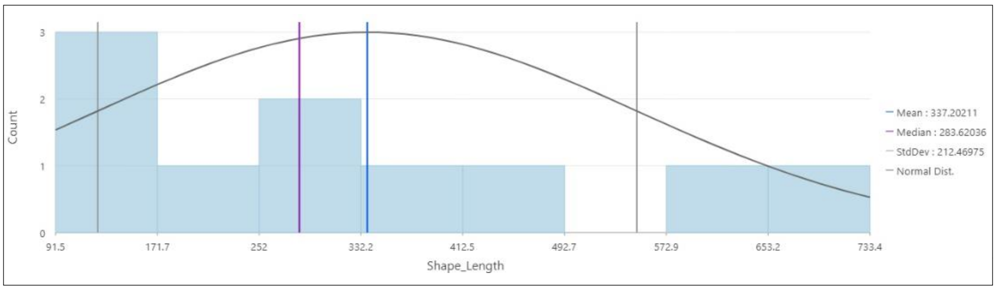
Resultant equation: **y = 1802.7 + 5.0*x*** (R-square value = 0.21)

Figure 27(i): Scatter plot and resultant equation representing NV_2 (less dense deciduous trees)



Resultant equation: y = -8514.4 + 29.0*x* (R-square value = 0.45)

Figure 27(j): Scatter plot and resultant equation representing NV_3 (dense deciduous trees)



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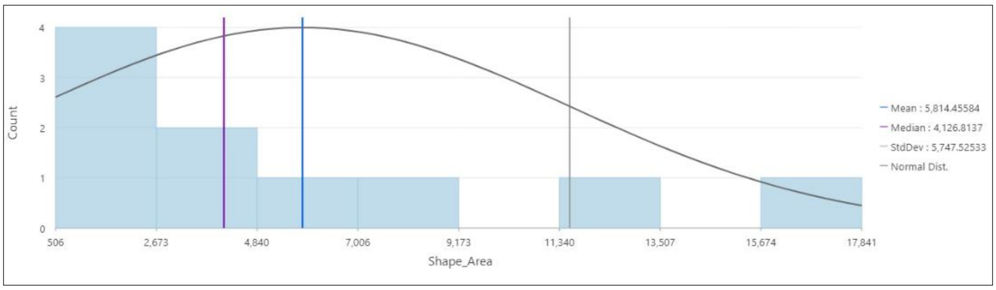
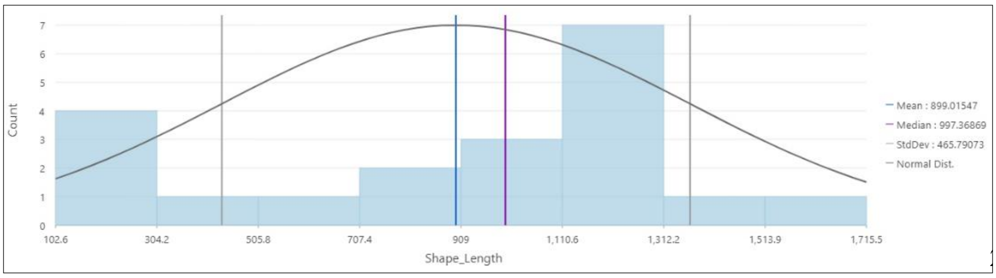
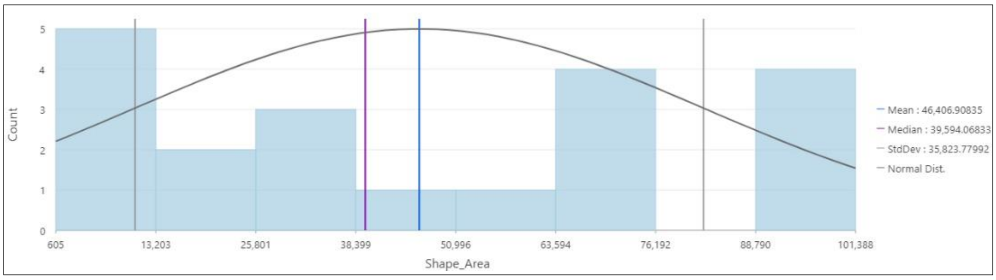


1 (b)



2 (a)



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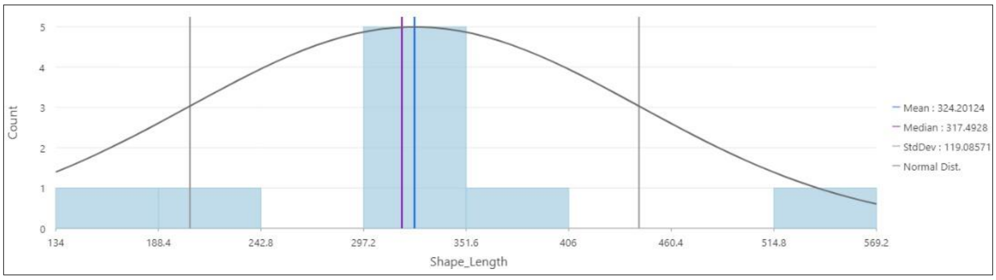
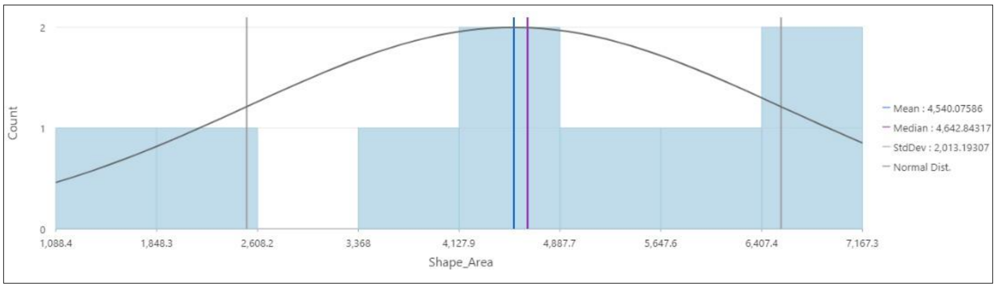


3 (a)



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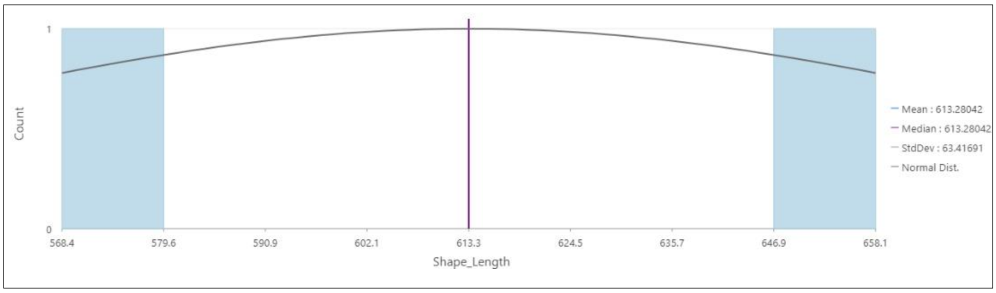

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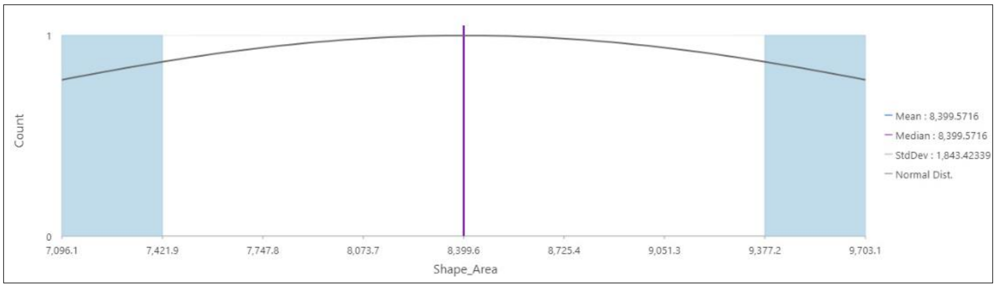

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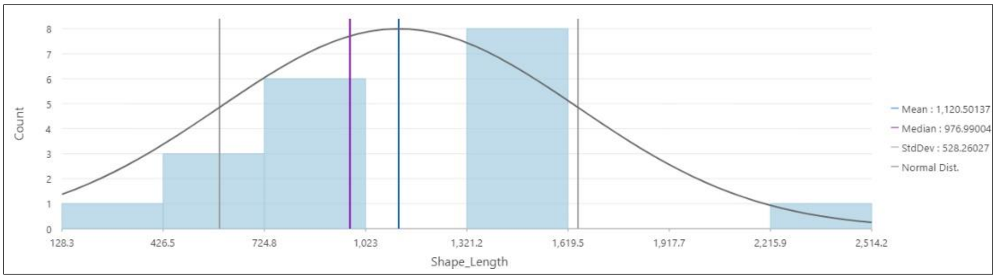

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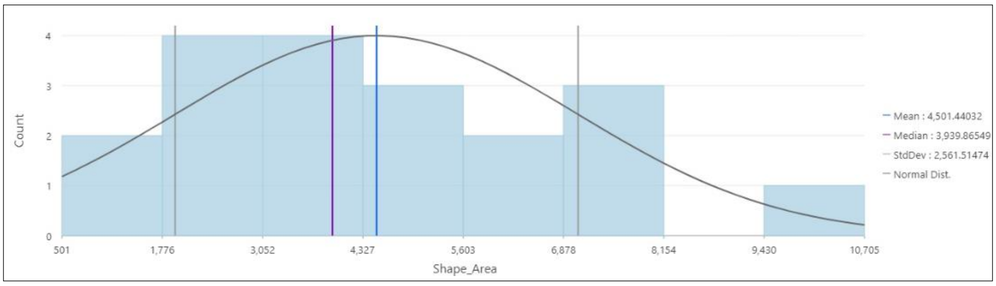

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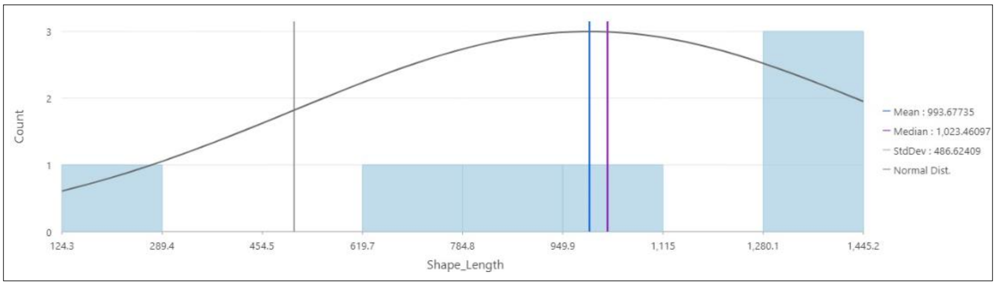
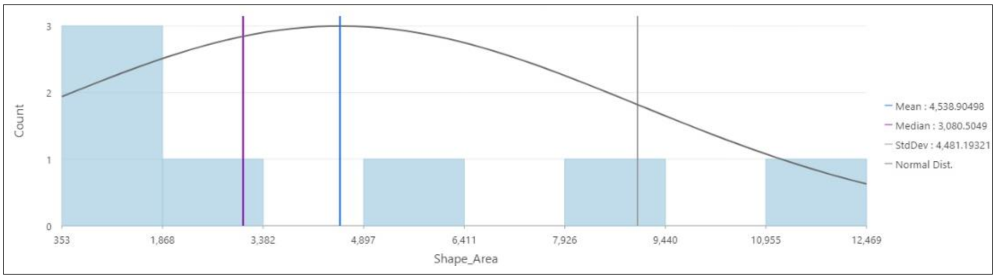


6 (a)



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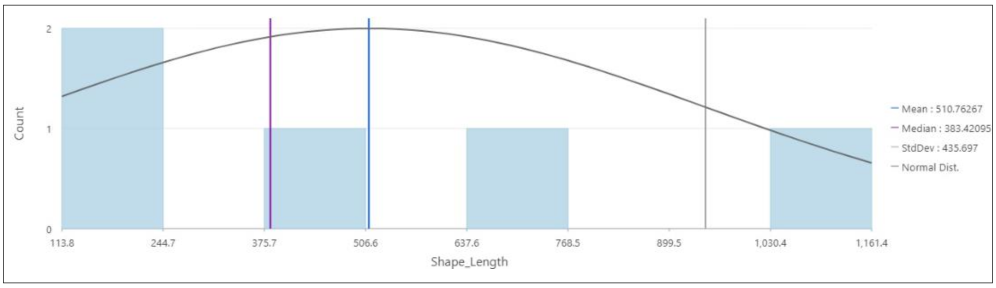
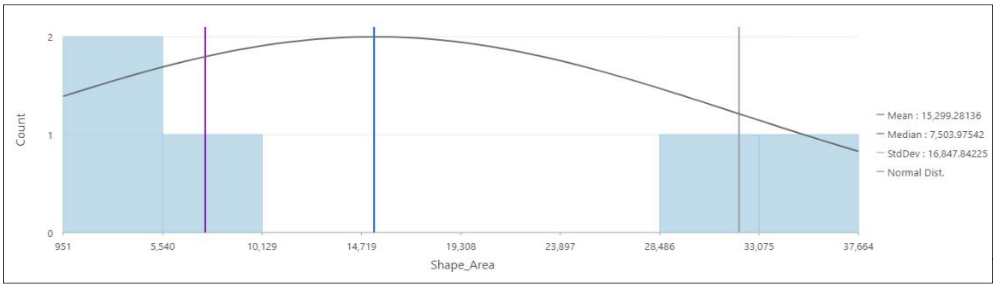


7 (a)



