INFLUENCE OF CLIMATE FOR THERMAL COMFORT AND LAND COVER ELEMENT CHANGE IN SUBURBAN CITES IN SRI LANKA

A DISSERTATION SUBMITTED TO THE UNIVERSITY OF MORATUWA, SRI LANKA AS A PATIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN ARCHITECTURE

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ABSTRACT

ABSTRACT

It is known that Urbanization has great correlation with its own micro climate. In planning and urban design point of view urbanization has to consider and deal about the changes of the physical environment / land cover. (Built areas, tree covered areas, green / grass areas, open areas, water bodies, roads and paved areas). To identify the effects of urbanization to a particular area and its micro climate, use climate data and Arial photographs to calculate as thermal comfort and physical element change.

The study based on Time Rate Change Method, series of arial photographs from the Sri Lanka Survey Department taken within last three decades uses to get the idea of land cover / physical element change occurred to select cites. Climatic data (Day and night temperature, Maximum and minimum relative humidity) taken from the Meteorological Department provide basis to calculate monthly day and night thermal comfort of the cities over the research period of 30 years.

The study considered three suburban cities in Sri Lanka belongs to three climatic zones of the island; Galle, Trincomalee and Nuwara Eliya. For the study considered 1 km radius circle around the meteorological stations. As the research period take 30 years from 1971 up to 2000.

The study highlights the urban physical element change; occurred due to urbanization during the studied period contributed to thermal comfort variations. Finally this research pint out some very important relationships between urban physical element change and thermal comfort change.

CHAPTER ONE

Introduction

1.0 CHAPTER ONE
AN INTRODUTION FOR THE STUDY

1.1 INTRODUCTION

Climate has great contribution to forming cities or urban areas. Now it is identified that urbanization itself affects more to its own micro – climate of cities. In urban design and planning point of view urbanization must then be essential to recognize as a factor, which to the physical urban element change of a city. Followings are identified as the physical elements of an urban city.

1. Built Areas
2. Roads
3. Paved Areas
4. Green Covered Areas
5. Open Areas

It is important to study how the physical urban environment change is happened and happening in Sri Lanka and find out how much it effects to the micro climate of the cities. To get an overall idea about the way it happens through out the country selected three diverse cities in the island, which belongs to three different climatic zones other than Colombo Metropolitan Region.

1.2 SCOPE OF STUDY

From ancient civilizations up to now cities were formed and urbanized. When considering Sri Lanka it has a history of more than 2500 years. From there up to the beginning of the 19th century many cities were appeared, developed, and functioned as capitals of the country. Ancient Anuradhapura and Polonnaruwa was two of very highly organized urban cities within them. But it is difficult to identify a continuous development in one of certain capitals. Therefore change of physical elements due to urbanization is almost nearly a perpendicular line in a graph drawn according to the time.

But when the island becomes a colony of Europeans, especially the British's, identifiable development started. Because of the Coffee, Tea, Rubber, and Cinnamon cultivations; roads small, railways, large commercial centers and ports were developed. At that period the industrial revolution accelerate the urbanization process.

After having the independence from the British Empire in 1948 physical development of the country further increased. When introducing the open economy to the country it made the path to a rapid urbanization.

Especially commercial centers or the cities were highly urbanized. Migration of people from rural areas to the cities also increased the urbanization.

Due to this change previously existed micro - climate of urban centers changed within last three decades and which is now effects to its own environment. Also because of the urbanization buildings, residential zones, factory areas are overlapping each other. And due to lack of properly developed road networks the traffic congestion in the urban areas also high. By the heat emits from the buildings, vehicles and the people effects to the microclimate and reduces the thermal comfort of the city. When the urbanization takes place it effects to the original physical environment (including physical elements) of the city, which is also effects to the thermal comfort and the microclimate of the city. Therefore it is useful to find out how much urbanization involves for the change of microclimate, environment, and physical elements, in a city.

Increasing of built areas has a potential to reducing of green areas ', by doing this research study

can identify the relationship between these kind of statements, and by doing such kind of research study to a rural or to a sub - urban cities belong to different climatic zones of the island, can get an idea about other cities also within those regions which has unique climatic conditions.

1.3 JUSTIFICATION

Climate has a great connection with human beings and their day today activities. Even to start civilizations in an early period of the world. Ancient civilizations like Mohedojaro – Harappa in Arabia, Nile valley in Egypt, Indu valley in India, and Howangho in China happened near the riverbanks. Those settlements were based on agriculture because the climate was very good for farming. It has very clear evidence that climate responded to formation of these civilizations.

Sri Lanka is an island which is in the Indian ocean between latitudes north 5 55 and 9 51 , and is situated some 60 miles from the south western tip of India. It has an area just over 25,000 squire miles, a length of about 270 miles and a maximum width of 140 miles. The northern and north central areas of the island form a single plain that extends from sea to sea and continuous along the coast to the other parts of the island. In the south central part of the island the land rises to form a plateau having an area of 4000 squire miles. A range of mountains runs across the center of the plateau, the principle peak being over 8000 feet high. According to the topography and its existence in the Indian Ocean, and the elevation; the island has various micro – climates other than its average hot humid climate, which is common to all the tropical countries.

Various microclimates helped to the formation of cities in the island. When urbanization takes place in the cities rapidly, haphazard developments and developments without proper master planning happened. Therefore again urbanization creates great impact on the microclimate of the

city wise versa. This is very important situation to study, and by doing a research can be find out whether this is true for Sri Lankan sub urban cities and how it happens, and how the microclimate and urban physical elements changed due to the urbanization.

Here when microclimate changes overall thermal comfort of the city area getting change. In a situations like that Architects, designers and Planners have to think about the microclimate of the city, physical environment and it's changing pattern, and the thermal comfort of that city area which is very important for future developments.

1.4 BRIEF METHODOLOGY

For the research study select three cities out of the Colombo Metropolitan Region and belongs to three different climatic zones, which has different climatic conditions.

1. Galle - belongs to the wet zone of the island a city based on trade due to its natural harbor, tourism, and has very long history.
2. Trincomalee - belongs to the dry zone of the country and it is a commerce based port city, which has very ancient history.
3. Nuwara Eliya - belongs to the mountain climatic zone of the country and it is a city based on tourism and an agriculture.

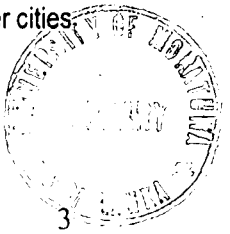
From the research study first will try to understand the historical trends evolved to form these cities and then the study diverts to the urbanization happened during last 30 years which is more crucial.

Therefore the study framed on the Time Rate method.

1. Study focus on to physical element change of the selected areas like built areas, streets, paved areas, green areas etc.
2. Use the day and night temperature and humidity values to indicate the change of thermal comfort and micro - climate of the area. (Monthly)
3. Use series of Arial photographs taken from the Survey department in different years to have a clear understand about the changing patterns of the physical elements.

By doing this study, try to highlight the urban physical element change occurred due to urbanization process during the studied period of time contributed to thermal comfort variations; and hope to find out some of the very important relationships between climate and urban physical element change and thermal comfort change in the selected cities.

For the study cities selected diversely because according to the results of the study hopes to get a rough idea about the change of physical elements due to the urbanization in the other cities belongs to the major climatic zones in the island.



CHAPTER TWO

Related Background Studies

2.0 CHAPTER TWO

RELATED BACKGROUND STUDIES

2.1 CLIMATE

The word 'climate'comes from the Greek 'Klima', referring to the inclination of the Sun. 'Climate' can be defined as the integration in time of weather conditions, characteristics of a certain geographical location. Simply the climate is an average condition to a specific geographical area, analytically and statistically derived from the weather data collected through a certain long period of time.

At the global level climates are formed by the differential solar heat input and the uniform heat emission over the earth's surface. The movement of the air masses and of moisture bearing clouds is driven by temperature differentials and strongly effects to the climate. Also land and sea areas, being variable, react in many differential ways to the atmosphere, which is constantly circulating in a state of dynamic activity. Day-by-day variations in a given constitute the weather, where as climate is the long-term synthesis of such variations. Weather is measured by using thermometers, rain gauges, barometers, and the other instruments; but the study of climate relies on statistics. Now, such statistics are handled effectively by using computers with advanced softwares. A simple long them summary of weather changes however, is still not a true picture of climate. To obtain this, requires the analysis of daily, monthly, and yearly patterns.

Besides the effects of solar radiation, climate is also influenced by the complex structure and composition of the atmosphere and by the ways in which it and the ocean transport heat. These for any given area on earth, not only the latitude (the sun inclination) must be considered. But also the elevation, terrain, distance from the sea, relation to the mountain ranges influenced to the climate.

Climate has profound effect on vegetation and animal life, including humans. It plays statistically significant roles in many physiological processes, from conception and growth to health and disease. Humans in turn can affect climate by changing their environment, both through alterations of earths, (physical element change) and the introduction of pollutants and chemicals such as carbon dioxide into the atmosphere.

2.1.1 ELEMENTS OF CLIMATE

To describe climate use variety of climatic elements and climate comes as collection of these elements. Following are the main elements of the climate.

1. Temperature - Dry bulb temperature

2. Humidity - Express as relative humidity, or the wet bulb temperature or dew point temperature may be stated, from which the humidity deduced.
3. Air movement (Wind) – Both wind speed and direction is indicated.
4. Precipitation – The total amount of rain, hail, snow, dew, measured in rain gauges and expressed in mm per hour unit time, (day, month, year).
5. Cloud Cover – Based on visual observation and expressed as a fraction of the sky Hemisphere covered by clouds, (measured in tenths or octas = eights)
6. Sun Shine Duration – The period of clear sun shine (when a shape shadow is cast), Measured by a sun shine recorder which burns a trace on a paper strip, expressed as hours per day or month.
7. Solar radiation – measured y a pyranometer. On an unobstructed horizontal surfaces and recorded either as the continuously varying irradiance (w/m2) or through an electronic integrator as irradiance over the hour or day.

From above elements four are directly affecting the thermal comfort. Those are temperature, humidity, solar radiation and the air movement. These are the most important constituents of climate for the purpose of building design rainfall data may sometimes be needed such as for designing drain systems and assessing the level of precipitation.

1. Temperature - monthly mean of daily maxima (deg C)
   monthly mean of daily minima (deg C)
   standard deviation of distribution
2. Humidity - early morning relative humidity (in%)
   early afternoon relative humidity (in %)
3. Solar radiation - monthly mean daily total (in MJ/m2 or Wh/m2)
4. Rainfall - monthly total (in mm)

2.1.2 FACTORS AFFECTING THE CLAIMATE

There are various climates in the world. For there variations majorly three factors are affecting.