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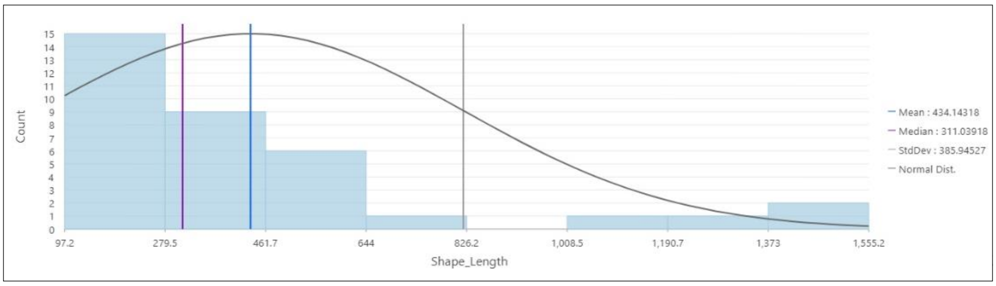
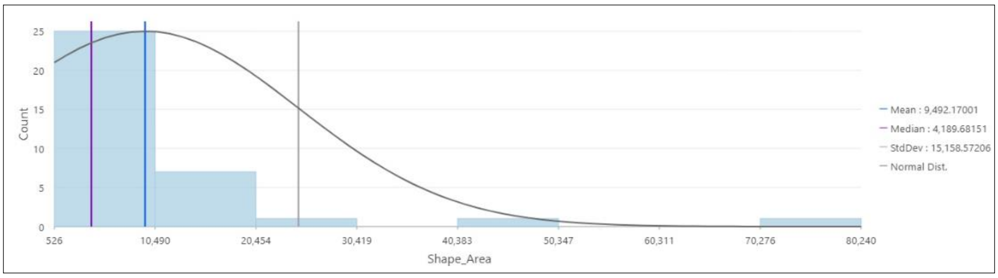
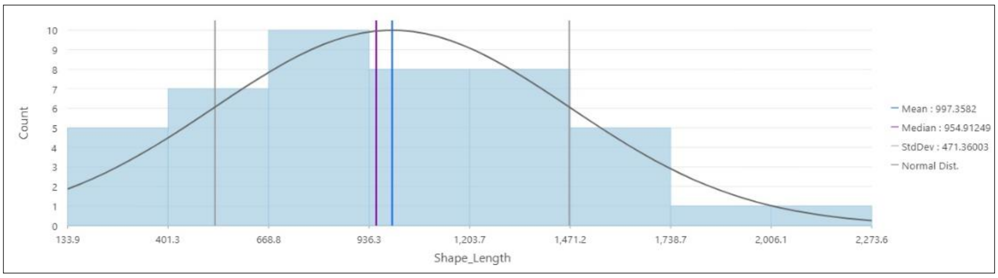


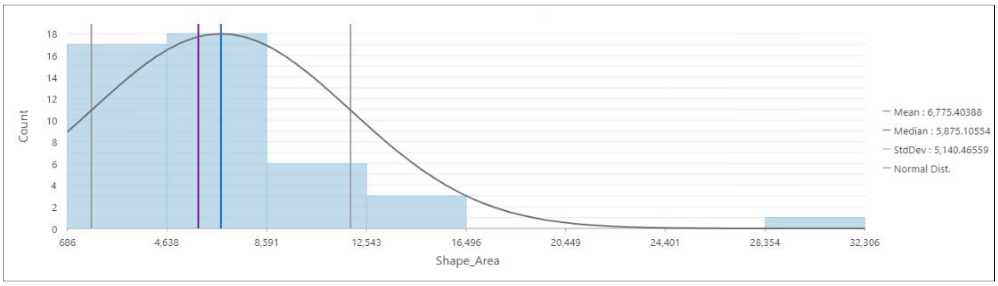
8 (a)



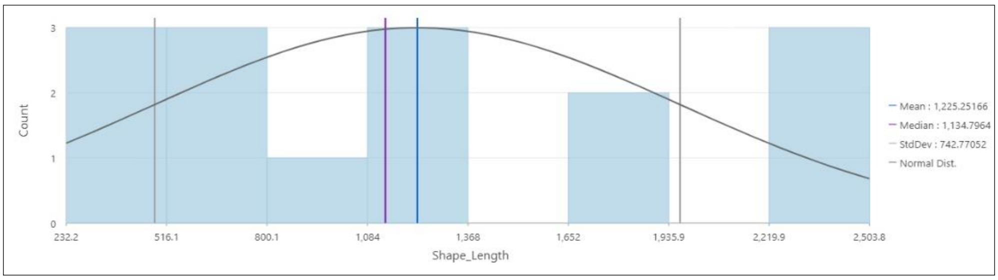
8 (b)



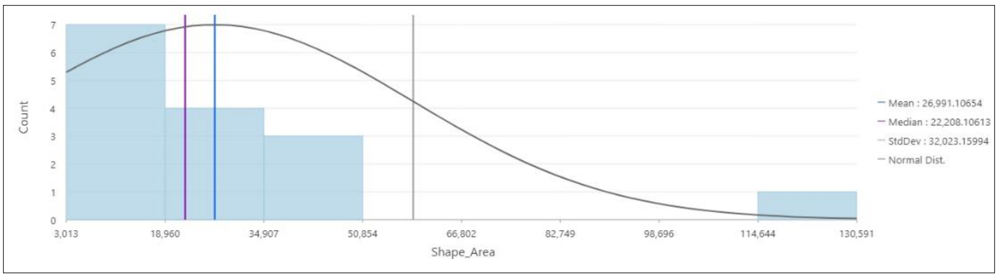
9 (a)



9 (b)



10 (a)



10 (b)

Figure 28: Histograms (a) representing estimated areas and (b) representing estimated lengths or perimeters for (a) BLDGS_1A (for large extent informal settlements), (b) BLDGS_2 (for low rise settlements), (c) BLDGS_3 (for mid rise settlements), (d) BLDGS_4 (for high rise settlements), (e) ROADWAYS (for roads and pedestrian pavements), (f) RAILTRACKS (for railway tracks), (g) WATER_BODIES (water bodies), (h)NV_1 (groundcover, bushes and shrubs), (i) NV_2 (less dense deciduous trees), (j) NV_3 (dense deciduous trees)

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The analysis for the stretch-3 comprising the Ward No. 36 area (mostly wetlands) under the jurisdiction of Bidhannagar Municipal Corporation (BMC) in Kolkata is being done as follows:

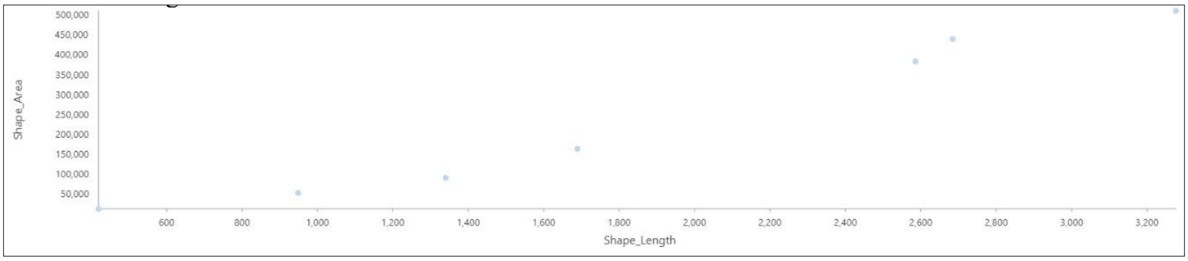


Figure 29(a): QQ plot representing WATER_BODIES (water bodies)

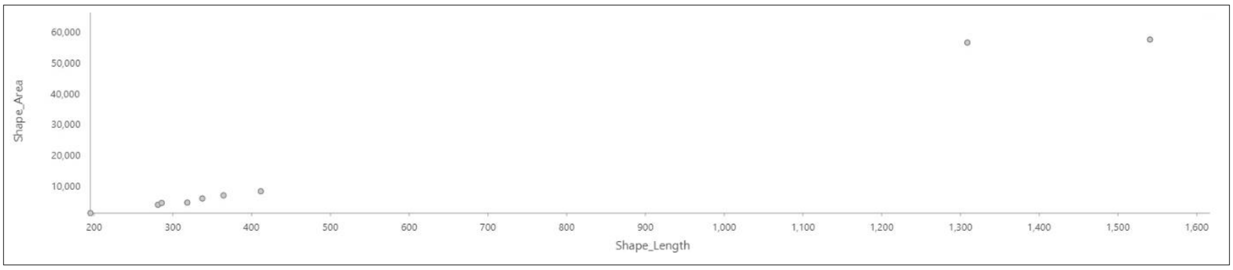


Figure 29(b): QQ plot representing BLDGS_1 (for compact informal settlements)

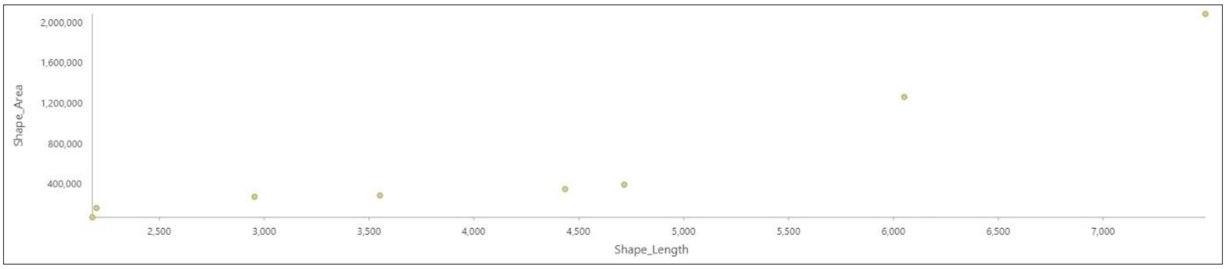
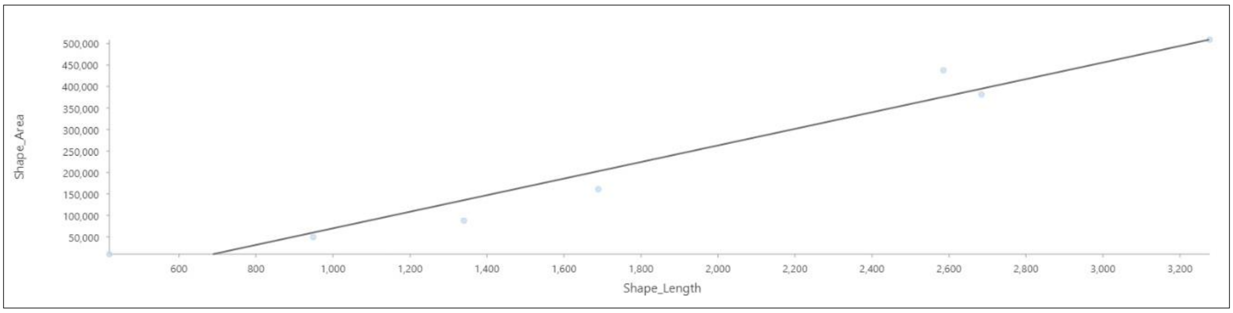
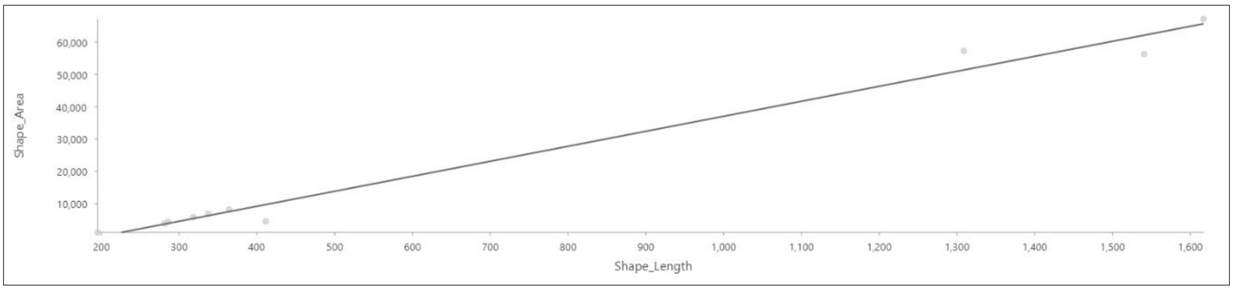


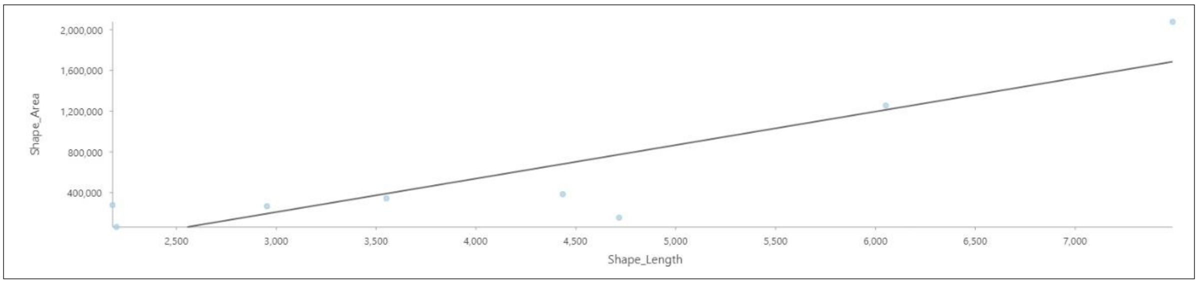
Figure 29(c): QQ plot representing NV_1 (groundcover, bushes and shrubs)



Resultant equation: **y = -123089.7 + 193*x*** (R-square value = 0.96)
Figure 30(a): Scatter plot and resultant equation representing WATER_BODIES (water bodies)

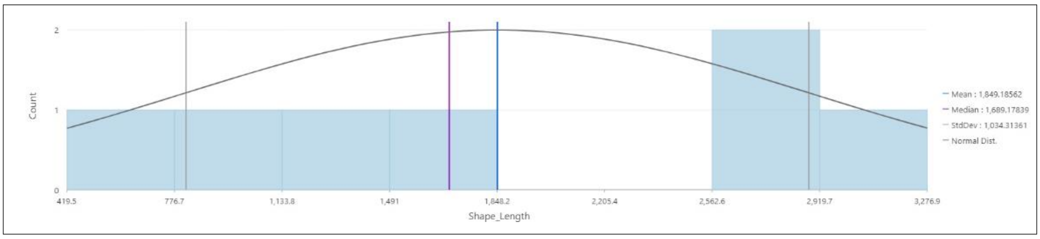


Resultant equation: **y = -9320.4 + 46.4*x*** (R-square value = 0.98)
Figure 30(b): Scatter plot and resultant equation representing BLDGS_1 (for compact informal settlements)