1. Temperature
2. Precipitation
3. Atmospheric Pressure and Winds

2.1.2.1 TEMPERATURE

Temperature is a measurement of heat of an area or an object. I measure by using thermometers. Internationally there are two scales using for measure the temperature.

a. Faronhight
b. Degrees Celsius

Globally temperature varies for region-to-region, time-to-time and place-to-place. There are many factors affecting to these temperature variations.

i. LATITUDINAL LOCATION

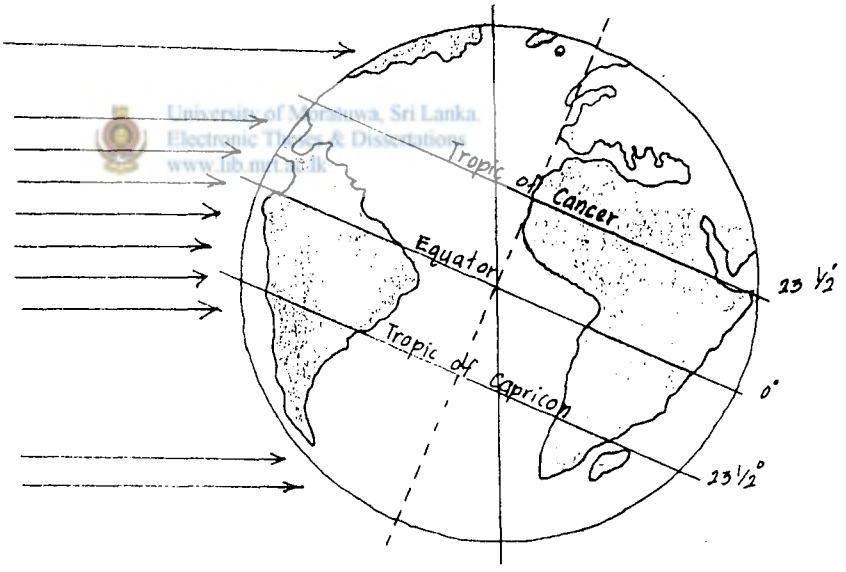


Figure 1. The way solar radiation comes to the Earth

The earth considered as a global planet and it rotates around it's own axis while rotating around the sun in an ellipsoid path of an angle of 23 ½^0. Therefore the earth hasn't getting equally distributed solar radiation throughout the surface of the hemisphere, which is facing to the sun. To the region near the equator solar radiation comes almost perpendicular to the surface while to the other areas in an angle. This creates a temperature variation in the earth.

ii. DISTANCE FROM THE SEA

The land heat up and cool quicker than the water. Even in same latitude temperature can vary in coastal areas and inland areas due to this reason. In summer land is warmer than the sea and in winter sea is warmer than the land. Therefore in summer temperature of the coastal are as are lower than the inland areas. In the winter temperature of the inland areas are higher than the coastal areas. According to the distance from the sea in the summer and winter temperature variation of the inland is large.

iii. ELEVATION FROM THE MEAN SEA LEVEL

Global atmosphere warms more by getting heat from the warmed earth surface than the solar radiation. Therefore air layer near the earth surface is warmer than the higher layers of the atmosphere. According to that temperature varies at the higher elevations than the sea level. Normally each and every uprising of 100m from the mean sea level, temperature reduces by .64 degrees Celsius. Other than these major factors,

Mountain barriers,

Land and water bodies,

Cloud cover,

Oceanic currents, also slightly affects to the temperature variations.

2.1.2.2 PRECIPITATION

Amount of sky water receives by an area within a given period of time known as precipitation. The sky water can receive as rain, hail, snow, and dew. It measures by using rain gauges and expressed in mm per unit time, (day, month, and year). Precipitation occurs by cooling and freezing the humidity within the atmosphere. But globally there's no distribution of equal precipitation. Moisture content of the wind, distance from the sea, temperature variation from the equator to poles and mountain barriers are affecting to the global variation of precipitation.

2.1.2.3 ATMOSPHERIC PRESSURE AND WINDS

Atmospheric pressure means the pressure of air. The amount of air masses over a place creates this pressure. Therefore atmospheric pressure in the sea level is higher than the mountains. It measures by using barometers; and expressed in mm s. generally considered the world is having both high and low zones of atmospheric pressure.

Ideally hot air can be thought of as rising by convection along the equator and sinking near the poles. Thus, the equatorial belt tends to be a region of low pressure and calms, interrupted by thunderstorms associated with towering cumulus clouds. Because of the calms, this belt is

known as the doldrums. It shifts somewhat north of the equator in the northern summer and south in the southern summer. By contrast, air sinks in the Polar Regions this leads to high atmospheric pressure, and dry icy winds that tend to radiate outward from the poles.

Complicating this simplistic picture is the earth's rotation, which deflects the northerly and southerly components of the atmospheric circulation. Thus, the tropical and polar winds both tend to be easterlies (wind from the east) and two intermediate belts developed in each hemisphere. Around latitude 30^0 north and south is a zone of high pressure, where the upper air sinks and divides, sending air streams towards the equator. Steady northeast trade winds blow in the northern hemisphere, and southeast trade winds in the southern hemisphere. These high-pressure areas lead to arid areas on the continents but to moist air over the oceans, because of the evaporation. If these trade winds is pushes up into cooler elevation, and heavy rainfall might occur.

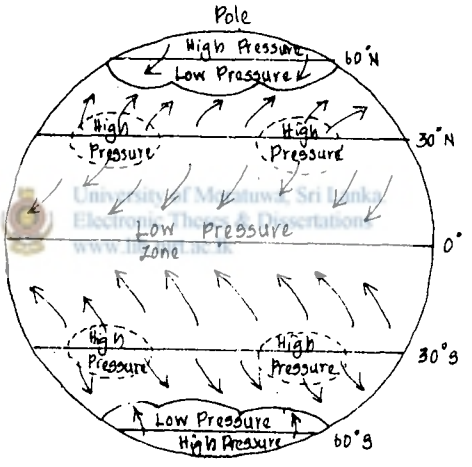


Figure 2. Global Atmospheric Pressure Zones

Around latitude 50^0 to 60^0 north and south is a belt of low pressure characterized by the prevailing westerlies, which are deflected to the south west in the northern hemisphere and to the north west in the southern hemisphere. These are relatively mild, moist winds that tend to bring frequent cyclonic precipitation to all elevations along the waste facing side of continents. The precipitation is characterized by polar fronts, where cold air from the polar easterlies drives in under warm, moist air of the westerlies, which, on cooling, drop their moisture. In winter this is the cause of moist snowfall in continents.

2.1.3 CLIMATIC ZONES OF THE WORLD

Globally climate can speak of in terms of zones, or belts that can be traced between the equator and the pole in each hemisphere. Zoning of climatic regions happen according to the factors affecting to the climate

a. Temperature
b. Precipitation
c. Atmospheric Pressure and Winds
d. Mountain barriers
e. Land and water bodies
f. Cloud cover
g. Oceanic currents

Considering these factors world divides into three major climatic zones.

1. Tropical Climatic Zone
2. Temperate Climatic Zone
3. Cold Climatic Zone

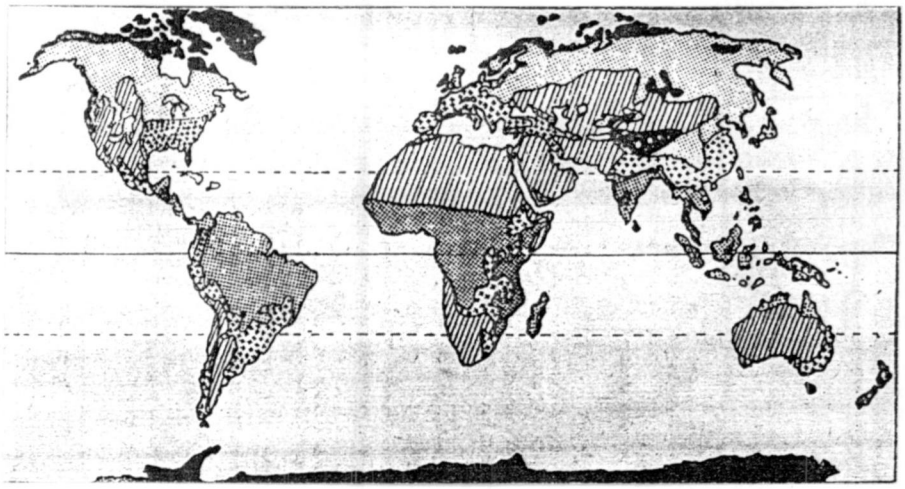


Figure 3. Climatic Zones of the World

2.1.3.1 TROPICAL CLIMATIC ZONE

Belong the area between tropic of Cancer in 23 ½ ^{0} northern latitude and the tropic of Capricorn in 23 ½ ^{0} southern latitude. Subjecting to the direct solar radiation and 12 hours of daytime is unique to the region. Due to the factors like distance from the sea, elevation and wind can identify four sub climatic regions within the zone of tropical climate.

i. Equatorial Climate
ii. Tropical Monsoonal Climate
iii. Tropical Savannah Climate
iv. Hot Desert Climate

2.1.3.2 TEMPERATE CLIMATE

Belongs the area between tropic of Cancer up to circle of Arctic in northern latitudes 23½^0 and 66 ½^0 in northern hemisphere, and area between tropic of Capricorn up to circle of Antarctic in southern latitude 23 ½ ^{0} and 66 ½ ^{0} in southern hemisphere. It is a combination of climates in cold and tropical climates. Basically temperate climatic zone has five sub climatic zones.

i. Mediterranean Climate
ii. Cool Temperate Oceanic Climate
iii. Cool Temperate Continental Climate
iv. Cold Temperate Climate
v Warm Temperate Climate

2.1.3.3 COLD CLIMATIC ZONE

Area spread from the Arctic and Antarctic circles towards the poles belongs to this climatic zone. Throughout the year this region has cold climate that can divide into two sub climatic zones.

i. Tundra Climate
ii. Arctic Climate

2.1.4 THE TROPICAL CLIMATE

Among the three climatic zones the zone of tropical climate spreads between north and south latitudes 23 ½ ^{0}. Throughout the year tropical region gets equal sun light. 12 hour day and night time is unique to the region. But there are some various sub climates that can clearly visible due to, latitudinal location, elevation from the mean sea level, and distance from the see,

mountain barriers, land and water bodies, and oceanic water streams. For example, elevation of each and every 100m from the mean sea level temperature reduces from .64^0 C.

Normally the tropical zone is warmer than the other climatic zones due to its direct subjection of solar radiation. The rain comes from the monsoonal winds, convection, and depression.

The macro level wind patterns in the equatorial tropics are generally weak. Even the large-scale monsoonal systems, bringing changes in wind direction and speed, are more little practical help due to this weak overall wind pattern. (Nieuwolt, 1968:32)

Monsoonal wind comes from the southwest and northeast directions in different seasons of the year. Generally the region is having equally distributed rainfall during the year.

The constancy of rain is a special characteristic of the equatorial tropics, as opposed to humid tropics. While there are no 'dry months' in the equatorial tropics, there are definite dry zones of at least two months or more in the humid tropics. Due to increase wetness, the equatorial tropics are cloudier; consequently lower daytime and higher nighttime temperature and higher relative humidity are prevalent. (Nieuwolt, 1968:33)

But this can vary according to the above-indicated factors, which affects to the climate. Even for the formation of deserts, distance from the sea to that particular area is directly involves. Moisture of the wind blows over the oceans is absorbing by the initial parts of the vast land areas, and rest of the wind blows as dry with very less moisture content. Therefore rain is very rare to these regions. The Sahara is one of the best examples for deserts, which is in the middle of an African continent, formed due to distance from the sea.

Within tropical climate there's having four sub climates, which are identifiably different in characteristics from each other.

2.1.4.1 EQUITORIAL CLIMATE

The region between 5^0 to 10^0 northern and southern latitudes is having equatorial climate. Annually spread equally distributed temperature and heavy rainfall is the basic characteristics of this region. In general the annual temperature is 27^{0}C and annual average maximum and minimum temperature difference is below 5^{0}C. Daily temperature difference is in between 10^{0}C 25^0 C day and night. Annual precipitation is higher than 2000mm consists of heavy rains with thunder and lightning. April and November are the highest rain falling months.

Because of the equally distributed temperature, solar radiation and rainfall equatorial topics are very suitable for vegetation growth. Rain forests or the Selvas, equatorial ever green rain forests are the specific ecological systems in the region and having highest bio diversity of plant and animal life. Amazon in South America, Congo in Africa, Sinharaga in Sri Lanka, and the forests

of Java, Sumatra and other Southeast Asian islands are the best examples for the evergreen rain forests within tropics having the world's highest bio diversity.

2.1.4.2 EQUATORIAL MONSOONAL CLIMATE

This specific climate is in the regions of India, Southeast Asia, northern Australia and east coasts of Africa. The word monsoon came from the Arabian word 'monseen'. According to the low and high-pressure zones developing in the Asian continent and the ocean, monsoonal winds are blowing. When summer, monsoonal winds coming from the oceans it contains lots of moisture and brings heavy rains. When the winter, it comes through vast land areas the moisture content of the wind is less. Therefore the rainfall is less. Annul rainfall is above 1500mm. Vegetation growth is like Selvas and the trees of these areas have high commercial values.

2.1.4.3 EQUATORIAL SAVANNAH CLIMATE

African, Australian, Brazilian, and Venezuela's grasslands belong to this climatic zone. The region is demarcating by the direction of equator from the equatorial tropical climate and the direction of poles from the hot deserts. Climatically in summer this zone subjected to the convectional rainfall of the equatorial belt. Therefore seasonal climatic changes can identify, throughout the year and these areas having high values of temperature. It is generally between 24^0 C and 32^0 C. it is only very rarely drops the temperature below 21 c. near the equatorial climatic zone the annual rainfall is 1500mm in an average and near the desert boundaries it decreases to 380mm annual rainfall. Three seasons can clearly identify within the savannah climatic zone.

i. Hot Dry Season
ii. Cold Dry Season
iii. Rainy Season

Because of the high evaporation and long dry season it is not suitable for vegetation growth. Unique natural vegetation type is the grassland. Umbrella shaped trees can visible in long distance away from each other.

2.1.4.4 HOT DESERT CLIMATE

African, Arabian countries and Australia has the desert climate, which is very hot. Day and night temperature variation is much higher than in other climatic zones. Annual rainfall is below 380mm. There's no unique character for vegetation otherwise small bushes, various types of cactuses, and different kinds of small plants having beautiful flowers in a short rainy seasons and bushes of different kinds of grasses. Palm trees are the highest trees growing in the desert climate.

2.1.5 CLIATE OF SRI LANKA

Sri Lanka is an island situated in the Indian Ocean, northern hemisphere of the world. Climatically it belongs to the equatorial tropics. Exact location of the island is in between latitudes north 5' 5" and 5' 5" and longitudes 79' 49" and 81' 5" of east; near the southwestern tip of Indian sub continent. It has an area of 65610 km^2, the length of about 44 7 km from north to south and maximum width of 227 km; from east to west.

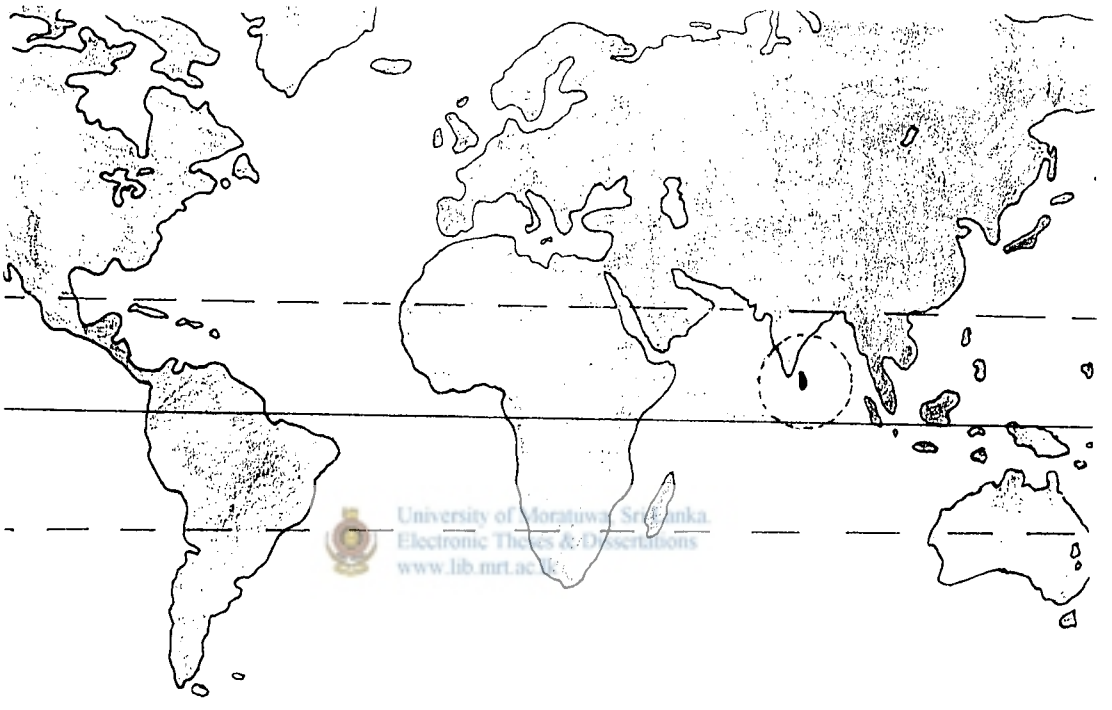


Figure 4. Location of Sri Lanka

Geographically the island can divide into three major zones.

i. Coastal plane
ii. Intermediate place
iii. Central hills

i. **Coastal Plane** - Area between 0m to 30m contour lines belongs to the coastal pane , and the vegetation of this region shows clear difference form the other areas. One of the special features in coastal planes is marsh having near the river calidos. They help to control the floods, and is a well balanced eco system found form the tropical regions.

ii. **Intermediate Plane** - From 30m up to 300 m contour lines takes as the intermediate plane. 1/3 of Sri Lanka's areas therefore belong to this geometrical zone. Intermediate plane spread widely in the northern part of the island and as tight belt to the southern part.

iii. **Central hills** - As central hills consider the area above from the 300m contour line. This region is 1/5th of the total area of the country, and consists of mountain ranges, planes and deep valleys.

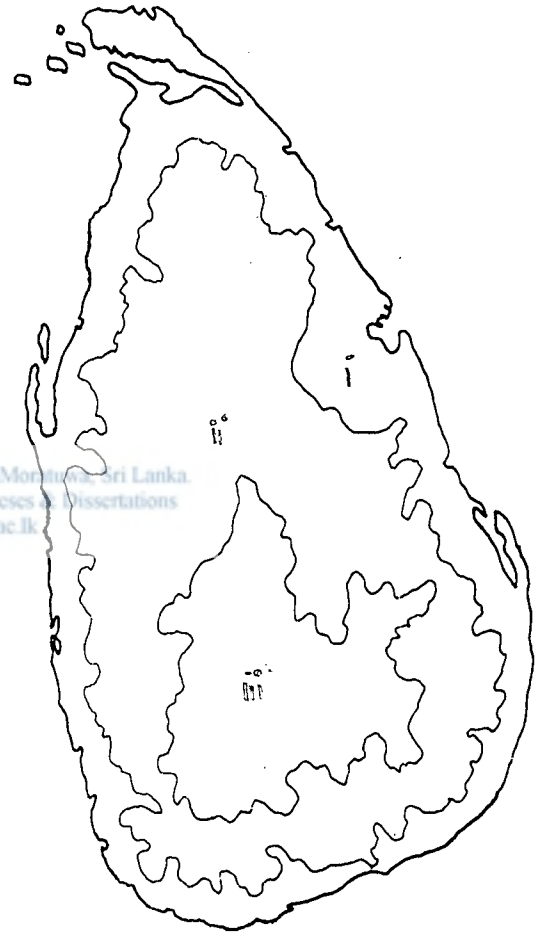


Figure 5. Geographical Zones of Sri Lanka

According to the famous geologist Adoms, Sri Lanka formed into three stages. When - Studying a cross section taken from Colombo to Pothuvil these three stages can identity clearly. From that the oldest part of the country is the central hills and youngest is the coastal planes.

Due to topography and it's existence in the Indian ocean Sri Lanka has various micro climates; other than its average hot humid climate which is common to the equatorial tropics. Normally relative humidity of the atmosphere varies from about 70% during the day to about 90% - 95% at night, rising as temperature drop even Mannar and Hambantota the direst areas of the island, humidity drops to about 60%. Average temperature of the country varies for m 18^{0}C to

30°C. But in the central hills according to the height, temperature drops to nearly 6°C and occasionally more than that.

According to the factors effecting to the climate the island can divide into three major climatic zones.

i. Dry zone
ii. Wet zone
iii. Mountain zone

i. Dry Zone - Northern and Eastern parts of the country belongs to the dry zone. Having rain by the north east monsoon; and the average rainfall is below 2000 mm. there is a clearly identifiable dry and wet season within the year. Dry season spread form February to August; and average temperature is higher than 27°C. After the independence had from the British government the local government orientated the multi – purpose development projects based on irrigation in the dry zone. Therefore most of the areas now had agricultural settlements. (Under the Galoya and Mahaweli multi –purpose development projects).

ii. Wet zone - Areas of western and southwest belongs to the wet zone. South west monsoonal winds bringing the rain to the region and average rainfall is above 2000mm. Average temperature is 27°C and relative humidity is nearly 79%. Because of the equally distributed rain and solar radiation wet zone is very good for vegetation growth. Majority of the island's population is in the wet zone; therefore rapid growth of urbanization can visible in the wet zone.

iii. Mountain zone - Areas above 1070m from the mean sea level belongs to the mountain zone. Due to the higher elevation temperature is low; and it is nearly 15°C. Mountain zone has equally distributed rainfall throughout the year and the air is full of water vapors. Temperature in the daytime not goes more than 22°C and drops to 6°C or more in the nighttime.

2.2 URBANIZATION

Most of the world civilization began near the riverbanks of the village. Water and the proper climate is the most important factors which helped for the formation of first civilizations. In that period also water used for agriculture and transportation cities were began due to many reasons within these civilization. Basically there were the centers used to exchanges the extra production. Through these initial small scale commercial centers, especially surplus of the agricultural crops, distributed to the negihbourhood settlements with the other goods required for their day today life like, cloths, wipes, tools need for agriculture etc.

For many centuries these urban centers functions as small cities in a domestic level. Trade happened through Land Rivers, seas and the oceans by using carts and small and large vessels; sailed by using trade winds. Especially Arabians, Chinese, Persians, Malaysian and Romans were the pioneers of trade by using ships. When trade activities increased in 14th and 15th centuries port cities developed all over the world rapidly as large commercial centers.

After found steal, coal and the steam engines began the industrial revolution form the Europe and spread all over the world. Reason for it was the large empires of the Europeans had in America, Latin America and Asian continent. Always, the mother country introduced the technology to the colonies of their own to gain maximum production out of them. Industrial revolution was the very first incident happened throughout the history, which creates the rapid urbanization all over the worlds' commercial and industrial cities.

In the Europe, America and Russia cities near the coal mines were highly dense due to the migration of people form rural areas, who wish to get the higher income than doing agriculture. To provide accommodation for them, cities developed largely not according to proper development plans. These haphazard developments with higher growth of population tend to an enormous amount of pollution within the city areas. It creates environmental and social problems also. Due to the environmental pollution living conditions and health of the citizens got badly affected.

In the other hand than the cities near large mining and industrial area, commercial centers also developed with densely packed large buildings, factories, residential zones recreational centers etc, and as well as shanties and squatter settlements. Cities like London, Paris, Brisbane, and St. Petersburg, New York are the examples for these cities and they were originally product-oriented cities. Exchange of money and goods happened in these cities and most of them were the capital cities of powerful empires. Peripheral areas like colonies, industrial and commercial, always fulfill the requirements and demands of these large highly urbanized cities.

Michel Peter smith (1980) explains in his book, "The city and social Theory" that an urban area as a place of large size, high density and socially heterorganic place. Urbanization is not a strategy orientated towards only the built environment. Btu it is a vast change takes place in social,

environmental, economical and physical elements of the city. There are three main factors highly concern when describing urbanization.

i. Demographic factor
ii. Economic factor
iii. Social factor

In a city education, infrastructure and specially the job opportunities are the high - demographic phenomena happens through the migration of people from rural to urban for seeking those job opportunities and infra structure facilities. High administration and industrial sector activities polarized in the urban areas, and promote the migration of people. Due to the migration, population growth getting increase and through that many, like lack of lands, pollution, decrease of qualify of life in urban areas and health and sanitary problems.

When considering economic factor in urbanization, economic development regarding to the urbanization associated with the structural change in the occupation. After migrating occupancy change form agricultural to non-agriculture. According to the occupation the income level change. Due to the income level there is a formation of many different social classes as high income and low income. As well as their life styles also shows differences from the rural way of life.