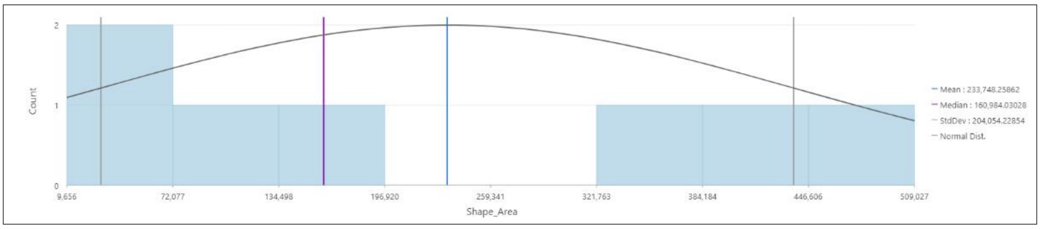


Resultant equation: **y = -777380.4 + 328.8*x*** (R-square value = 0.78)

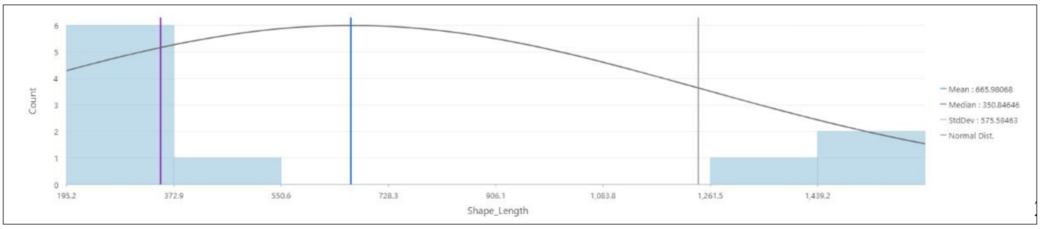
Figure 30(c): Scatter plot and resultant equation representing NV_1 (groundcover, bushes and shrubs)



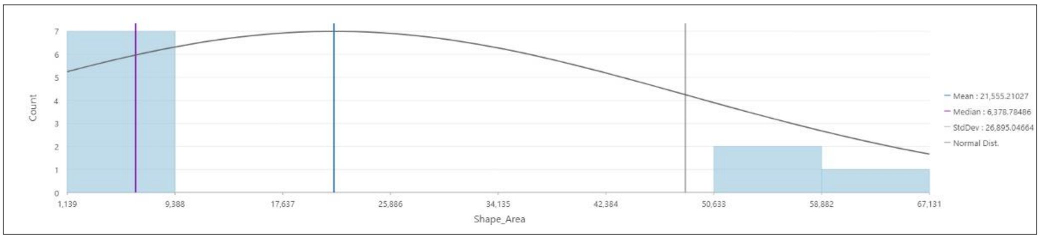
1 (a)



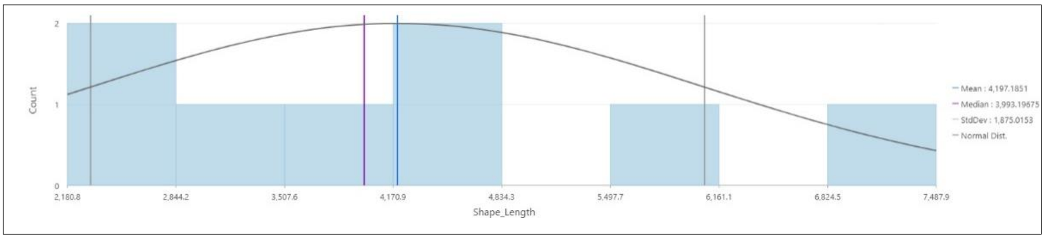
1 (b)



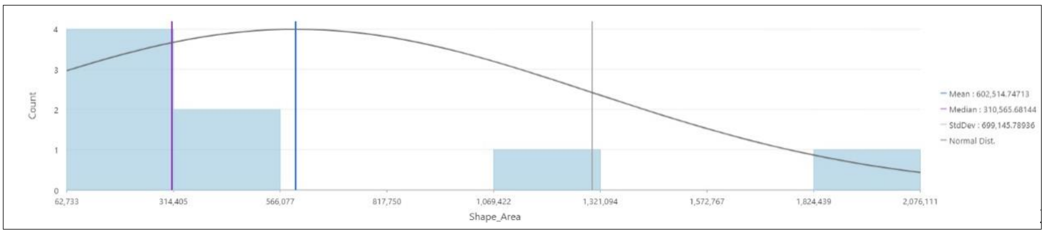
2 (a)



2 (b)



3 (a)



3 (b)

Figure 31: Histograms (a) representing estimated areas and (b) representing estimated lengths or perimeters for (1) WATER_BODIES

(water bodies), (2) BLDGS_1 (for compact informal settlements), (3) NV_1 (groundcover, bushes and shrubs)

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The analysis for the stretch-4 comprising the Ward No. 39 area (mostly slum settlements) under the jurisdiction of Bidhannagar Municipal Corporation (BMC) in Kolkata is being done as follows:

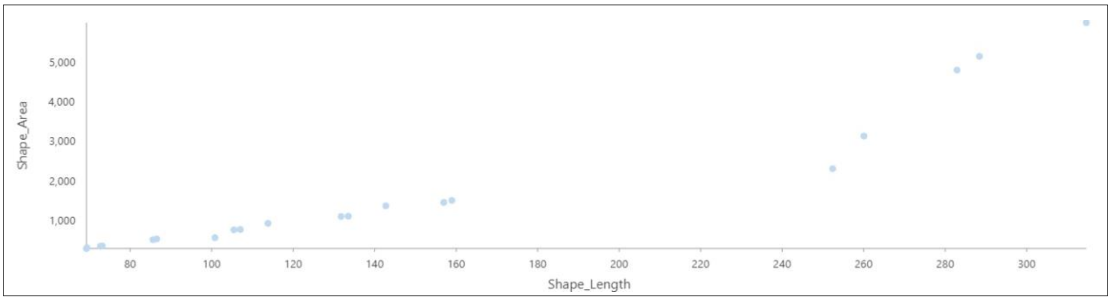


Figure 32(a): QQ plot representing WATER_BODIES (water bodies)

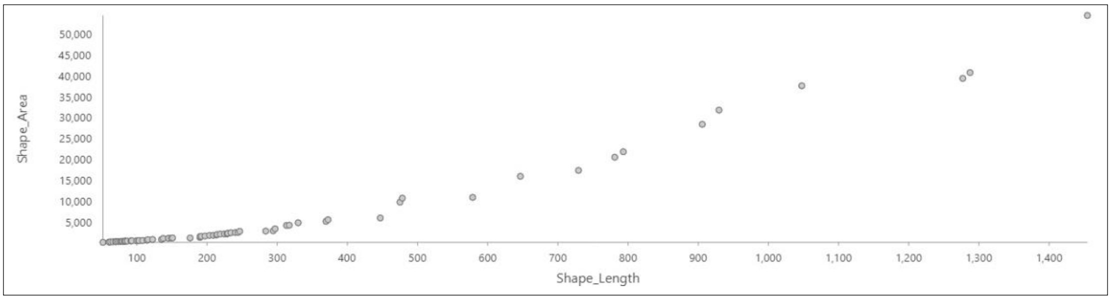


Figure 32(b): QQ plot representing BLDGS_1 (for compact informal settlements)

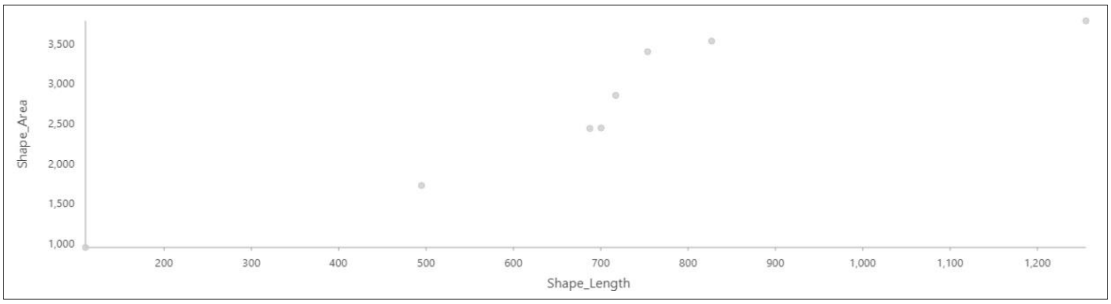


Figure 32(c): QQ plot representing ROADWAYS (roads and pedestrian pavements)

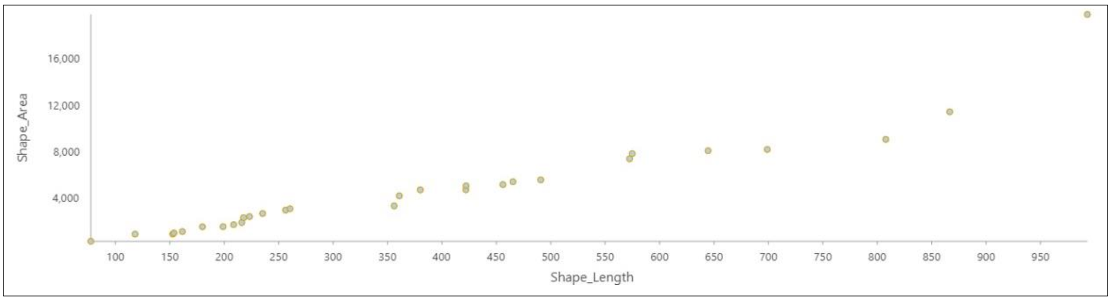


Figure 32(d): QQ plot representing NV_1 (groundcover, bushes and shrubs)

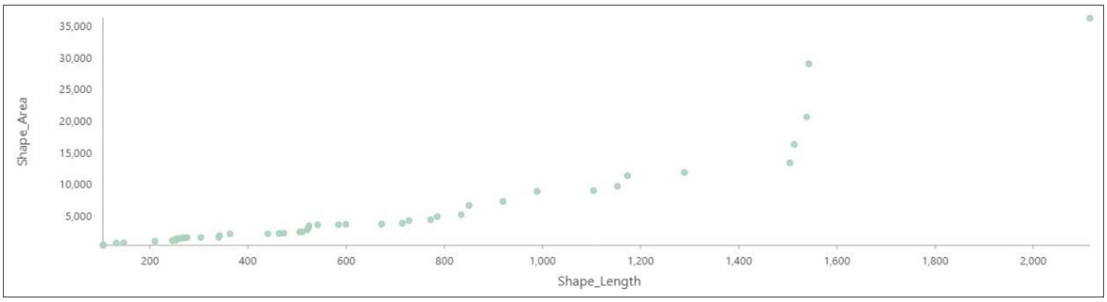
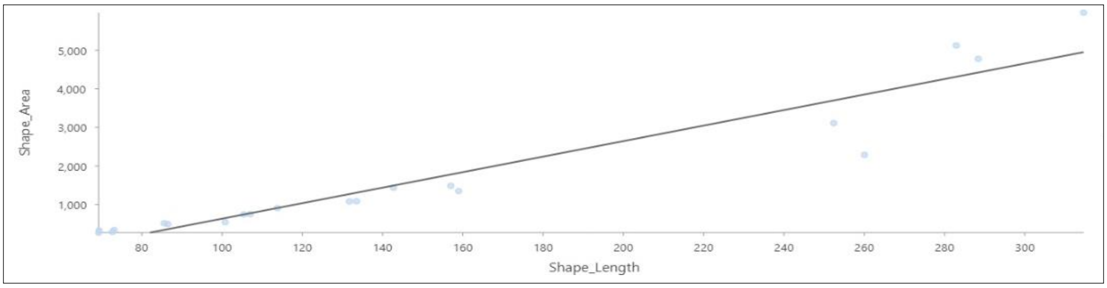
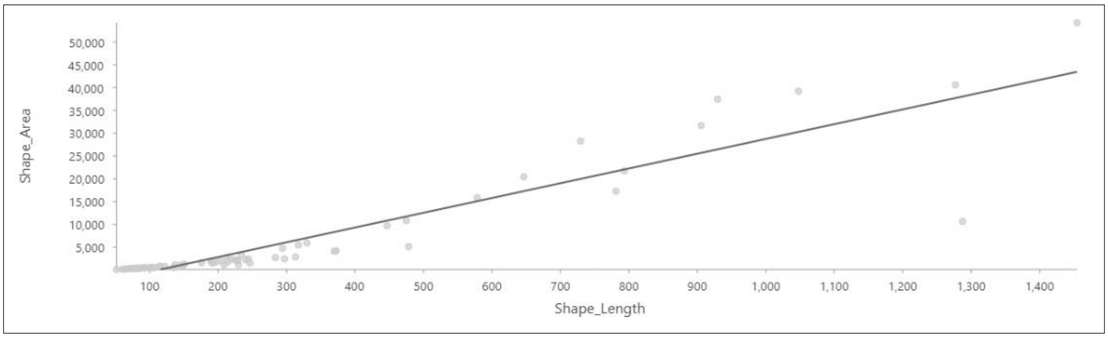


Figure 32(e): QQ plot representing NV_2 (less dense deciduous trees)