In social point of view urbanization created large difference in the physical environment, which is related to the life style of the people. Various social groups were formed; and an urban area is a mix of multi ethnic, multi - religious and multi cultural groups of people. Most of them are job oriented. There fore social interactions are less than rural areas. In a living situation of densely packed, people within urban society are highly orientated to the nuclear family system. The overall culture and attitudes also differ from the rural areas.

Urbanization is a social change in a vast scale. It mean deep and irrevocable changes that later all sections of a society apparently the impetus of urbanization upon society such that society gives way to urban interaction, urban values and urban demands. (McGee, 1970: 18)

Urbanization is not a bad process. It is necessary for the development of a country. But there must be a properly analyzed and planed method for it. Otherwise it creates intolerable social, economical, physical and environmental problems. Due to growth of population, density increases and supplying accommodation, sanitary and health facilities with the other entire infrastructure and basic needs within a comparatively small area is not doubt a crucial problem occurs when there is rapid urbanization.

In a situation like, there isn't a plan for the developments of a city the constructions of buildings all over the region due to high demand, creates problems form very basic levels. If there

isn't a pattern, proper grouping or zoning for the development of the city human activities and traffic flow getting confused. Impact on the natural environment, microclimate and urban physical elements is high.

2.2.1 URBANIZATION IN SRI LANKA

In Sri Lanka to the urbanization has great history. It goes back to the 4th Century BC and from there continuous throughout the history to present situation of urbanization.

2.2.1.1 HTORICAL PERIOD

The earliest information on record respecting Sri Lanka, which seems to have reached the continent of Europe, is contained in the writing of Nearchus and Onesicritus, the admirals of the fleet of Alexander the great dispatched form the Indus to Persian Gulf. Sri Lanka was described by then under the name of Thaporbane, which is identical with the Thambapanna of Vijaya's followers and its Sanskrit equivalent, Thambapanni. The Mahavamsa thus accounts for the name: "At the spot where the seven hundred men with the king at their head exhausted by (sea) sickness and faint from weakness, had landed out of their vessel, supporting themselves on the palms of their hands pressed on the ground, they sat themselves down; hence their palm became copper – colored (tamba – pannyao) and form this circumstance that wildness obtained the name of Thambapanna. From the same cause, also, this renowned land became celebrated under that name.

Sri Lankan historic urbanization began at least two millennia after the second wave of historic urbanization.Yet the organizational structure of the society; gradual unification attempts of the early leaders; the urban form of the earliest cities and the characteristics of the built environment suggests that the Sri Lankan historic urbanization is comparable with the second wave of historic urbanization, despite the large time gap. (Manawadu; 1994: 15)

The historic urbanization of the Sri Lankan city and its urbanization process could be categorized into three different eras the first phase occurred in the central dry zone. After prince Vijaya came to the country. The first large city emerged was Anuradhapura. According to the history, Prince Vijaya and his men came form a kingdom near the west coasts of the Indian sub continents in the 5th century BC starts the first Aryan settlements beside the banks of River Malvathu or Kandmaba Nadee the name used at that time in the dry zone of the island.

The reason to select the dry zone was basically the climate and the water. Dry zone climate and its geography matched with the agricultural vegetation. Monsoon rains given enough water for the paddy and chena cultivations and there is no flooding in the region very often.

One of Prince Vijaya's ministers named Anuradha built a village called 'Anuradhpagama' near the bank of the Malwath oya, which was agriculture based settlement. They built 5 tanks later, to store sky water for cultivations.

In 4th century BC Anuradhagama and surrounding settlements were developed largely and their communities selected Anuradhagama, which was situated at the near center to all the other settlements for exchanges their surplus of production and for trade. This small-scale commercial center gradually developed as a city and later to a citadel. The name changed from 'gama' indicates the village to 'pura' indicates the city in Pali Language. When it becomes more powerful city, they covered the core of the city and created the citadel.

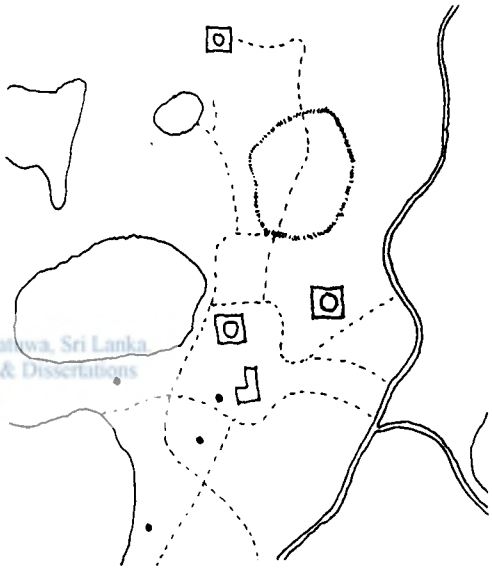


Figure 6 Ancient City Plan - Anuradhapura
Source: Archaeological Department

The agricultural lands were left outside the city bounders. When Buddhism introduced there was vast change of social economical and political background of the people. Many professions related to the arts and crafts also mixed to the community, and helped for the further development of the city. The areas of high grounds which has not used for agricultural or commercial activities and, was still with a short distance form the citadel made as monasteries for thousands of monks for practices Buddhism.

The city has four major streets and four city gates orientated to the cardinal directions. According to the early description of Fahian a Buddhist monk came form China, there were many noblemen and rich householders within the city. The houses of Sa – pho (sabean) merchnets were very beautifully adorned; and buildings with two, three stories. The streets and passages are all

smooth and level. Anuradhapura kept as well urbanized city, which had enormous power and wealth form 377 BC upto 995 AD

In this year south Indian Cholans invaded and established Polonnaruwa as their capital. This started the shift of city centers towards the southern part of the country. Polonnaruwa was a fort city used by prince Dutugemau, against the war between him and the Dravidian king named Elara who ruled the kingdom more than 40 years. The proudest king of the Polonnaruwa kingdom was King Parakramabahu I, who worked much for the agricultural community. He planned and done network of canals linked to the large reservoirs to stores the sky water for agriculture. It helped to spread the human settlements all over the dry zone of the country.

The city has tow major part stills can clearly visible. The inner city with palace of 7 stories, palaces for queens, and Tooth Relic Square belongs to the inner city. Outer city separates form the inner city by a large wall and it has four gates to the cardinal direction. Monasteries were in the outer city and there was a large monastery called ' Alahana Prirvena' with two large Stupas, 5-storied image house called 'Lankathilaka vihara' and chapter house called 'Baddhasima Prasada', and there were clusters of buildings for monks densely constructed. Form the ruins still can visible the construction pattern, layouts, type of buildings, materials used, heights and detailing.

Polonnaruwa is very good example to a well-planned city with proper grouping of buildings located within the city area with organized streets and landscaping. The pattern of agricultural settlements arranged around the city still gives the idea about a neatly developed administrative city surrounds by the agricultural communities.

After Polonnaruwa in 13th century capital of the country shifted to the wet zone. Consequently many cities emerged in the wet zone. This could be seen as the second phase of urbanization in the country.

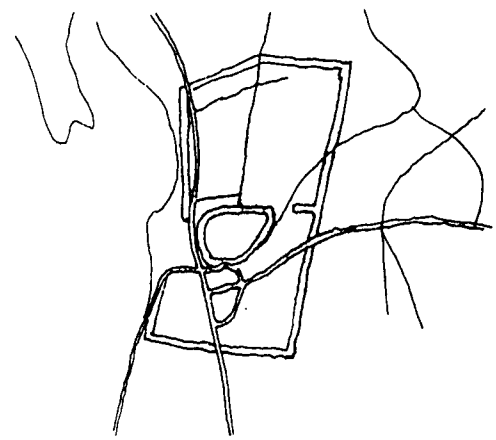


Figure 7. Ancient City Plan – Polonnaruwa
Source: Archaeological Department

2.2.1.2 COLONIAL PERIOD

The third wave of urban migration occurred with the arrival of Europeans in the 16th century and their colonization of southern and westerns Maritime Provinces to established more urban settlements along the coast.

This led to abandoning and subsequent destruction of older cities since the major impulses for urbanization were form foreign domination of the region during this period. The process could be classified as urban colonization. The first cities emerged from this phase are Galle and Colombo.

Then (Europeans) choose sites with an eye for commercial advantage in terms of overseas trade. Physically and there morphology the new port cities clearly revealed their western and colonial origins. They began as fortified trade posts and evolved into little urban islands of Europe in Asia. (Murphey 1969; 63)

Their urban form is different not only in street development and architecture but in their special manifestation as well. The urban skyline came to be dominated by larger building is almost purely European style and the look of at least the city center was and romaine unmistakably western.

Professor Willie Mendis states in his book 'Urbanization and Development in Sri Lanka' (1982), that an ancient Sri Lanka, urban settlements use located either around agricultural hinder or at sea ports. In such context agricultural and trade provided the basis of the early cities, colonial intrusions brought about new addition and the decay of older urban settlements.

Specially Galle and Trincomalee, which has world's first-class natural habours, functions form about centuries. According to the literature the first reference to Colombo was in the 14th century and it appeared as a trading settlement and small seaport, used by Arabian, Chinese and Persian traders. The trade winds helped them (Arabian, Roman, Indian Persian, Chines and Malay traders) to sail those ports for gems, spices elephant tusks etc.

When the country is under British Empire they used Colombo and Galle as major commercial centers. They collect tea, rubber, coffee, cinchona and spices to these cities and export them to their mother country; and to keep secure the power throughout the entire Asia.

However within the period of colonial urbanization, have two important impacts on Sri Lankan cities. First it imposed a new set of values, which the colonists have brought here, upon our cities. Second during this period Sri Lanka lost its older cities; thus almost obliterating some of the older urban traditions. Infact Kandy is the only large city from a previous era, which continues through the third phase of urbanization in Sri Lanka to the present day.

2.2.1.3 POST IINDEPENDENCE PERIOD

When gain the independence from British Empire in 1548 the next important change happened in the urbanization process of Sri Lankan cities. There arose a new awareness of tradition among the people. This was well maintained in architecture of this era through not so such in terms of urban design. It also shows a rapid growth of suburban cities in the wet zone Attempt have been made to reurbanize the dry zone through multi – purpose development projects (Galoya valley development project) as well as 'planning' existing towns. The Sri Lankan city as it is today is a postcolonial phenomenon. But this does not mean that their tradition is limited to this era only.

2.2.1.4 COLOMBO METROPOLITAN REGION AND OTHER AREAS

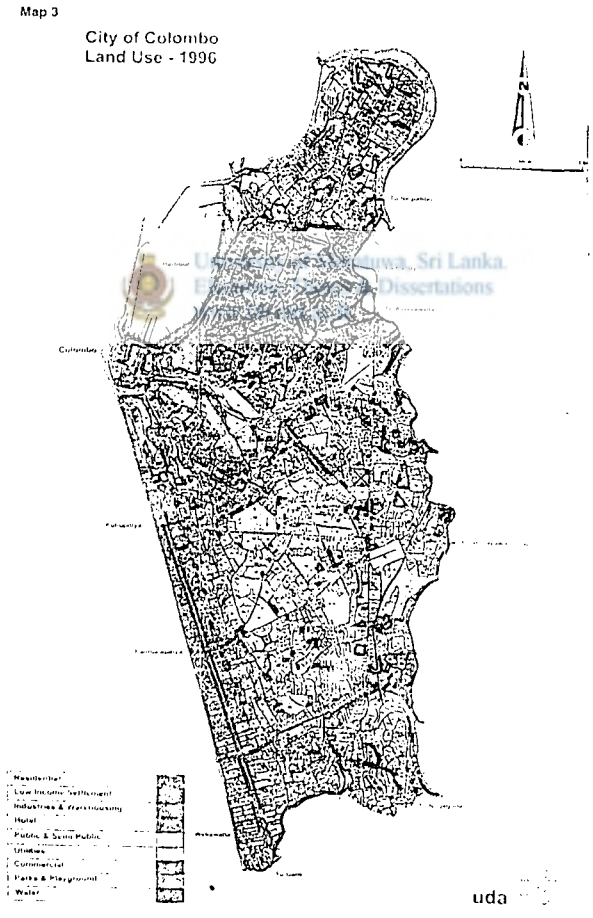


Figure 8. Colombo Metropolitan Region – Land Use Map

Source: Colombo Metropolitan Region Structure Plan - Volume: 04

After introducing open economy to the country development increased in an accelerated rapid way. Within last three decades Colombo and its suburban regions subjects to this rapid kind of urbanization, because it functions till as the commercial capital of the Country. Education, trade and job opportunities attract the people from rural to the city. Due to migration population of the city increased. To fulfill their requirements buildings came up without any master plan for the city. This haphazard development and high population density make the Colombo a metropolitan region.

With the complex vibrancy, the Colombo city today is also the inheritor of a host of problems. Its cultural heterogeneity did not emerge smoothly but thorough many political power struggles and economic changes, the scares of which remain in the urban form today Colombo metropolitan region is faced with enormous problems such as cauterization, lack of identity and poverty. Recent development has pushed the city towards western cultural attitudes, which is equated with the "world cultue" today. Thus at the same time with the recently acquired economic power in the region there is a renewed awareness about its inherent cultural identity.

When the density of population increases in the Colombo city the scarcity of residential facilities, direct the urbanization to suburban cities around Colombo, Rathmalana, Moratuwa, Nugegoda, Maharagama, Homagama, Baththaramulla, Kiribathgoda, Kadawatha, Waththala and Katunayake are some of the suburban cities around Colombo, which helped to make Colombo a metropolitan region, due to rapid development.

It is found that rapid urbanization of a city creates changes of its original microclimatic conditions. When considering the climate according to Emmanuel (1999) works on compiling the historical trends in urban climate modifications in the metro region urbanization has brought negative thermal comfort changes to the regions climate. According to his study (1968 – 1998) diurnal variation in temperature are minimal but the heat index change for the region during the last 30 years indicate positive trend.

2.3 CLIMATES AND URBAN DESIGN

Climate has a major effect on building performance and energy consumption. The relationship between inside and the outside environmental conditions helps the comfortability of human beings. But today due to unplanned urbanization process cities facing a problem of changing their original micro climate buildings coming up all over the cities makes the situation a mess; and reduction of green areas accelerate the problem. Extra heat reflects form the building masses heat up the city and heated air stack within the spaces of the city is the worst, which make the city a much uncomfortable place. Because of the uncomforlability in an urban areas energy should have great contribution to draw the comfort level form uncomfortable level. While designing an urban area therefore should have to consider the existing microclimate of the city. As well planners, architects and urban designers should rethink about the new strategies related to urban design which minimize the effects of the original micro climte of the cities; otherwise it is badly affected to the thermal comfortability and physical environment of the city.

2.3.1 THERMAL COMFORT

Man has always striven to create a thermally comfortable environment. This is reflected in building traditions around the world from ancient history to present day. The all-encompassing term, comfort, is very subjective and is a statement of not only the physical but also psychological satisfaction.

Thermal comfort is identified in the ISO 7730 standard as being "that condition of mind which expressed satisfaction with the thermal environment." A definition most people can agree on but also a definition, which is not easily converted in to physical parameters. However the comfort zone, the range of conditions in which thermal comfort is experienced and defined as the range of climatic conditions within which the majority of people would not feel thermal discomfort either heat or cold. There are six parameters that largely influenced thermal comfort.

i. Air temperature
ii. Mean radiant temperature
iii. Air velocity
iv. Relative humidity
v. Clothing
vi. Metabolic activity level of person

While the effect of air velocity on comfort is significant, the problem in urban areas, particularly in the equatorial tropics is that macro level winds are weak and urbanization trends to reduce this further. Therefore radiant heating is considered as an alternative approach to thermal comfort in the equatorial tropics.

The study is limited to the effects of radiant heating on the thermal comfort. This takes in to consideration the air temperature and relative humidity, while keeping the clothing and metabolic activity level within the spaces constant. While particular combination of above parameters may provide comfort in an out door: for thermal comfort can occur in a particular environmental combination only if people are exposed to it for considerable period of time.

Such is not the case in the outdoors where maintaining the heat balance with he environment in and by itself is indicate for thermal comfort. While such a balance can be achieved by a variety of combinations of environmental variables, only a narrow band of such combinations are helpful in achieving and maintaining thermal comfort. (Emmanuel, 1993: 27)

Fanger shows that there is n appropriate skin temperature and sweating rate for each type of human activity to achieve comfort.

The skin temperature decreases with increasing activity. At high activities, moderate sweating is therefore necessary for comfort...

Relative humidity's effect on comfort is only moderate, providing air temperature can be kept low. For short exposure (like in the out doors) humidity effect can be great. .....

Increases in activity or clothing cover must compensated by decrease in air temperature...

The influence of temperature (air and radiant) falls with rising air velocity ...

A given change in air velocity has the greatest effect when speeds are moderate.

(Fanger, 1972: 37).

Studies with human subjects have shown that radiant cooling can compensate in air temperature provided air velocity is low. (Plumley, 1975: 153)

As long as surfaces surrounding a person are within comfortable range the environment may even be asymmetric about radiant temperature. (Plumley, 1975: 153)

It therefore seems clear that the alternative approach for thermal comfort in the equatorial tropics could be an effort to reduce radiant heating of the environment.

(Emmanuel, 1993: 29) Therefore the primary goal in urban design is the equatorial tropics is shading.

During the night time equatorial tropics are typically warm, thus the special attention should be made about the comfort in these areas the most possible approach is to minimize the built masses in urban areas and reduce the provision to store heat within urban masses.

By a study of urban elements it is possible to identify the physical urban elements, which act as great influences to its microclimate; such as

i. Roads and paved areas
ii. Density of built-up areas
iii. Height and shape of buildings

iv. Green areas

v. Water bodies

vi. Open areas

2.3.2 URBAN HEAT ISLAND EFFECT

Howard identified this urban heat Island effect in his urban climate study in 1833. He has mentioned in his article, that urban climate of London has found significant departure form the climate of the surrounding area. However present research studies in this subject are is mostly done in this United States and these are only about thirty or forty years old.

According to the studies, on the average the diurnal temperatures in a densely urban built area, is warmer than the surrounding open (rural) country. The largest elevations of the urban temperatures occur during clear and still nights. This nocturnal elevation of the urban temperature above the surrounding rural areas is commonly defined as urban heat Island.

A heat island is best visualized as a dome of stagnant warm air, over the heavily built up areas of the city. These have been observed particularly all over the world except in extreme cold countries. The effect is not so much felt during the day, as the increase in the maximum temperature is minimal.

However, heat islands are increase at night, occurring a few hours after sunset. This has fore - reaching implications for urban design in the equatorial tropics where nighttime theremal stress is usually high (Emmanuel, 1993: 15)

According to present studies it is related that urban heat islands strongly feel in the calm weak night. It is also clear that a rapid rise in minimum temperature and a slow rise in maximum temperature are the direct result of urbanization. The following changes in climatic elements are also recorded.

Effect of Urbanization on Climatic Parameters

Climatic Parameters	Effect on urbanization
i. Temperature	Rise in minimum temperature some changes in maximum temperature.
ii. Precipitation	Higher increase in summer (upto 20%) and smaller increase in winter (5 – 8%) in the tropics the increase in attributed more to air pollution that heat emission.

iii.	Humidity	Reduction in daytime humidity but increase in night time values.
iv.	Wind	Increases in the number of calm periods observed. Up to 20% reduction in wind speeds are known. The effect is greater upon weaker winds.
v.	Solar Radiation	Thought incoming radiation values are not changed, the apparent values are , due to the containment of reflected radiation by the heat dome.

Source: Emmanuel 1990; Chalender, 1976; Londsberg, 1981.

2.3.2.1 SPATIAL PATTERN OF URBAN HEAT ISLANDS

The boundaries of the heat island follow the urban air dome. The horizontal temperature gradient, rise from the periphery to the center, especially during the nights, is largest of the outer boundaries of the urban area. During the periods with light winds the heat island is extended downwind beyond the boundary of the urban built up areas. The 'height' of the heat island is rather shallow, extending upward about 3 or 5 times the average height of the buildings and coincidence approximately with the urban air dome. Above this height the differences between the 'urban temperature' especially near ground level, which contributed to the development of the urban heat islands and the regional temperature at the same height are very small (Givoni, 1998: 244)

2.3.2.2. LOCALIZED DESTRIBUTION OF UHI SOURCES

The diurnal temperature patterns at any specific location in a city depend to a larger extend on the local conditions, with respect to the density of the ground covered by buildings and the height of the buildings, the nature of the ground surface the exposure of the site to the regional wind etc. Any local place can be warmer or cooler than the surrounding area (Givoni, 1998: 246)

The intensigty of the heat island at night is related more to density of buildings rather than to city size. (Calander, 1971)

The warmer air above small – scale heat is lands mixes eventually with the bulk of the urban air and thus slowly elevated the 'ambient air' flowing across the city downwind. Therefore,

although the origins of the 'urban heat island' may be in small pockets their effect accumulates, to produce the peak of the temperature elevation near the town's center. (Givoni, 1998; 247)

2.3.3. HEAT ISLANDS IN TROPICAL AREAS

There are very few research studies done about the heat islands in tropical region. From them can only predict the common characteristics of urban heat islands in equatorial tropics. According to the research study done by Nieuwolt in 1966, air temperature and relative humidity measurements various points in the city and the suburban areas were recorded and compare them with the readings taken from the rural areas. The found result was the city warmer 3 – 3.5^{0}C, and drier (20% low relative humidity) tan the rural areas. It also indicated the narrow streets in the core if the city had the warmest microclimate during the daytime. The sea fronts are wetter and cooler than the rest of the city even in the daytime. But this is for only very narrow strip of land near the sea.

When there is tall buildings near the coastal belts of the city, the wind comes from the sea is blocking; is the reason for that. Other than that Nieuwolt found there was an effect of wind to increase the comfort difference between the city and the rural areas. Because the absorption of solar radiation by the city is higher than the rural areas and city has lack of vapor transportation, comparing to the rural settings. He further identified daily temperature variation in equatorial urban areas was 5^{0}C. But due to heavy thunderstorms it dropped by more than 7^{0}C, which is very significant for the tropical areas.

Other than Nieuwolt, Sani did a research to Kualalampur – Manila in 1973. He founded that there is a relationship between the city, country temperature difference and cloud cover, and vertical air mixing that keeps hot air trapped at body level in urban areas which are most similar to Nieuwolt's findings.

2.3.4 INFLUENCE OF URBAN DESIGN ON URBAN HEAT ISLANDS

According to the recent past research there are series of relationships between urban factors and climate such as

- Urban geometry – climate pattern
- Anthropogenic heat – Thermal characteristics
- Obstruction to wind flow – Lack of vegetation etc

However the widely prevalent view among the urban criminologists is that at the urban geometry leas the list of possible course for the heat island. The dominant causes for urban heat island's in deified so far includes

i. Heat trapping by urban geometry

ii. Changes in vegetation cover

iii. Man mad (Anthropogenic) heat input

iv. Alterations to urban thermal properties.

In the early studies surface characteristics have been sited as the cause of urban heat islands; at the present most of the researches suggest the geometry of urban canyons, namely the street to building height and width relationships as the main cause of the urban heat island. When considered as an urban design tool it is more important; the street geometry than other urban design factors; like surface colors materials etc. According to the previous studies the following important relationships can be made between urban geometry and heat island effect.

* Sani in 1973 explained in his research; high thermal capacity urban surfaces are prime suspect in the UH 1 built-up in the urban area.

* But after Oke studies done in 1981; he has found there are no significant co relationship between types of man-made surfaces and heat island intensity. The only significant difference observed was between man made and natural surfaces.