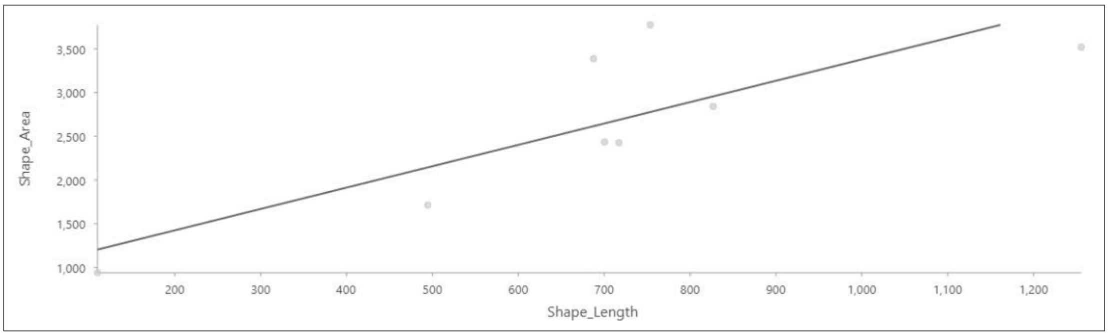
Resultant equation: **y = -1382.2 + 20.1*x*** (R-square value = 0.9)

Figure 33(a): Scatter plot and resultant equation representing WATER_BODIES (water bodies)



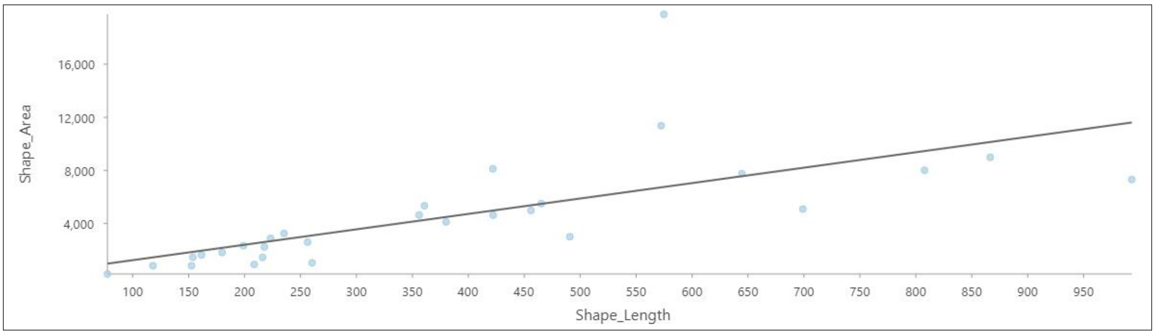
Resultant equation: **y = -3613.0 + 32.4*x*** (R-square value = 0.84)

Figure 33(b): Scatter plot and resultant equation representing BLDGS_1 (for compact informal settlements)



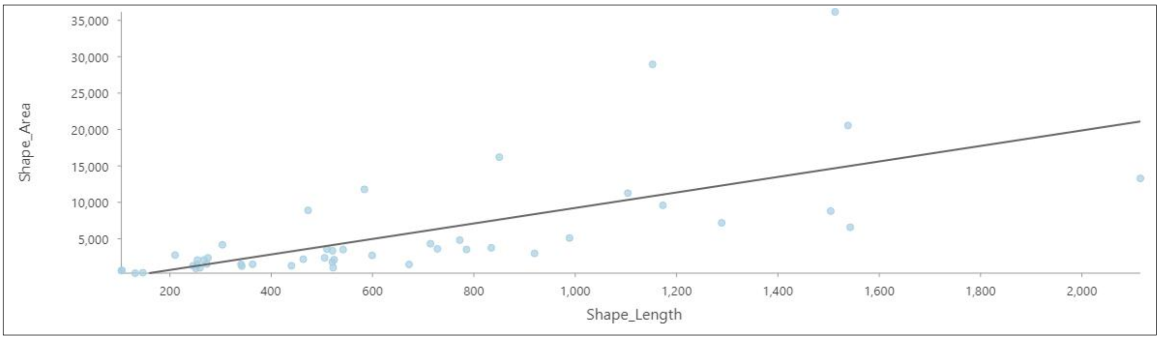
Resultant equation: **y = 935.8 + 2.44*x*** (R-square value = 0.66)

Figure 33(c): Scatter plot and resultant equation representing ROADWAYS (roads and pedestrian pavements)



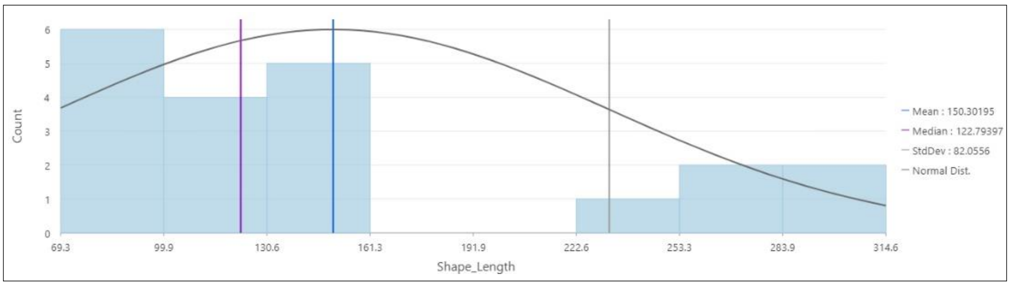
Resultant equation: **y = 63.2 + 11.6*x*** (R-square value = 0.46)

Figure 33(d): Scatter plot and resultant equation representing NV_1 (groundcover, bushes and shrubs)

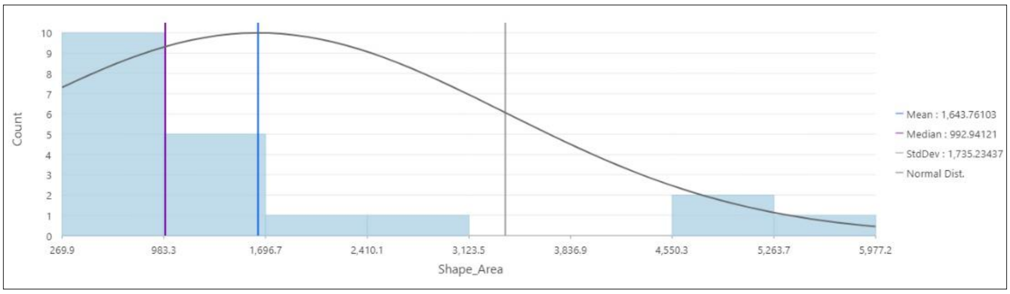


Resultant equation: **y = -1410.6 + 10.6*x*** (R-square value = 0.46)

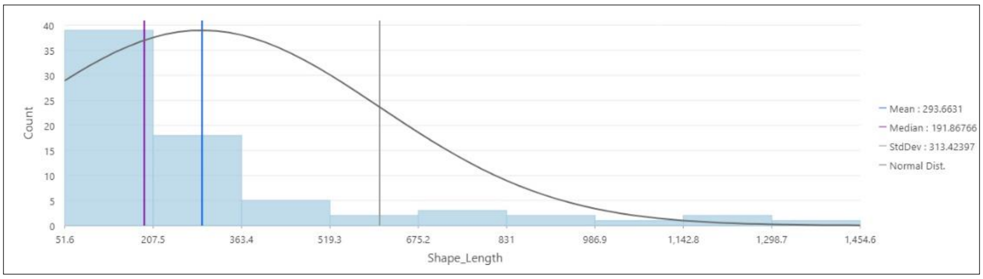
Figure 33(e): Scatter plot and resultant equation representing NV_2 (less dense deciduous trees)



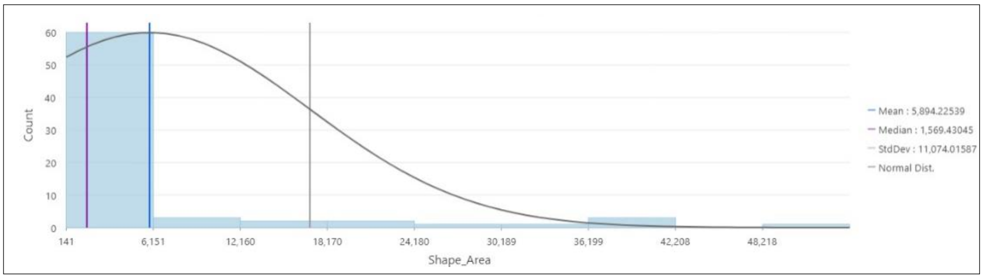
1 (a)



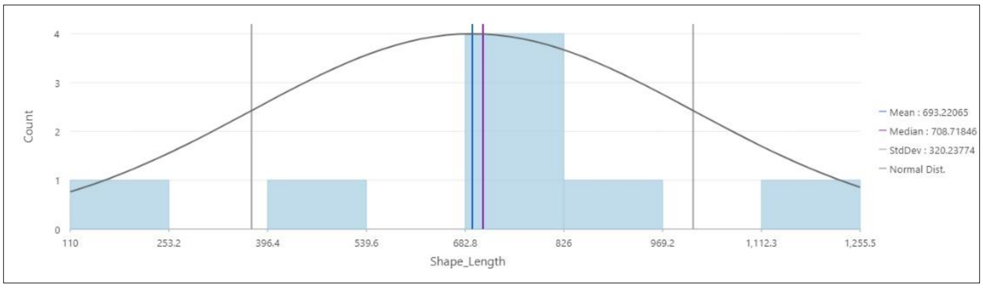
1 (b)



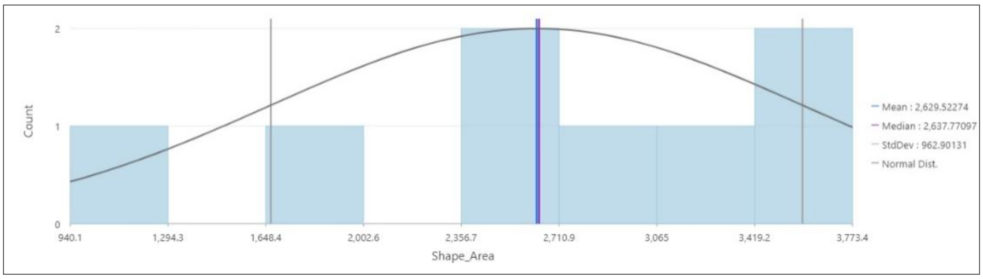
2(a)



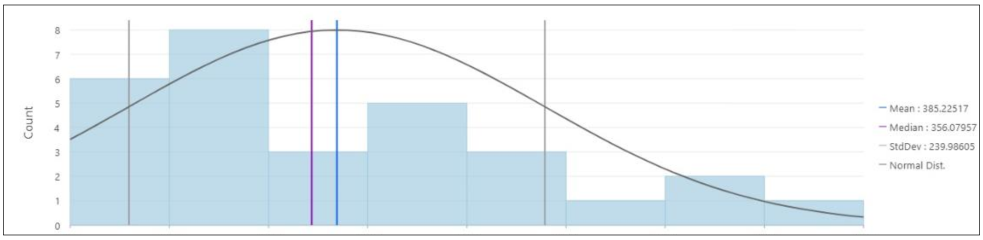
2(b)



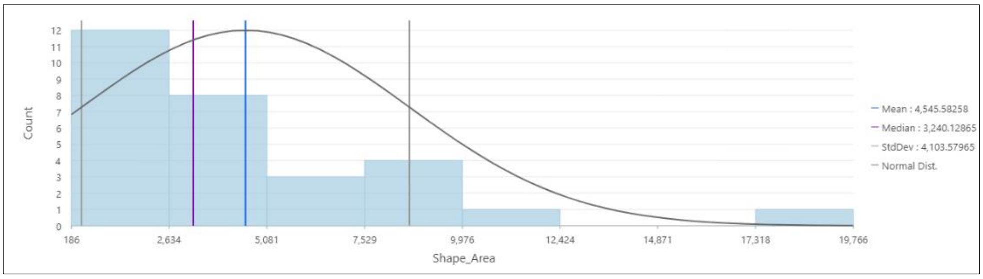
3(a)



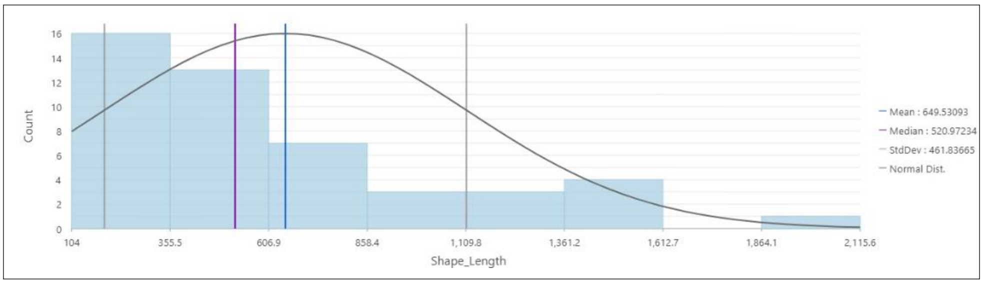
3(b)



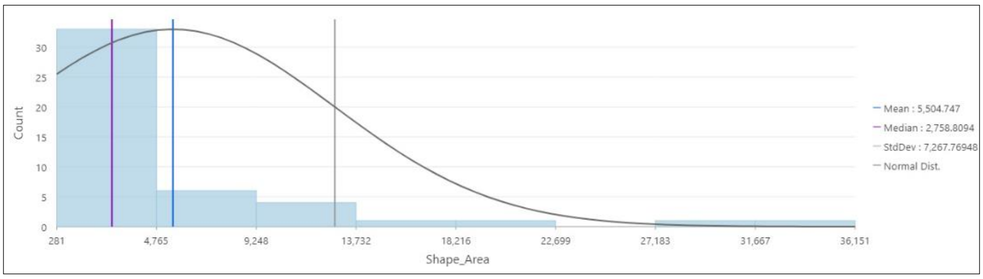
4(a)



4(b)



5(a)



5(b)

Figure 34: Histograms (a) representing estimated areas and (b) representing estimated lengths or perimeters for (1) WATER_BODIES (water bodies), (2) BLDGS_1 (for compact informal settlements), (3) ROADWAYS (roads and pedestrian pavements), (4) NV_1 (groundcover, bushes and shrubs), (5) NV_2 (less dense deciduous trees)

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The analysis for the stretch-5 comprising the Ward No. 41 area (mostly residential settlements) under the jurisdiction of Bidhannagar Municipal Corporation (BMC) in Kolkata is being done as follows:

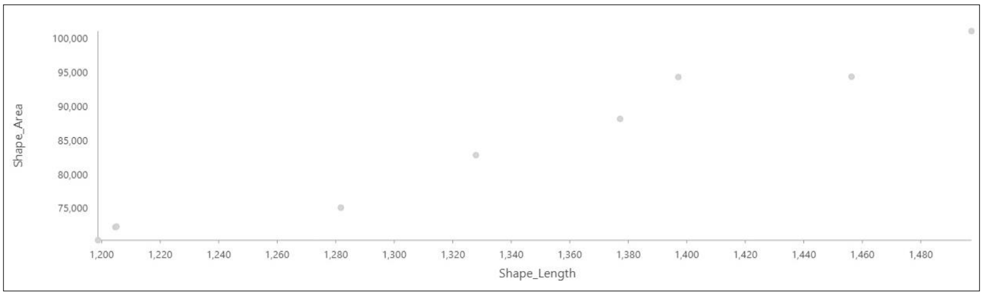


Figure 35(a): QQ plot representing BLDGS_2 (for low rise settlements)

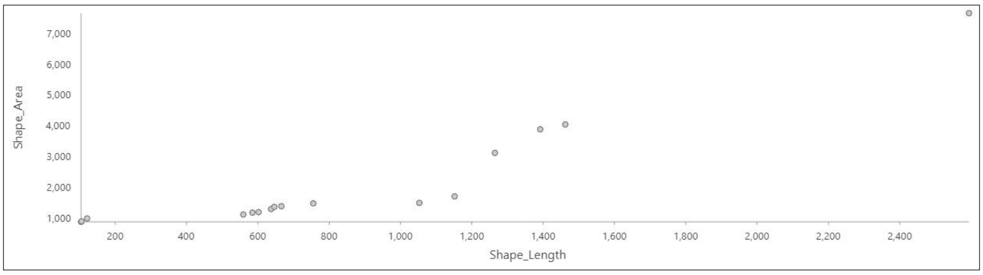


Figure 35(b): QQ plot representing ROADWAYS (roads and pedestrian pavements)

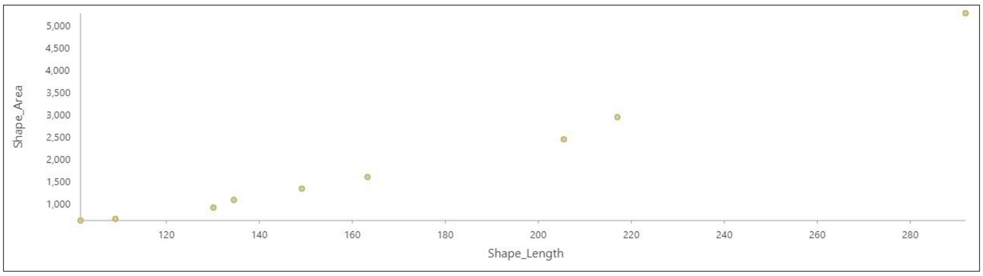


Figure 35(c): QQ plot representing NV_1 (groundcover, bushes and shrubs)

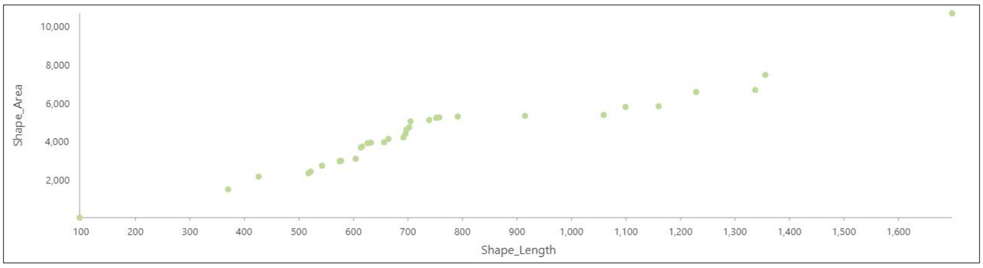


Figure 35(d): QQ plot representing NV_2 (less dense deciduous trees)

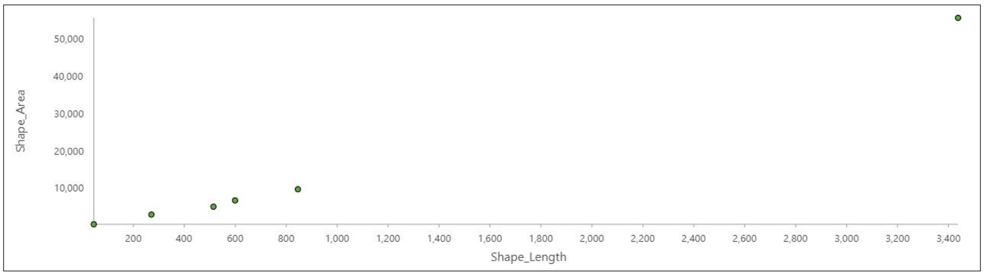
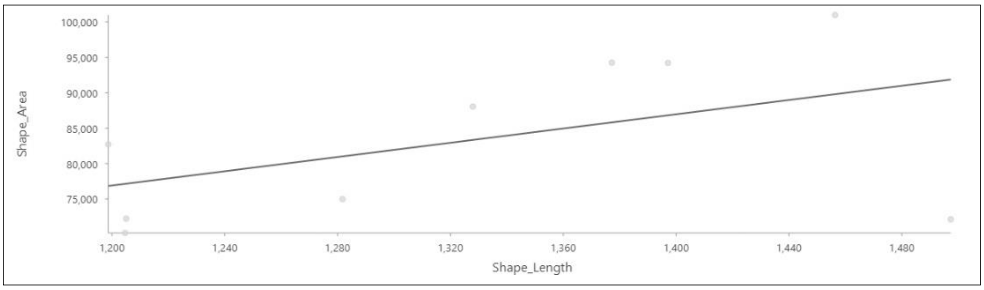
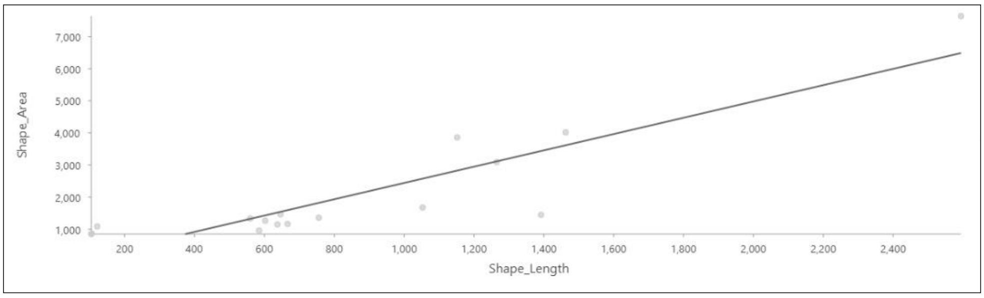


Figure 35(e): QQ plot representing NV_3 (dense deciduous trees)



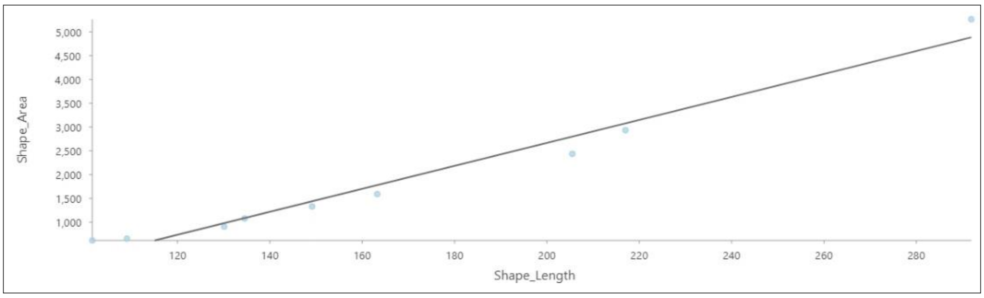
Resultant equation: $\mathbf{y = 16531.4 + 50.3}\boldsymbol{x}$ (R-square value = 0.24)

Figure 36(a): Scatter plot and resultant equation representing BLDGS_2 (low rise settlements)



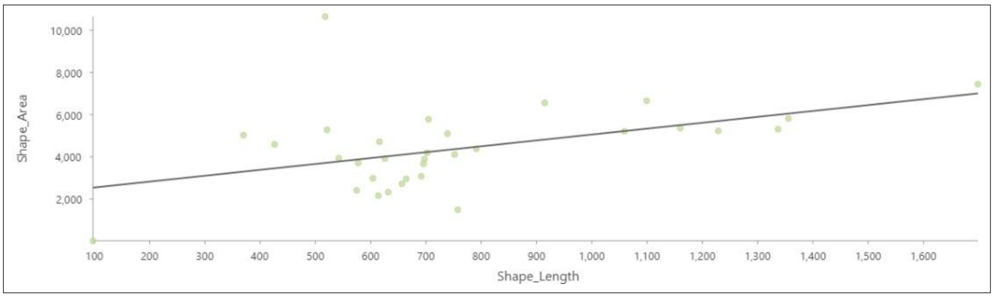
Resultant equation: $\mathbf{y = -98.9 + 2.54}\boldsymbol{x}$ (R-square value = 0.8)

Figure 36(b): Scatter plot and resultant equation representing ROADWAYS (roads and pedestrian pavements)



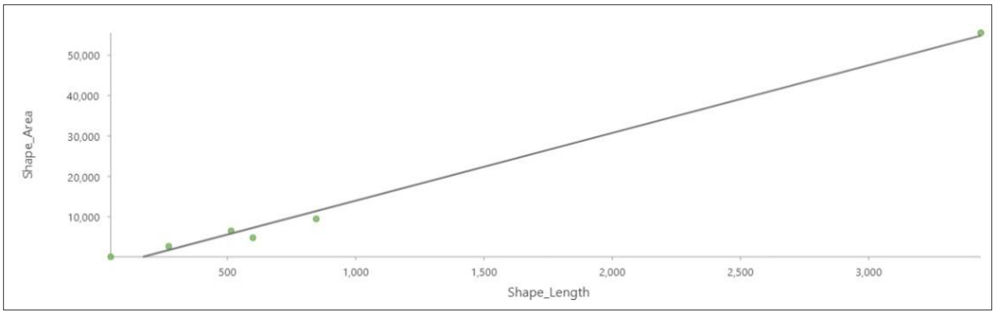
Resultant equation: $\mathbf{y = -2159.9 + 24.1}\boldsymbol{x}$ (R-square value = 0.97)

Figure 36(c): Scatter plot and resultant equation representing NV_1 (groundcover, bushes and shrubs)



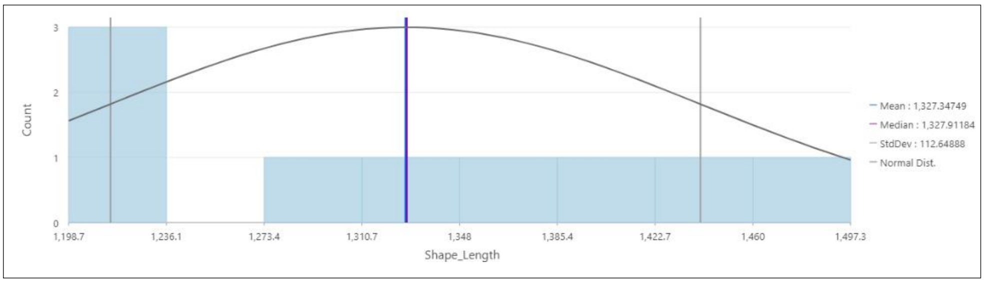
Resultant equation: **y = 2269.4 + 2.8*x*** (R-square value = 0.213)

Figure 36(d): Scatter plot and resultant equation representing NV_2 (less dense deciduous trees)

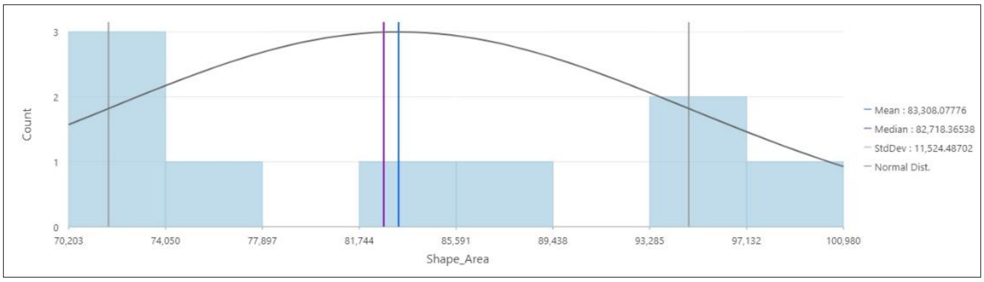


Resultant equation: **y = 2762.3 + 16.8*x*** (R-square value = 1)

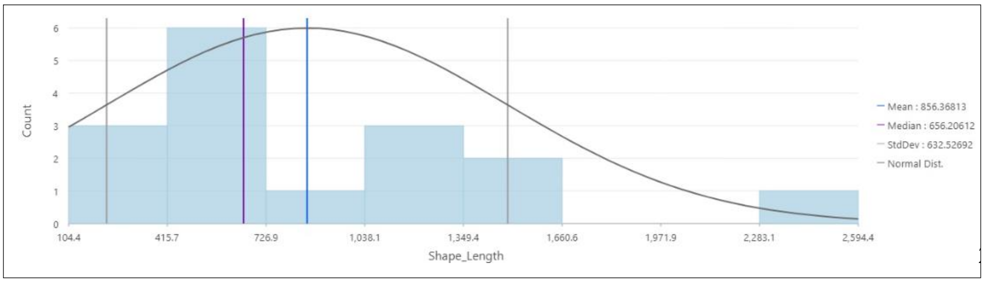
Figure 36(e): Scatter plot and resultant equation representing NV_3 (dense deciduous trees)