* In Lawrence Kansas, Henry and Dicks (1987) found that the temperature difference between highly developed part of the city and a representative rural area to be actually 1.9 ^{0}C higher in the rural case. This unexpected change was due to the almost urban like street geometry of the particular rural setting.

* In 1990 Todhunter argues that both the geometry and surface thermal characteristics play an equal role in UHI effect in urban context.

WIND MOVEMENT AND UHI EFFECT

One of the most important climatic factors for urban design is wind movement. But it is very difficult to use as design factors because it is unpredictable, specially in equatorial areas due to monsoons as well as the lower wind movements, which is proportional to the difference of skin and air temperature, is little in value

VEGETATION COVER AND UHI EFFECT

Vegetation is not directly connected to reduction of air temperature but it reduces the direct radiation coming form the sky. Thus in a way vegetation has an effect on human comfort and building energy budget. At the same time it prevents heating up to urban canyons. That means due to urban vegetation an immeasurable effect on reducing heat built up is greater than the direct temperature reduction. However, vegetation in a city can reduce the overall ambient temperature by as much as $2^0C - 3^0C$. Therefore reduction of vegetation percentage due to urbanization within a city helps to develop urban heat islands.

WATER AND UHI EFFECT

Water is an important element in urban areas, which helps to reduce the effect of UHI. Normally by having large water bodies, increase the air temperature of urban area. But it properly shaded and located on major wind path, the cooling potential of water is immense even in the equatorial tropics. In combined presentation by R.K. Kadiragamer and R. Emmanuel's "Energy Efficient Cities", they have clearly mentioned, that doubling the moisture availability in cities was found reduces the heat island effect by 20%. According to that water used in urban design helps to avoid the effect of urban heat islands. Therefore reclamation of water bodies due to high urbanization of a city should avoid when considering the urban designs.

CHAPTER THREE

Description about the Selected Cities

PART ONE

GALLE

3.0 CHAPTER THREE

DESCRIPTION ABOUT THE SELECTED CITIES

PART ONE

3.1 GALLE

Galle is the main administrational and commercial city of the southern province of Sri Lanka. The city has very long history based on trade, and it is because the harbour which was an important good exchange centre; through out the Asia. Urbanization of the city starts in the period of Dutch, then the British's and it is still continuing. The Old Dutch fort with their buildings having significant, unique architectural characters fortified by a huge rampart is one of the UNESCO heritage sites in the world; now archaeologically conserved.

The city belongs to the wet zone of the island, which has average daytime temperature of 29^{0}C, as well as equally distributed rainfall throughout the year over an average of1500 mm. Galle city developed and still developing along the Colombo-Galle main road; and to the landside bit away from the harbour. The city of Galle selected for the study is because it to the has a historical site, conserved and prevent form further developments as well as the developing city which is the largest commercial center in the southern province.

3.1.1 HISTORICAL BACKGROUND OF THE CITY

The strategic location of Galle as a natural harbour in relation to main sea routes, which provided a servicing point for transportation and trading activities, and a mile wide bay gives shelter from all elements of climate, specially protected by the south west monsoon has given its prominence among the outer ports of Sri Lanka.

Figure 9 Galle – Ancient Plan of the Fort

Figure 10 Galle Habour in Colonial Period

Source: Illustrations and Views of Dutch Ceylon

It has in addition one exceptional gift from nature unwatched form elsewhere in Sri Lanka on the western side of the bay a level rock, ringed peninsular provided the roadstead not only with extra protection from the winds. The rocky nature of the bay prevents entry to the nature without a safe passage is negotiated with pilot. Topographically, the most distinctive physical features are the two ridged hills that runs in the north south direction, while rest of the town gently slopes away form these ridges and the canals which meets the sea at various points. Originally the Galle was a settlement whose inhabitants traded with the Arab merchants who exercised great influence over opulent commerce of Ceylon.

This opulent commerce was then passed over to the Portuguese (1505 – 1658 AD). In 1505 a fleet of Portuguese ships under who command of Don Lorenzo de Almeida set out for Maldives to intercept Moorish ships carrying spices but owing unfavorable weather conditions were drives off course and took refuge in the port of Galle.

Figure 11. Rampart of the Galle Fort

Figure 12. Entrance of the Dutch Fort

They continued to use the port for trade and due course established a fortification in 1588 AD. The Portuguese built three bastions to the north of the town with interconnecting wall and other defenses to guard the harbour. Unfortunately little is known of Galle during the period of Portuguese, the fact that Van Toll, secretary to Gerrit de Mere, Governor of Colombo, burned most of the records accidentally.

However by the17th century the Indian Ocean was full of competing European nations namely the Dutch, British, and the French in addition to Portuguese. Among them the Dutch were the next who established their power in the Maritime Provinces over the Portuguese in Sri Lanka.

In March 1640 an Armada of twelve Dutch ships and two thousand men attacked the Portuguese fort of Galle by sea and land after short but fierce battle St. Lagos's Bastion was breached. Soon after the capture of the fort and the harbour the Dutch set about building the ramparts and constructing the fortification, which enclosed so acre of land and accommodated all

sectors of populations who were loyal to the Dutch, while the Portuguese could afford to be complacent about the sea ward frontier the Dutch could not. It is quite interesting to note that the Dutch forts weren't merely fortification against a land enemy but also defended the habours. The security of their fort depended on their ability to hold the harbour. Therefore the forts were designed very similar to the fortified cities of Europe.

In 1796 the fort was surrendered to the British and it gradually ceased to functions as a fortified base but continued as the administrative and legal center for the south. As a consequence of residential activities moved out from the fort continued mainly as an administrative centre and major banking institution, industrial organizations and other various state developments are permanent features within the fort even today, it continues as the administrative centre of the southern province.

The fort of Galle is irregular in shape and strongly fortified, where the attack was expected form the land, but fortified all around following the shape of the coastline of the promontories on which they were situated. The city is built with symmetry and neatness but only half as big as Batavia.

3.1.2 PHYSICAL FABRIC

Figure 13. Old Dutch and British Buildings inside the Galle Fort

The city of Galle is situated in a flat area than the Old Dutch fort and the Roomassala forest reserve. In an ancient period Dutch were in the city, and as soon as they established a civil government, started the development works of the city. They built a hospital, a church and other building inside the fort and many other building a city required. Old buildings are now conserved and use for administration and museum functions, which has significant characters of old Dutch and British architecture.

Figure 14. Physical Fabric – Inside the Fort

Present city is rapidly developed and still developing without having any significant characters of old Dutch and British architecture. Most of them are not more than 5 storeys high, use of much concrete and glass for the buildings makes different form the old building style of the city. |Other than Colombo Galle main road the streets of the city is narrow and buildings came to the edge of the roads. City is a mixture of old and new building came up without an organized manner. The city is expanding form along the main road to the landside.

Figure 15. Rapid Development of the City of Galle

3.1.3 OPEN AREAS, GREEN AREAS AND WATER BODIES

There are large open areas near the city centre of Galle. Loans inside the fort Galle International Stadium, 'Samanala' (Butterfly) grounds, are major among those. Roomassala natural reserve is the largest green area near the city. And there's another green area within the city center, near the Town hall of Galle functions as a garden, Part of this green area is using as a park for kinds. The largest water body near the city is the Indian Ocean.

Figure 16. Large Open Area – Inside the Fort Used to place the Artillery Guns

Figure 17. Indian Ocean – The Largest Water body of the City

Figure 18. Galle International Cricket Stadium the Largest Open Area of the City

3.1.4 STREETS AND TRANSPORTATION

Old roads of the fort and the city were very narrow. There were no gaps between the buildings most of the times. Streets are shady due to casting of shadows. The city is having a network of roads for transportation. Galle road starts from Colombo, ends up form Galle, and from there it continuous across the city as Matara road to the city of Matara.

Figure 19. Narrow Street inside the Fort

Figure 20. The City Center and Galle Road

Other than this main road, which is much wider, comparing to the other streets with buildings came up to the street edge. The railway line rums parallel to the coast comes to the railway station of Galle in the city centre and continuous up to the city Matara.

Figure 20. Road Network of the City of Galle

Source: Travel Maps, ISBN No: 955-9276-02- 6

PART TWO

TRINCOMALEE

PATRT TWO

3.2 TRINCOMALEE

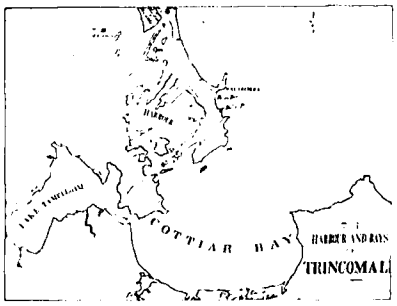


Figure 21. Ancient Map of Trincomalee
Source: Early Prints of Sri Lanka, Pg: 17

Trincomalee is the regions largest city; sitting in the middle of two bays it is acquired to have one of the most picturesque sights seeing, with the most virgin and incredible beaches. Trincomalee harbour is the 5th largest natural harbour of the world. According to the Lord Nelson, a teenage midshipman, when he was first arriving to the country in 1775, the Trincomalee harbour is one of the most beautiful harbours in the world (de Silva R.K., 1988; 49).

The harbour made the city an appealing stopping point for merchants and conquerors alike. The east coast monsoon is during the months of October to January. The maximum temperature in region is 35°C. Form April to September it drops to below 30°C. During rest of the year with an average temperature between day and night is 26 °C to 30°C. The town used to be more important in the olden days and it covers wider area than Colombo; even today it has only half the number of inhabitants.

3.2.1 HISTORICAL BACKGROUND OF THE C ITY

Trincomalee is a place having of great antiquity. After seventh century the principle; arena for the east west has shifted form the Arabian Sea to the Bay of Bengal. Consequently there was an increasing interest in the north – eastern zone of Sri Lanka where was located Gokanna (Trincomalee) habour. It is significant that between seventh and tenth centuries A.D. four Sinhalese kings, Aggabodhi iv, Aggabodhi vii, Udaya I, and Sena I, left Anuradhapura and ruled from the north eastern city of Polonnaruwa situated near the banks of Mahaweli river, within easy access to Trincomalee. Thus the emergence of Polonnaruwa and the port of Gokanna is significant in terms of changing patterns of trade in the Bay of Bengal and Sri Lanka's interest in it Indian Cholas occupation of Polonnaruwa (1017 – 1070) was partly motivated by the commercial policy of the Cholas aimed at controlling the western sea – board of Bay of Bengal. The importance of

Gokanna for the Bay of Bengal and south east Asian trade was realized also by the Sinhalese rulers of Polonnaruwa particularly Vijayabahu i (1070 – 1110), and Parakramabahu i (1153 – 1186).

Figure 22. Historical Map of Trincomalee
Source: Illustration and views of Dutch Ceylon

Figure 23. Trincomalee Harbour
Source: Early Prints of Sri Lanka, Pg: 169

Later in the colonial period of Sri Lanka Trincomalee has a great political value because of its natural habour. The harbour entrance, which faces southeast, is guarded by two projecting headlands about half a mile apart. The form of the harbor is irregular and the numerous indents of the coastal line, present many charming features. In about 1900 Henry Care describes it thus; the rocky headlands which is made up of a placid expense of water, dotted with wooded inlets that seems to float on its surface. In the highest place of the city now existing the Thirukoneshvaran Kovil, was the ancient Gokanna Temple. There after it was destroyed by the Malabar invaders and adopted it as the site of one of their most celebrated shrines the temple of Thousand Columns dedicated to God Shiva, an attractive pilgrim form all parts of India.

Figure 24. Entrence of the Fort Federic

The north of the habour is a horse shoe shaped bay guarded on one side by a rocky headland known as Dutch point and on the other side Fort Federic, the military headquarters. Fort Osternberg, built originally by the Dutch overlooks the entrance of the inner harbour from the top of eastern hill, which bears the date 1676.

In 1612, following the establishment of alliance with the Dutch (with whose aid he hoped to get rid of the Portuguese) the king of Kandy permitted them to erect a fort and Cottiar on the southern side of ht bay of Trincomalee.