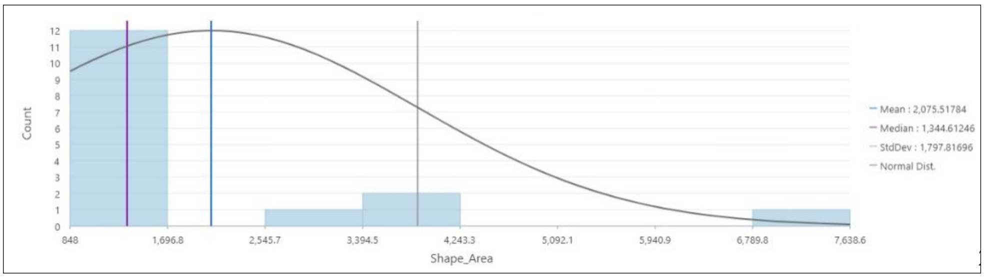
1 (a)



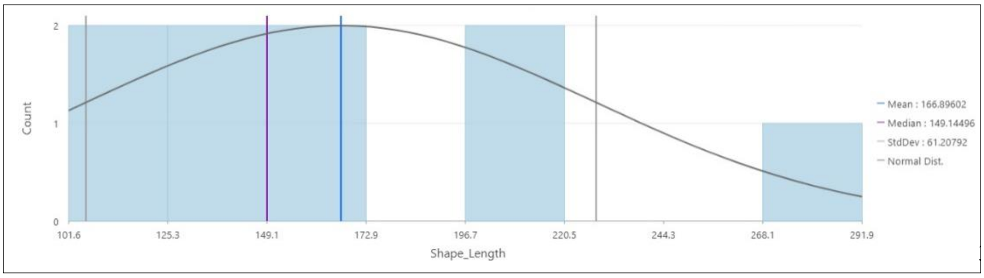
1 (b)



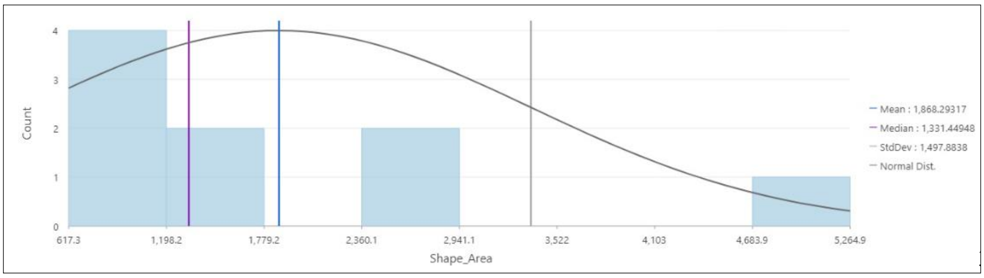
2 (a)



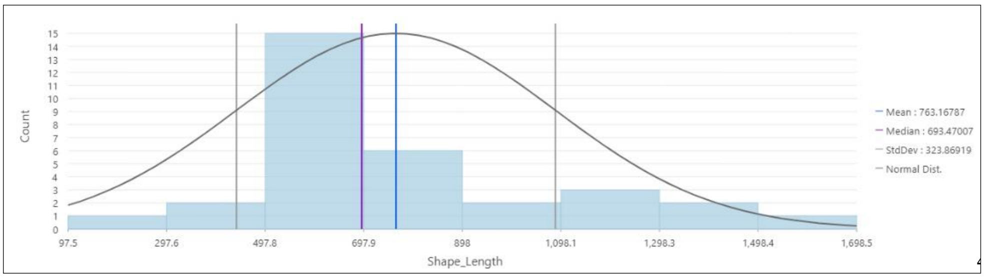
2 (b)



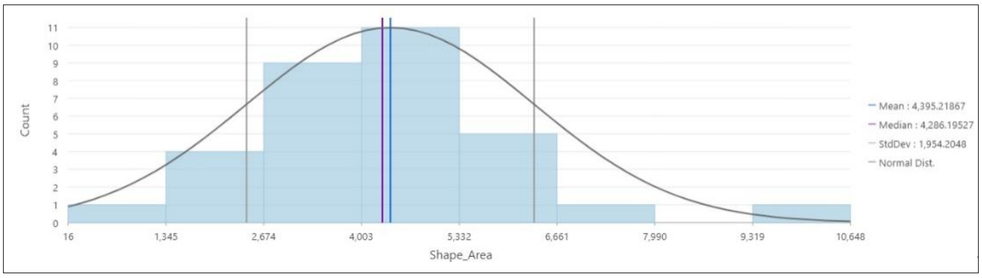
3 (a)



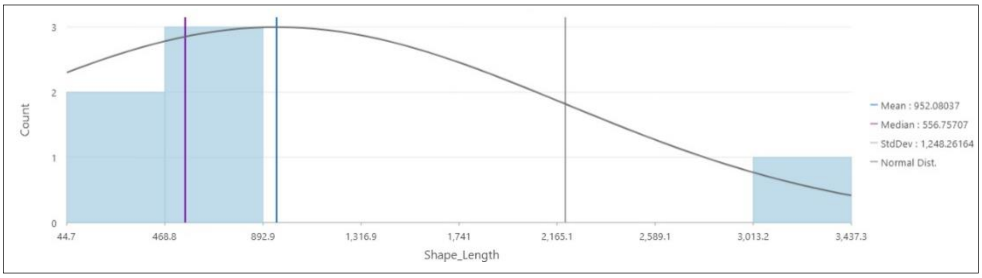
3 (b)



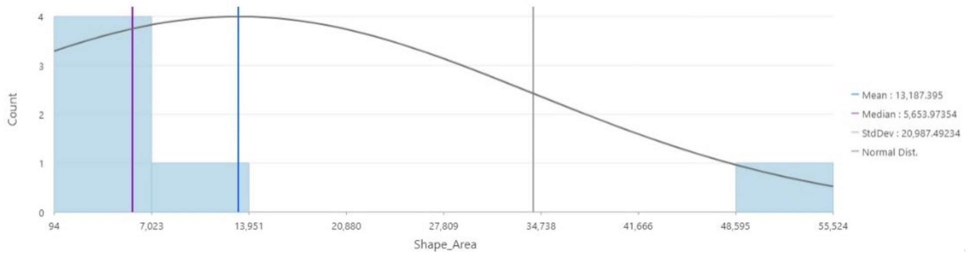
4 (a)



4 (b)



5 (a)



5 (b)

Figure 37: Histograms (a) representing estimated areas and (b) representing estimated lengths or perimeters for (1) BLDGS_2 (low rise settlements), (2) ROADWAYS (roads and pedestrian pavements),(3)NV_1 (groundcover, bushes and shrubs), (4) NV_2 (less dense deciduous trees),(5)NV_3 (dense deciduous trees)

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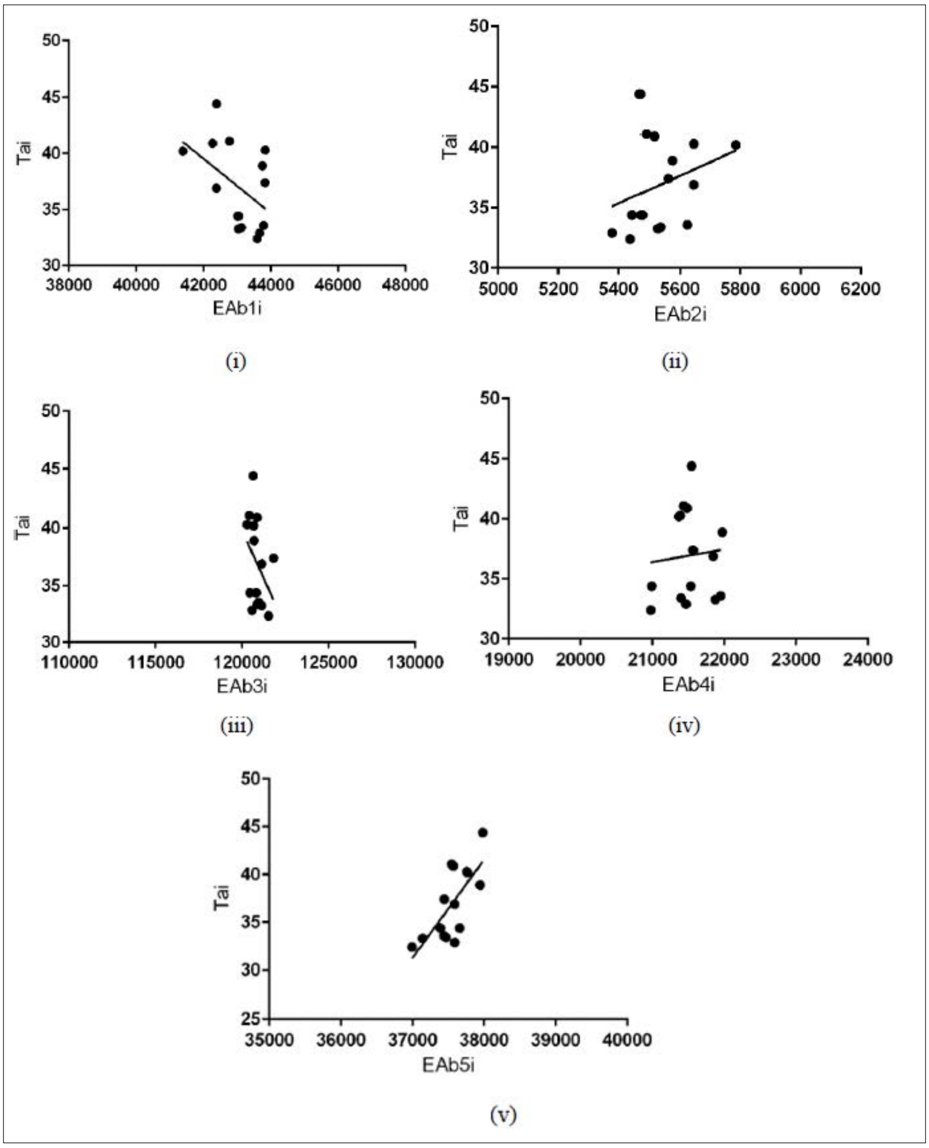
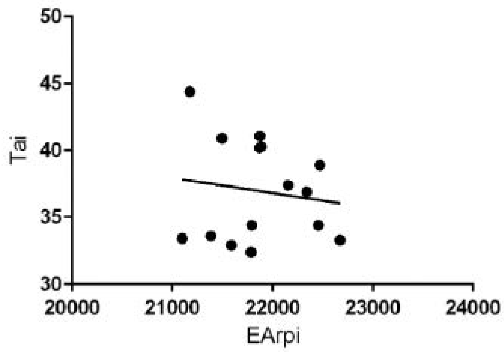
Establishment of Relationships – Regressional Analyses of Meteorological and Spatial Parameters with The Help of OTC Indices
This step and section has been implemented in three major steps as follows:

Step 1: By linear regression, the average estimated area (EA) values of the different urban infrastructural components have been related with the mean air temperature (Ta) values by considering EA values as stationary or independent on the x – axis and Ta values as non-independent on the y – axis

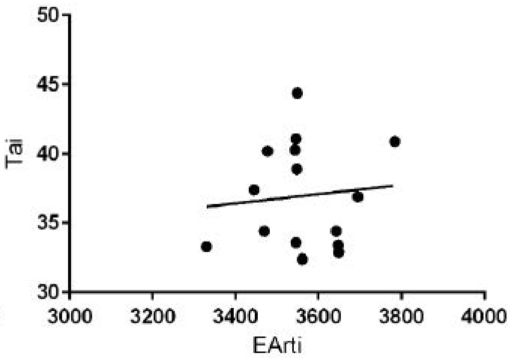


Equations corresponding to: (i = 1 to 15)

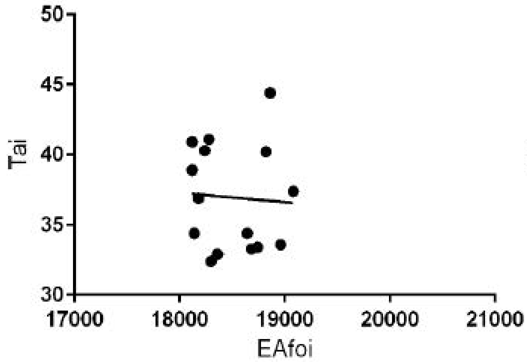
(i) Tai = -0.002430 EAb1i + 141.6 (R-square value = 0.2143)
(ii) Tai = 0.01134 EAb2i – 25.85 (R-square value = 0.09527)
(iii) Tai = -0.003303 EAb3i + 436.1 (R-square value = 0.1317)
(iv) Tai = 0.001065 EAb4i + 14.04 (R-square value = 0.007164)
(v) Tai = 0.01027 EAb5i – 348.6 (R-square value = 0.5127)



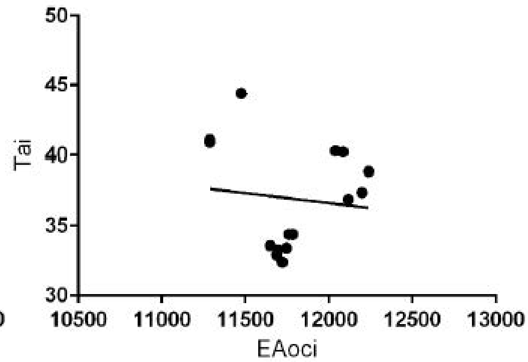
(vi)



(vii)



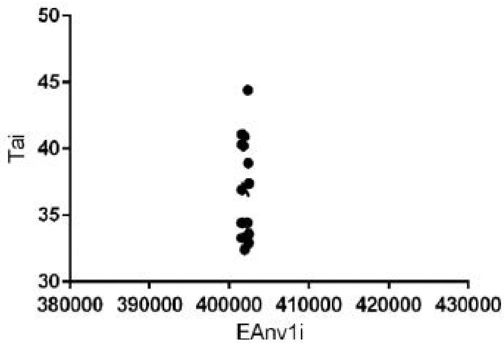
(viii)



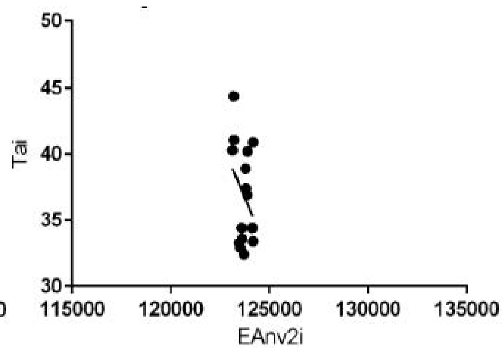
(ix)

Equations corresponding to: (i = 1 to 15)

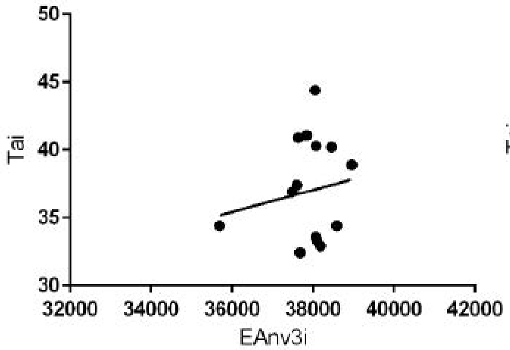
(vi) Tai = -0.001137 EArpi + 61.84 (R-square value = 0.02059)
(vii) Tai = 0.003343 EArti + 25.06 (R-square value = 0.009603)
(viii) Tai = -0.0006553 EAfoi + 49.09 (R-square value = 0.003382)
(ix) Tai = -0.001434 EAoci + 53.87 (R-square value = 0.01299)



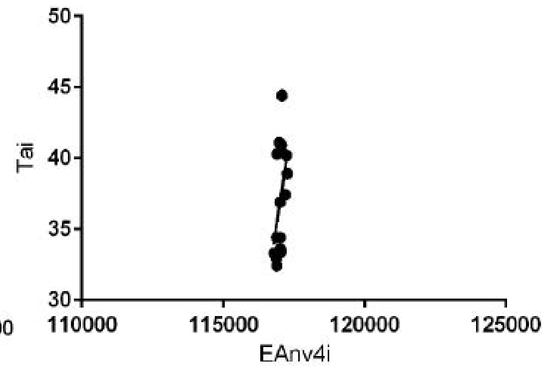
(x)



(xi)



(xii)



(xiii)

Equations corresponding to: (i = 1 to 15)

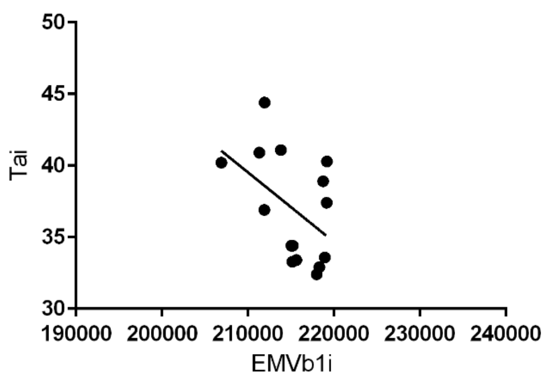
(x) Tai = -0.001211 EAnv1i + 523.8 (R-square value = 0.01419)

(xi) Tai = -0.003477 EAnv2i + 467 (R-square value = 0.1020)

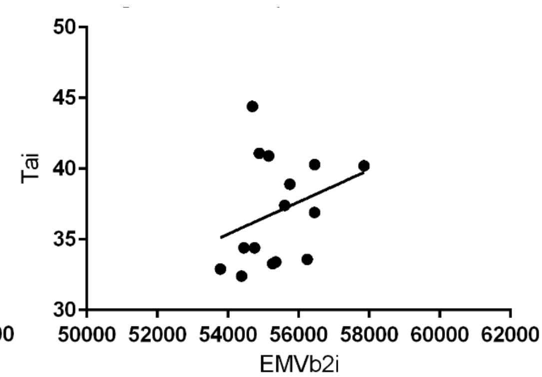
(xii) Tai = 0.0008071 EAnv3i + 6.379 (R-square value = 0.02388)

(xiii) Tai = 0.01355 EAwbi – 1549 (R-square value = 0.2378)

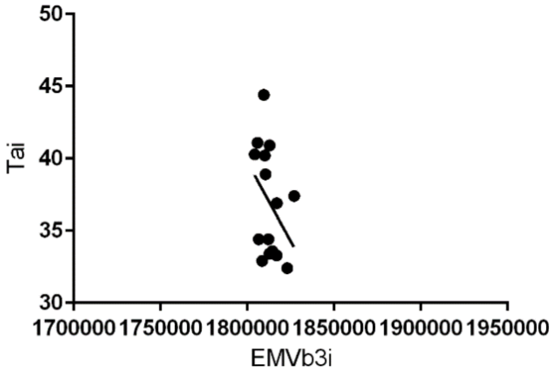
Step 2: By linear regression, the average estimated maximum volume (EMV) values of the different urban infrastructural components have been related with the mean air temperature (Ta) values by considering EMV values as stationary or independent on the x – axis and Ta values as non-independent on the y – axis



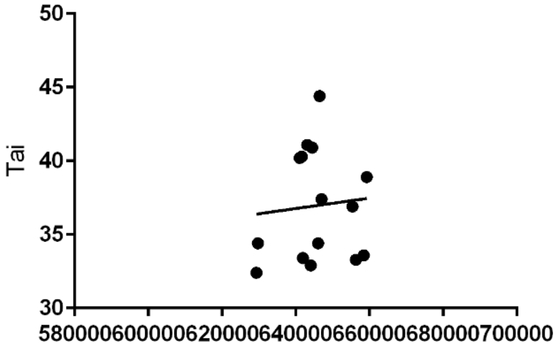
(xiv)



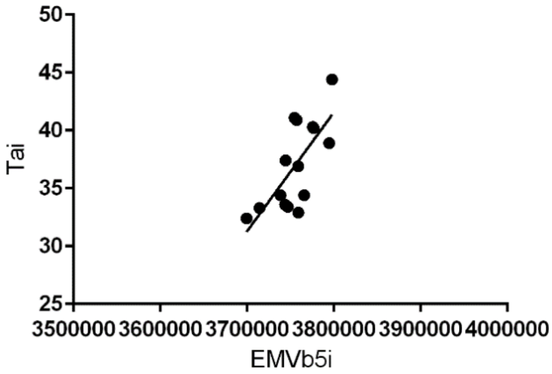
(xv)



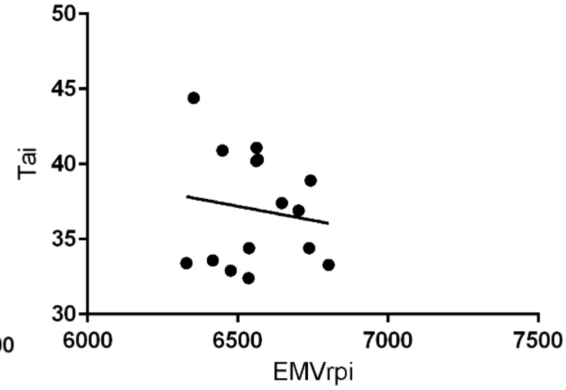
(xvi)



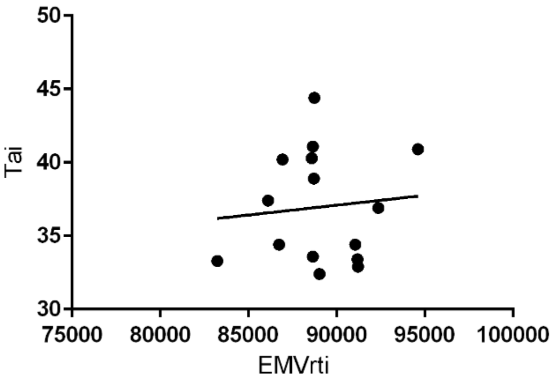
(xvii)



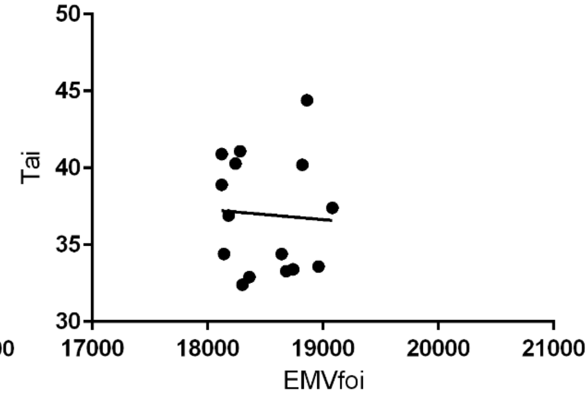
(xviii)



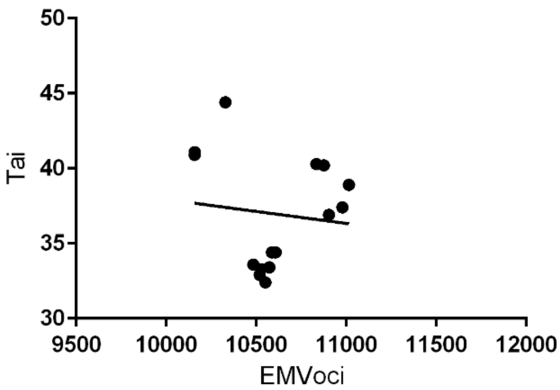
(xix)



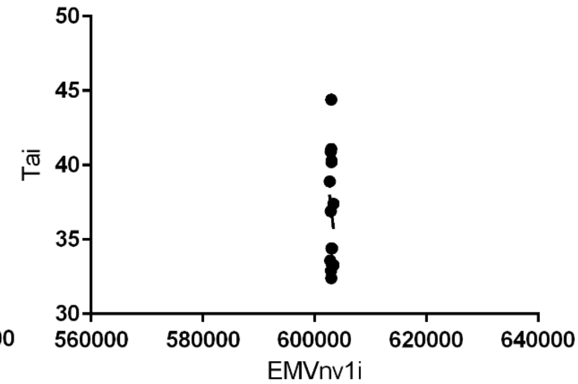
(xx)



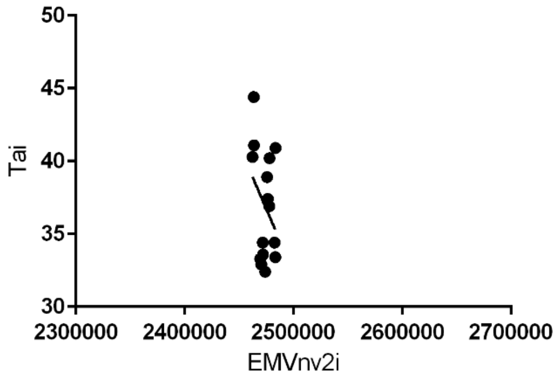
(xxi)



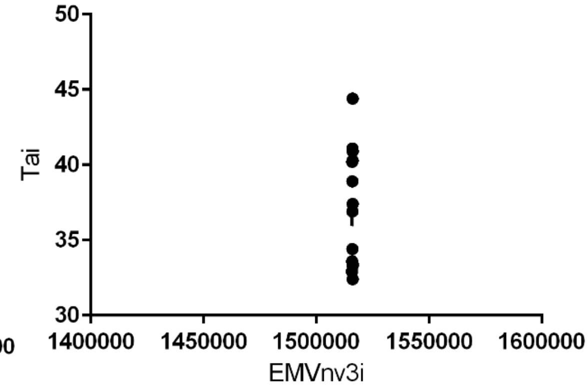
(xxii)



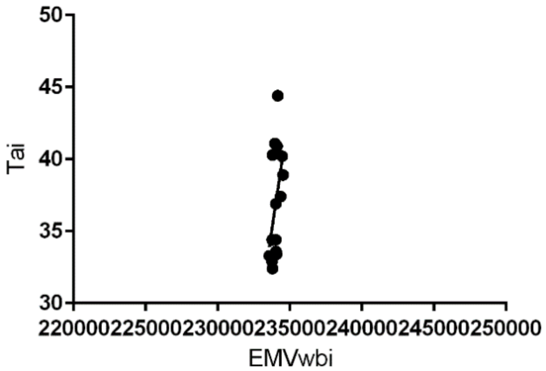
(xxiii)



(xxiv)



(xxv)



(xxvi)

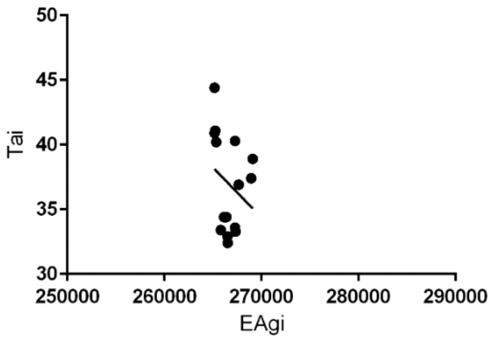
Equations corresponding to: (i = 1 to 15)

(xv) Tai = -0.0004859*EMVb1i + 141.6 (R-square value = 0.2143)
(xvi) Tai = 0.001134*EMVb2i - 25.85 (R-square value = 0.09527)
(xvii) Tai = -0.0002202*EMVb3i + 436.1 (R-square value = 0.1317)
(xviii) Tai = 3.552e-005*EMVb4i + 14.04 (R-square value = 0.007164)
(xix) Tai = 0.0001027*EMVb5i - 348.6 (R-square value = 0.5127)
(xx) Tai = -0.003757*EMVrpi + 61.61 (R-square value = 0.02019)
(xxi) Tai = 0.0001337*EMVrti + 25.06 (R-square value = 0.009603)
(xxii) Tai = -0.0006553*EMVfoi + 49.09 (R-square value = 0.003382)
(xxiii) Tai = -0.001596*EMVoci + 53.89 (R-square value = 0.01303)
(xxiv) Tai = -0.003302*EMVnv1i + 2028 (R-square value = 0.02546)
(xxv) Tai = -0.0001739*EMVnv2i + 467.0 (R-square value = 0.1020)
(xxvi) Tai = 0.005232*EMVnv3i – 7894 (R-square value = 0.01844)
(xxvii) Tai = 0.006775*EMVwbi – 1549 (R-square value = 0.2378)