No sooner was this done than it was captured and destroyed by the Portuguese in 1622; the Dutch seized and garrisoned Trincomalee itself, employing the materials form the Temple of Thousand Columns in fortification. But since this was of no use to the cinnamon trade they soon abandoned it. The Dutch rebuilt the fort but abandoned again in 1672 to the French fleet, which was under the command of Admiral De La Huge. The French were unable to supply the fleet and soon forces to abandon their conquest.

It was in 1782 that Britain first aspired on the scene. But they captured the fort in 1795 and in 1803 they armed the fort and rename it as Fort Federic, the military headquarters and the name Federic belongs to the Duke of York in 1803. And after having the independence to the island form British Empire in 1948 the fort is given to the military forces of Sri Lanka.

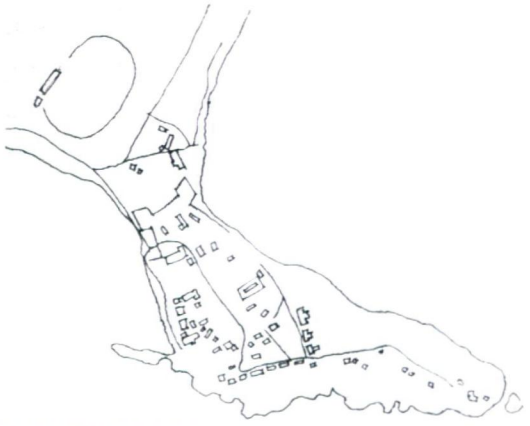


Figure 25. Plan of the Fort Federic

Form the history the city developed near the fort and the harbour facing number of invasions done by the eastern and western nations. Even in the Second World War, Japanese attacked to Trincomalee to capture the habour, farm of oil tanks and the city.

3.2.2 PHYSICAL FABRIC

The harbour is house shoe shaped bay to the north and the town of Trincomalee is at the bend of the horse shoe facing the sea front is a wide esplanade which form a recreational and parade ground.

Figure 26. City, Developed along the Coast

The town used to be more important in the olden days and even now, covers a wider area than the city of Colombo. Even today it has only half the number of inhabitants when comparing with Colombo. Buildings are single, two storied; and rarely go up to that. Around the city centre buildings are not densely packed. But this loosen effect is avoiding by the tightly packed small shops and other buildings in the core of the city. Still can visible, some old Dutch and English buildings among the other buildings which are newly constructed.

Figure 27. Loosely Built up Areas of the City

Figure 28. Highly Built up Areas of the City

Within those buildings there is some, having importance due to the antiquity architecturally, religiously, and administratively.

Figure 29. Old Dutch Building inside the Fort

Figure 30. Old British Building

Figure 31. Thirukoneshvaran Kovil

Figure 32. A Kovil in the City Center

Figure 33. Provincial Secretariat Building

Figure 34. Mosque in the City Center

Inside the Fort Federic is much greener than the other areas of the city. Streets are like avenues shaded by large trees.

3.2.3 OPEN AREAS, GREN AREAS AND WATER BODIES

Figure 35. McHayzer Grounds

Figure 36. Public Ground of Trinomalee

In the city centre there's a 58-acre large esplanade facing to the sea helps to proper ventilation of the city. This is using as a recreational area the McHayzer stadium also belongs to this large open space. Other than that the Bus Park of the central bus terminal, public and school playgrounds are the opens areas, which the city is having. Fort Fredric and near mountain cliffs belongs to the green areas. Patches of threes can visible inside the city area otherwise having large continuous greens. The only water body nears to the Trincomalee city area is the sea of brilliant blue in colour.

Figure 37. 58 acre Large Esplanade in the City

Figure 38. Bus Park

Figure 39. The Fort and the City facing the Inner Harbour and the Indian Ocean

3.2.4 ROADS AND TRANSPORTATION

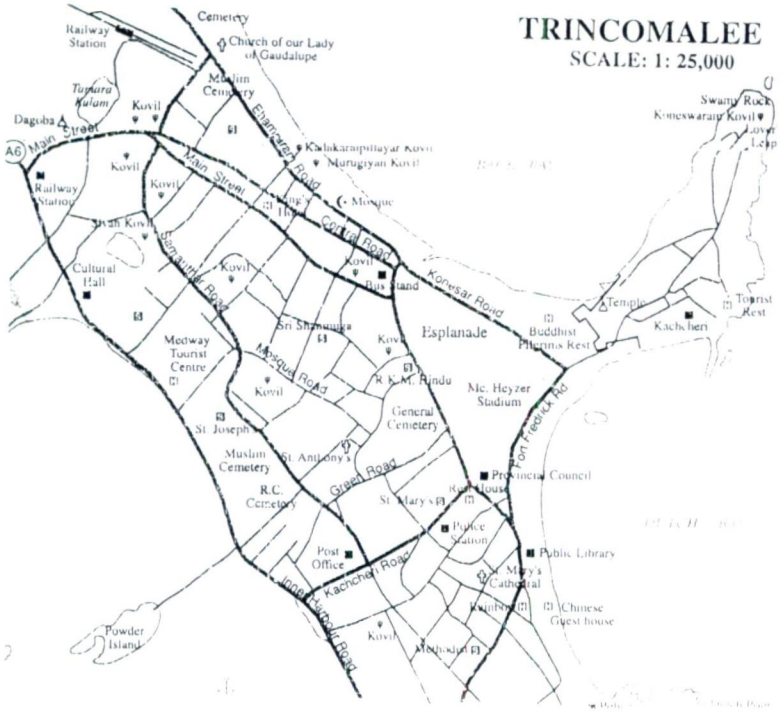


Figure 40. Transport Map of Trincomalee

There a ring road network runs round the city. The Colombo Trincomalee road divide into two near the entry point of the city to Central road and Inner Habour road completes the ring by connecting with Fort Fredric road runs parallel to the coastal line of Dutch bay, and the Koneser road. In the middle of the city, runs Samanthar and Kachchari roads, which are wider.

All the others are narrow roads and streets facilitate to easy access through the city. In the middle of the city there is less green cover, but inside the fort area and the area selected for the study has much green cover than the core of the city.

Figure 41. Tree Covered Road Inside theFort

Figure 42. Avenue – Outside the fort

Figure 43. Narrow Street in the City Center

Figure 44. Wider Road in the Middle of the city

PART THREE

NUWARA ELIYA

PART THREE

3.3 NUWARA ELIYA

Nuwara Eliya is in the central high lands of Sri Lanka, about 1880 m above the sea level. It has most mild and pleasant climate only really found in this tropic of Cancer. The summer has no tropical heat and in the winters is not free from ice. The average yearly temperature varies from 22^{0}C within the daytime and 7^{0}C during the nighttime. The city is located in a small valley surrounded by the mountains. British have found the valley and make Nuwara Eliya as one of the England's mountain villages. The valley is open, marshy plane, which is almost mile long and a third of mile wide with the Nanu Oya meandering through it.

3.3.1 HISTORICAL BACKGROUND OF THE CITY

Figure 45. Nuwara Eliya, Early Period
Source: Early Prints Of Sri Lanka,Pg: 245

Figure 46. Plane of Nuwara Eliya

Nuwara Eliya discovered by a hunting party led by Dr. John Darvy. It was Sri Samuel Baker who later converts it to holyday resort with a touch of an English Town. Nuwara Eliya established as a summer and health resort for the British officials in 1929 by the British governor of Ceylon Sir Edward Banes. In additional he built an extensive mansion for himself, which stands as a Grand Hotel today. Even until 1840 there were only military buildings, a hospital, rest house, kachcheri, Jail, bakery and a few dwelling houses In the mid of 19th century. The growing of coffee followed by the tea and Cinchona opened the door to the world of commerce, the British planters taking up residence in the district brought in the social and administrative institutions familiar to the Victorians England.

In the latter part of 19th century with the buildings of elegant cottages, Nuwara Eliya was transformed a wild open plane to a busy English hamlet.

3.2.2 PHYSICAL FABRIC

Nuwara Eliya is a small town when comparing to Colombo Metropolitan region. But within this small area there is large number of buildings packed densely. Its magnificent climate is very good for health. The city functions as a tourist resort from the beginning. Therefore it attracts large number of local and foreign tourists annually. The region has very rich and dark soil, which is very good for growing a much variety of European flowers and plants such as roses, carnation, violets and fruits such as strawberries, gooseberries, red currents, peaches, vegetables such as carrots, lettuce, cabbages, etc., and the finest potatoes. Tea is the major plant cultivating in and around the Nuwara Eliya. There are huge tea estates having hundreds of acres.

Figure 47. City Of Nuwara Eliya

The city's very old neat office buildings, hotels and gable roofed houses with front gardens, beautifully landscaped, tree lined avenues, park and the golf links, which gives an impression of an old English city. Characteristics of an old British architecture is still using for the buildings newly coming to the city. The post offices, grand hotel, the presidents' house, the police head quarters are some of the old buildings in Nuwara Eliya.

Figure 48. Post Office Building – Nuwara Eliya

Figure 49. House having British country Architectural Character

Due to the impotence of the city as tourist resort and agriculture, tea plantations based commercial center the construction of new buildings, as well the development of the city in going an accelerated path, also the pollution rate is high, which is badly effecting to its unique climate and the physical environment of the city.

3.2.3 OPEN AREAS, GREEN AREAS AND WATER BODIES

Golf links, Victoria Park, Race course and its middle recreational area are the major open areas in the city centre other than the small area where the city is surrounds by the forest reserves of Pidurutalagala and Hakgala. Water streams are all around Nuwara Eliya. Gregory's Lake and the Nanu Oya, a branch of the Mahaweli River are the water bodies existing in the city.

Figure 50. Golf Link – Nuwara Eliya

Figure 51. Race Course and Recreational ground

3.3.4 ROADS AND TRANSPORTATION

Figure 52,53. Wide Roads Runs through the City

Main road come form Kandy runs across the city as Bandaranayaka Road, New Bazaar Street and as Queen Elizabeth road. There is network of sub ways and streets giving access to each and every building in the city. Vehicular traffic is less in off seasons of Nuwara Eliya and much in the season in months of March, April and May.

Figure 54.Road Network– Nuwara Eliya

CHAPTER FOUR

Method of Study

4.0 CHAPTER FOUR

METHOD OF STUDY

To find out the thermal comfort, microclimate and physical element changes due to urbanization in Sri Lankan suburban cities within last 30 years, analyze the climatic data and Arial photographs. Other than that by using maps and photographs can have the ideas about the city's geographical location, its expansion pattern, transportation network and the physical fabric.

4.1 INDEPENDENT VARIABLES

There are two independent variables used for the study.

i. Arial Photographs

ii. Land Cover

4.1.1 ARIAL PHOTOGRAPHS

Arial photographs are those taken within the range of electromagnetic wave lengths visible to the human eye. These are the only way of visualizing the three dimensional reality in being. The applicability of Arial photography to town planning was recognized fifty year ago. Also in urban research an area of concentration can be analyzed over time. Air photos have long been employed to map making. While photo graphic representation is of the physical city is expressed in the three dimensional facts and features of the pattern, types, size, conditions of different land uses such as built areas, tree covered areas, water bodies, transportation routs etc. There are two different types of Arial photographs

a. Vertical Stereo Photographs

b. Oblique Photographs

a. VERTICAL STEREO PHOTOGRAPHS

These are the outstanding type of Arial photographs for urban planning and research, urban and environment studies. These present an overhead or plan view and showing difference in elevations, height and comparative relationship in the vertical dimension. Interpretation would depend on shade and shadow.

Figure 56. Vertical Stereo Photograph

b. OBLIQUE PHOTOGRAPHS

In general Arial oblique photographs are much less useful than vertical stereo photos. Features in the foreground of oblique photograph are distending. Those in the middle ground one less readily differentiated and those in the background are very small in scale and for the most part indistinguishable most. Urban elements like streets and much of the ground surface are obscure by the interposition of structures, vegetation or land foreskin comparative city planning research, urban studies, and environment investigations, oblique photographs are adequate for many purposes. They may show urbanization, the relationship of communities to their metropolitan and regional surroundings extent of vertical development, basic circulatory pattern and type or perhaps indication of visible air of water pollution.