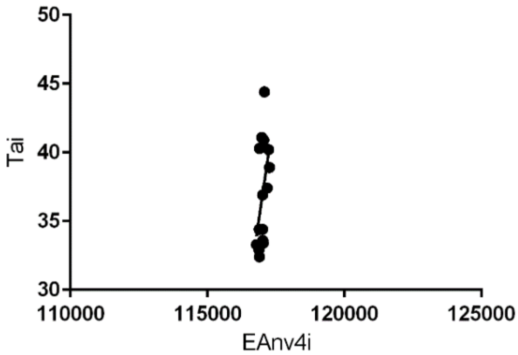
Step 3: First, all the previous components have been unified mathematically and then, by linear regression, the total average estimated maximum volume (EMV) and estimated area (EA) values of the different stretches have been related with the mean air temperature (Ta) values by considering EMV and EA values as stationary or independent on the x – axis and Ta values as non-independent on the y – axis

Considering i = 1 to 15,

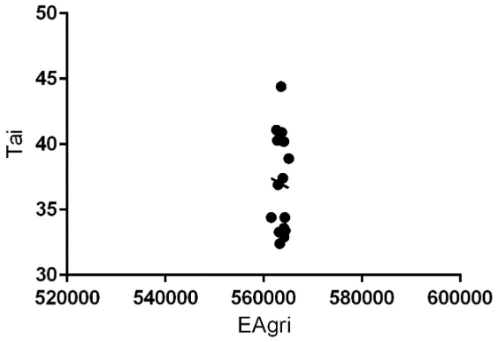
ΣEAgi = ΣEAb1i + ΣEAb2i + ΣEAb3i + ΣEAb4i + ΣEAb5i + ΣEArpi + ΣEArti + ΣEAfoi + ΣEAoci
ΣEAbi = ΣEAwbi
ΣEAgri = ΣEAnv1i + ΣEAnv2i + ΣEAnv3i
ΣEMVgi = ΣEMVb1i + ΣEMVb2i + ΣEMVb3i + ΣEMVb4i + ΣEMVb5i + ΣEMVrpi + ΣEMVrti + ΣEMVfoi + ΣEMVoci
ΣEMVbi = ΣEMVwbi
ΣEMVgri = ΣEMVnv1i + ΣEMVnv2i + ΣEMVnv3i



(1)

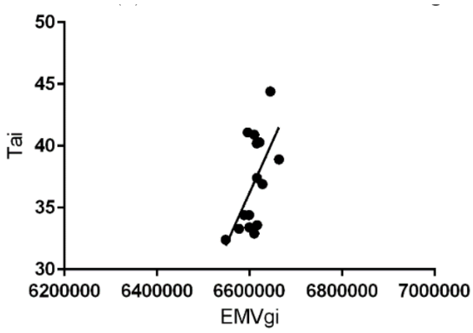


(2)

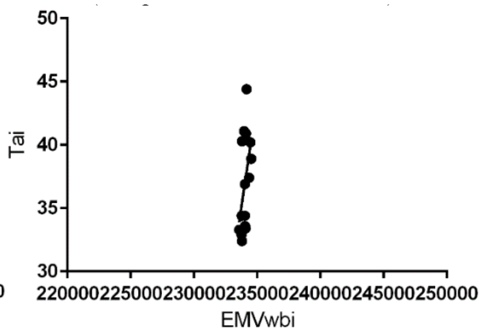


(3)

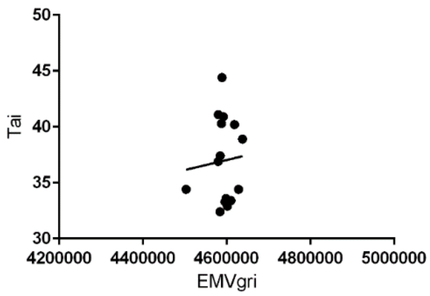
(1) Tai = -0.0007736*EAgi + 243.2 (R-square value = 0.06773)
(2) Tai = 0.01355 EAbi – 1549 (R-square value = 0.2378)
(3) Tai = -0.0002110*EAgri + 155.9 (R-square value = 0.002422)



(4)



(5)



(6)

(4) Tai = 8.338e-005* EMVgi - 514.1 (R-square value = 0.3580)
(5) Tai = 0.006775*EMVbi – 1549 (R-square value = 0.2378)
(6) Tai = 8.984e-006*EMVgri - 4.291 (R-square value = 0.005201)

Calculation Of Optimized Values of Spatial and Meteorological Parameters

The following values of EA and EMV are being calculated by taking the optimum preferred value of air temperature equal to 33.2°C (as evaluated before from calculated PET value after probit analysis):

(a) Tai = -0.0007736 EAgi + 243.2 (R-square value = 0.06773)
=> 33.2 - 243.2 = -0.0007736 EAgi
=> EAgi = 271458.1178903826
Calculated per stretch optimum value of EAgi = **271458.12** sq.m

(b) Tai = 0.01355 EAbi – 1549 (R-square value = 0.2378)
=> 33.2 + 1549 = 0.01355 EAbi
=> EAbi = 116767.5276752768
Calculated per stretch optimum value of EAbi = **116767.53** sq.m

(c) Tai = -0.0002110 EAgri + 155.9 (R-square value = 0.002422)
=> 33.2 - 155.9 = -0.0002110 EAgri
=> EAgri = 581516.5876777251
Calculated per stretch optimum value of EAgri = **581516.59** sq.m

(d) Tai = 8.338e-005 EMVgi - 514.1 (R-square value = 0.3580)
=> 33.2 + 514.1 = 8.338e-005 EMVgi
=> EMVgi = 6563924.20244663
Calculated per stretch optimum value of EMVgi = **6563924.20** cu.m

(e) Tai = 0.006775 EMVbi – 1549 (R-square value = 0.2378)
=> 33.2 + 1549 = 0.006775 EMVbi
=> EMVbi = 233535.0553505535
Calculated per stretch optimum value of EMVbi = **233535.06** cu.m

(f) Tai = 8.984e-006 EMVgri - 4.291 (R-square value = 0.005201)
=> 33.2 + 4.291 = 8.984e-006 EMVgri
=> EMVgri = 4173085.485307213
Calculated per stretch optimum value of EMVgri = **4173085.49** cu.m

(g) Optimum maximum height in each stretch of grey infrastructural components (dividing d by a) = (6563924.20 / 271458.12) m = **24.2 m**

(h) Optimum maximum height in each stretch of blue infrastructural components (dividing e by b) = (233535.06 / 116767.53) m = **2 m**

(i) Optimum maximum height in each stretch of green infrastructural components (dividing f by c) = (4173085.49 / 581516.59) m = **7 m**

Results and Discussion

First, let us consider the calculated optimized values of the required spatial attributes as follows:
(a) EAgi = 271458.12 sq.m, (b) EAbi = 116767.53 sq.m, (c) EAgri = 581516.59 sq.m, (d) EMVgi = 6563924.20 cu.m, (e) EMVbi = 233535.06 cu.m, (f) EMVgri = 4173085.49 cu.m

At the beginning, we have tried to correlate the estimated areas and maximum volumes of the infrastructural components (grey built-up structures i.e, low, low-rise, mid-rise, high-rise settlements, roads and pavements, railway tracks, flyovers and subways, blue infrastructure in the form of natural water bodies like wetlands, lakes and ponds and green infrastructure in the form of natural vegetation comprising shrubs, hedges, bushes, light and dense deciduous cover) with the air temperature on an individual category-wise basis. Then, in the next step, the same has been done in an unified way where the individual components of settlements of all types (low, low-rise, mid-rise and high-rise), roads and pavements, railway tracks, flyovers and sub-ways have been unified as grey infrastructure. Thereafter, the water bodies have been categorized as a whole as blue infrastructure and natural vegetation of all types (shrubs, hedges and bushes, light deciduous and dense deciduous covers) have been unified as green infrastructure. These individualized and unified approaches mainly denote the consideration of individual category-wise and overall summed up total stretch-wise estimated area and maximum volume values respectively. In both the cases, the mean air temperature values recorded in each stretch have been taken as the common dependent and non-stationary variable for the correlational analyses done by linear regression in all the stages. The R-square values depicting the proximity and inter-connectedness of the two variables in each case are being considered for further analytical discussion.

Among the grey infrastructural components, in terms of estimated areas, the settlements of the lowest and highest heights exert the maximum impacts on the air temperatures over all the stretches. That is reflected by their R-square values of 0.2143 and 0.5127 respectively. On the other hand, among the components of natural vegetation, the light deciduous cover of trees whose maximum growing height has been taken as 20 meters with a R-square value of 0.1020 exert the maximum impact on the air temperatures. As a whole, the water bodies with no sub-categories exert a considerable impact on the air temperatures with a R-square value of 0.2378. Then, after unifying all the sub-categories into three broad categories of grey, blue and green urban infrastructural components, it has been observed that overall, the grey and green infrastructure are not exerting too much effective influence on the air temperatures. On the other hand, the water bodies overall are exerting a considerable influence in regulating the air temperatures.

Considering the optimum calculated values of estimated areas and maximum volumes of the three broad categories of urban infrastructure, we compared the existing values of each on a stretch-wise manner. At the same time, the optimum calculated maximum heights of each obtained by dividing the maximum volumes by areas has also been considered. It has been observed that the optimum estimated area per stretch calculated as 271458.12 square meters is slightly more than the existing estimated areas of grey infrastructures found in each stretch. The optimum estimated maximum volume per stretch calculated as 6563924.20 cubic meters is lesser than the existing estimated maximum volumes of grey infrastructures found in each stretch. The optimum maximum height of grey infrastructures permitted in each stretch has been calculated as 24.2 meters. The decision that can be inferred from these results is that in terms of area, in case of required expansion of the various built-up structures coming under this category, further area expansion up to the optimum estimated area limit can be done up to heights ranging from 20 to 24 meters. This can regulate the preferred OTC conditions.

Next comes the water bodies which are mostly in the forms of wetlands and ponds made by partially reclaiming wetlands. This category can be referred to as the most optimized category of urban infrastructures among all. It has been observed that the optimum estimated area per stretch calculated as 116767.53 square meters is slightly lesser than the existing estimated areas of blue infrastructures or water bodies found in each stretch. The optimum estimated maximum volume per stretch calculated as 233535.06 cubic meters is also slightly lesser than the existing estimated maximum volumes of water bodies found in each stretch. The optimum maximum depth of water bodies feasible in each stretch has been calculated as 2 meters which is exactly equal to their maximum depth considered during the calculation of estimated maximum volume quantities. The suggestion that can be taken from here is that water bodies are already existing in proper magnitudes and forms within our study locations. They just require proper maintenance within the jurisdiction of urban laws and by-laws in order to ensure that their magnitudes do not undergo any kind of degradation to ensure preferred OTC levels.

Finally comes the natural vegetation of three sub-types (groundcovers, bushes and shrubs, light and dense deciduous covers of trees) that have been unified under green infrastructures. This category has been observed to be very crucial in terms of optimum existence and regulation of optimum OTC levels. It has been observed that the optimum estimated area per stretch calculated as 581516.59 square meters is considerably more than the existing estimated areas of green infrastructures or overall natural vegetation found in each stretch. The optimum estimated maximum volume per stretch calculated as 4173085.49 cubic meters is considerably lesser than the existing estimated maximum volumes of natural vegetation found in each stretch. The optimum maximum height of natural vegetation sustainable in each stretch has been calculated as 7 meters which denotes the trees that mostly comprise the light deciduous cover and exist in the forms of linear or non-linear clusters. This result holds tremendous significance in terms of the fact that in order to maintain the optimum OTC levels, initiatives to replant such tree species in the forms of green zones or lines should be taken.

Conclusion

In this study, we have focused in details on two major spatial attributes – Estimated Area (EA) and Estimated Maximum Volume (EMV) of urban infrastructural components. To ensure the regulation of optimized OTC conditions, the measured average values of air temperatures in each stretch have been correlated with each and every spatial attributes both individually and on an unified category-wise basis. This entire process can be inferred to have helped us in the following ways:

a. It has helped in understanding the variation of the different infrastructural components (grey, blue and green) in the different stretches in terms of their estimated areas and maximum volumes. Hence, it has also made the work of understanding the correlation of the same with meteorological parameter of air temperature more convenient. In the due process, the simultaneous variation or trend of both the spatial attribute and meteorological parameter has become easier to be understood in terms of their deviations from the optimum limits.

b. Fundamental processes like LCZ mapping and arithmetic techniques like mean, median and standard deviation have been involved through ArcGIS to keep the calculations making the base framework for the optimization and pre-modelling tasks compact and simplified. These processes along with the generation of near tables have made the process of analyzing the spaces easier thereby helping us to consider several features and characteristics that can turn out to be effective for the immediate next stage of outdoor thermal conditions analysis of the base model.

c. The calculations have helped us in keeping the approach parametric as aimed at the beginning. These parameters and attributes have enabled to keep the methodology focused on studying the direct ways in which the outdoor thermal conditions (mainly air temperature and relative humidity) are being affected by these chosen spatial attributes. The same process will enable us to conduct the model space analysis and thereafter simulate the optimized scenarios in the subsequent stages.

In the same phenomenon, the subsequent modelling, analysis and simulation stages will help us in furbishing the required guiding principles that are our ultimate objectives. These guiding principles will help us in implementing the urban LCZ scale measures that are necessary to enhance the existing OTC conditions up to the optimized levels. In the perspectives of strategic ecosystem monitoring and assessment, these approaches are expected to utilize the research outcomes on a comprehensive scale [24].

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