Figure 57. Oblique Photograph

Vertical stereo photographs are using much, successfully all over the world. They are sharp when the source of light casting shadows. For the study use nine black and white vertical stereo photographs of the three selected cities within last three decades (1970's, 1980's, and 1990's).

4.1.2 LAND COVER

Elements cover the earth surface known as the land cover elements. For land - cover elements include buildings, roads and paved areas, water bodies, and tree-covered areas. Due to urbanization, variations of land cover elements occur. When particular area subjecting to the urbanization process, new buildings may come up, then, shifts the bare land and tree covered areas, water bodies. To find out the changes of physical elements or the land cover elements can calculate the area of buildings, roads and paved areas, tree covered areas, open areas, water bodies etc. throughout long period of time. In the present study use Arial photographs to calculate the area of land cover elements. And by getting range of figures of areas can identify the change of land cover throughout the research study within the three selected cities.

4.2 DEPENDENT VARIABLES

There are two dependent variables used for the study.

i. Climatic Data

ii. Thermal Comfort Index

4.2.1 CLIMATIC DATA

For the study used climatic data of 30 years, from 1971 up to 2000.

i. Maximum temperature (day time) in °C. (Monthly Averages)
ii. Minimum temperature (night time) in °C. (Monthly Averages)
ii. Maximum relative humidity (early in the morning) as % (Monthly Averages)
iv. Minimum relative humidity (at 2.30 p.m.) as % (Monthly Averages)

METHOD OF MEASURING AND CALCULATING TEMPERATURE DATA

Sri Lanka Meteorological Department collects and records all the weather data related to climate from its weather stations spread each and every district of the country. To the data they collect includes temperature, relative humidity, atmospheric pressure, wind direction, wind speed, cloud cover, precipitation, solar radiation, sunshine duration etc.

Internationally recommended maximum and minimum Cassella thermometers are use to measure maximum and minimum temperature values manually in metrological stations in each and every day. At the same time a thermograph indicates the same reading mechanically both are interpolated and get the reasonably accurate value.

Then based on collected in formation on temperature values, average of 30 days minimum (night time temperature) and maximum (day time temperature) mean temperature has been calculated (monthly mean maximum and minimum temperature). The above temperatures are converted to annual mean maximum and minimum, for the current research purpose.

METHOD OF MEASURIN AND CLCULATING RELATIVE HUMIDITY DATA

The most convenient method of determining the humidity of the air is the use of wet and dry built thermometers. But it is known that the readings of the wet built thermometer depend not only on the humidity but also on strength of the wind.

Pernter's modification of Renault's formula for light wind conditions (almost) some with the August's formula, which has been used in the Indian meteorological department, is used to modify the readings taken from the dry and wet bulb thermometer.

Hygrometer is used to measure the same data in mechanical terms. Sri Lanka meteorological department also using the same data in mechanical terms, and hygrometric tables, which were published and revised by the Indian meteorological department in 1949. It gives the wet bulb, dry bulb temperature and the dew point temperature (the dew point temperature is the temperature to which the air temperature at which the saturation vapor pressure is equal tot the pressure of vapor present in air)

Then using the above data relative humidity is calculated. Ultimate accurate humidity values are taken by analyzing both manual and hydrographic data. Then the maximum and minimum humidity values are calculated. (The monthly mean maximum is the average of 30 days maximum where normally indicate the night time humidity values the monthly mean minimum is the average of 30 days minimum, where the daytime humidity values and established)

This research contains both manual mean temperature and humidity data since 1971 to 2000 for the selected three suburban stations within Sri Lanka. To identity the effect of temperature and humidity variations on human comfort THI (Temperature Humidity Index) should calculate by using the temperature and humidity data.

4.2.1 THERMAL COMFORT INDEX (THI) ANALYZING THE THI VALUES FROM DATA

Thermal Comfort Index is a scale, which can measure the comfortability of a place or an area. Using these temperature and relative humidity data calculate the Thermal Comfort Index(THI). THI value is calculated by using the following formula.

$$THI = (0.8 * Td) + ((RH * Td) / 500)$$

Td – Dry Bulb Temperature in ^0C

RH – Relative Humidity as %

Then calculate THI values regarding to the all three stations selected, (day and night for each and every year separately). To identify the percentage comfort and discomfort levels use the Discomfort Index for every THI value. 'Discomfort Index' is shows the relationship between the THI value and the percentage of comfort population.

THI Value	Percentage of Comfort Population
THI <= 21	100% Population are comfort
21<= THI <= 24	50% Population are comfort
THI >= 26	100% Population are discomfort

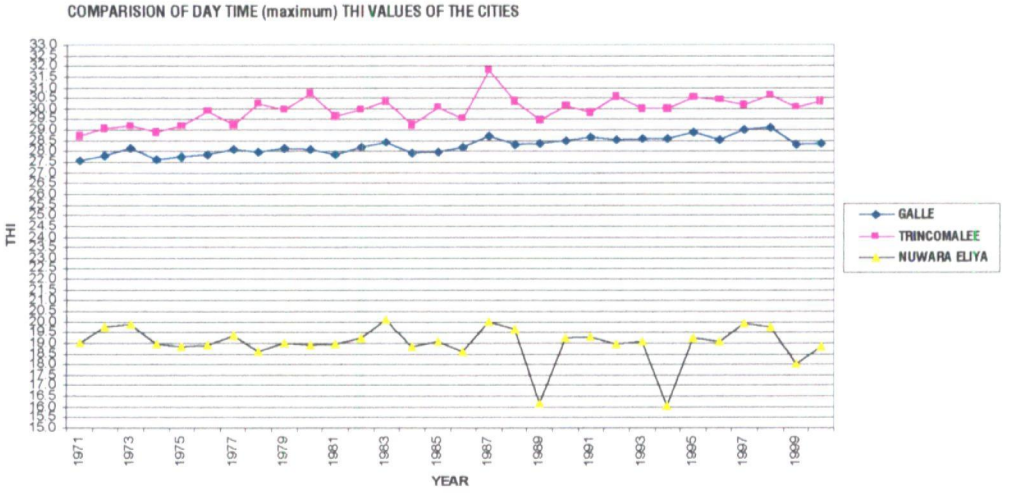
4.3 METHOD OF ANALYZING

Climatic data and Arial photographs are taking for the main analytical part of the study. The results will explain by using graphs drawn according to the calculated climatic data and areas of physical elements in Arial photographs.

For the comparisons then use graphs.

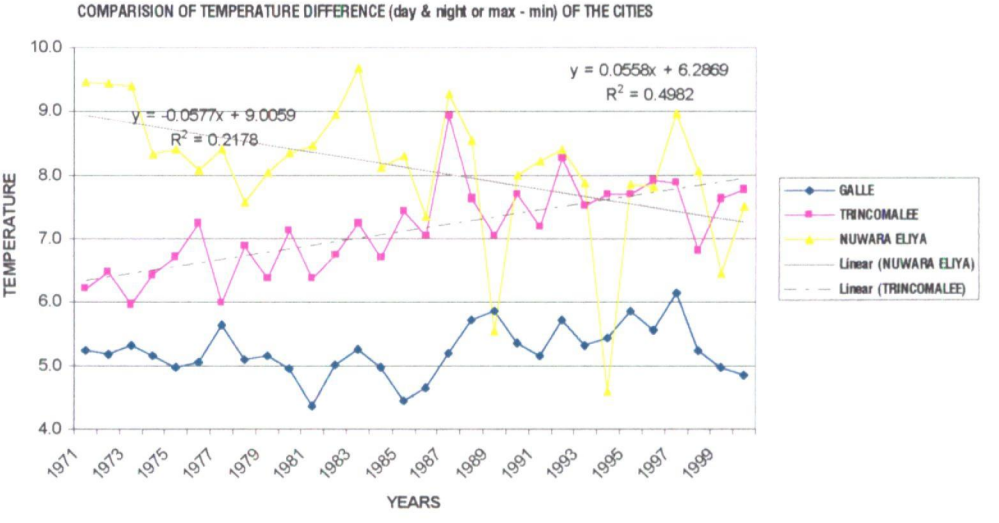
4.3.1 HISTORICAL TREND OF THI VARIATION

Calculate the average maximum and minimum THI values for the thirty years research period And prepare a graph having THI for the Y-axis and years for the X-axis. Then by using the discomfort index can find out the relationship between the THI variation throughout the research period of the three selected cities.



4.3.2 HISTORICAL TREND OF TEMPERATURE VARIATION

Calculate the average temperature variation by subtracting the yearly average minimum temperature from the yearly average maximum temperature of three cities. Then draw a graph using temperature variation for the y- axis and years for the x- axis, and find out the relationship between temperature variation and the urban heat island effect.



4.3.3 HISTORICAL TREND OF THE LAND COVER VARIATION

For the research used three Arial photographs from each city belongs to the three decades of research period.

i. Galle 1974, 1986, 1992

ii. Trincomalee 1971, 1984, 1992

iii. Nuwara Eliya 1975, 1987, 1999

Built areas, green areas, roads, open areas, and water bodies taken as major urban physical elements / land cover elements for the research. And by analyzing each and every Arial photograph separately for all the above elements by calculating the total areas of each element can clearly find the change of physical elements within the research period. To find out the relationship of the changes of the physical elements draw a graph using area of the area of land cover elements for the y- axis and years for the x- axis. For the calculations, use circular area of having 1 km radius of the selected cities. Here the reason for selecting three diverse cities is, to represent the different climatic zones.

By doing this research study hope to find out the relationship between thermal comfort changes according to micro climatic changes, physical element changes, due to urbanization within last three decades in selected suburban Sri Lankan cities.

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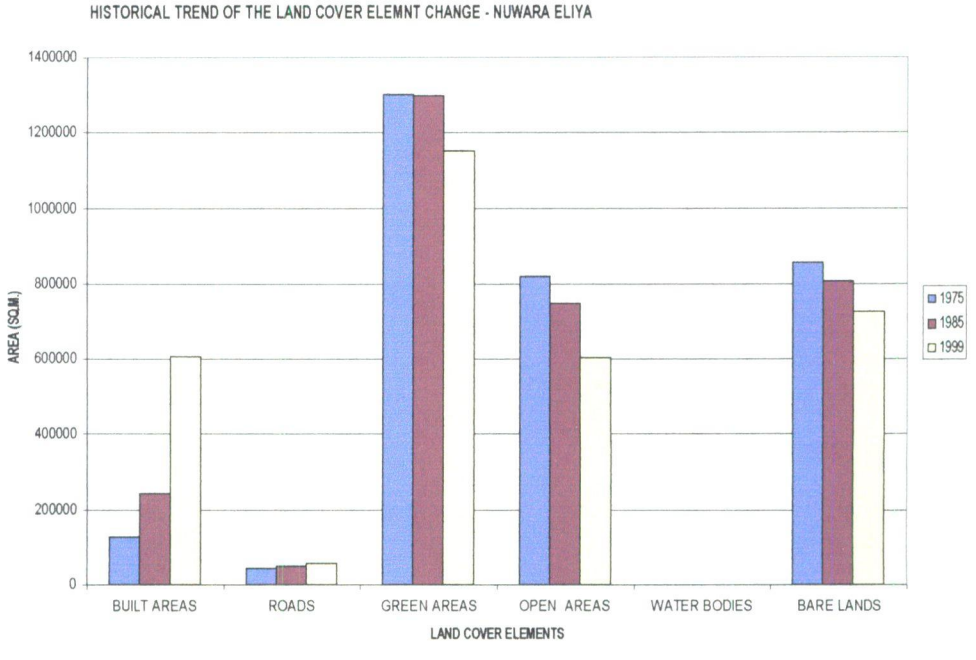


CHAPTER FIVE

Results of the Research Study

PART ONE

GALLE

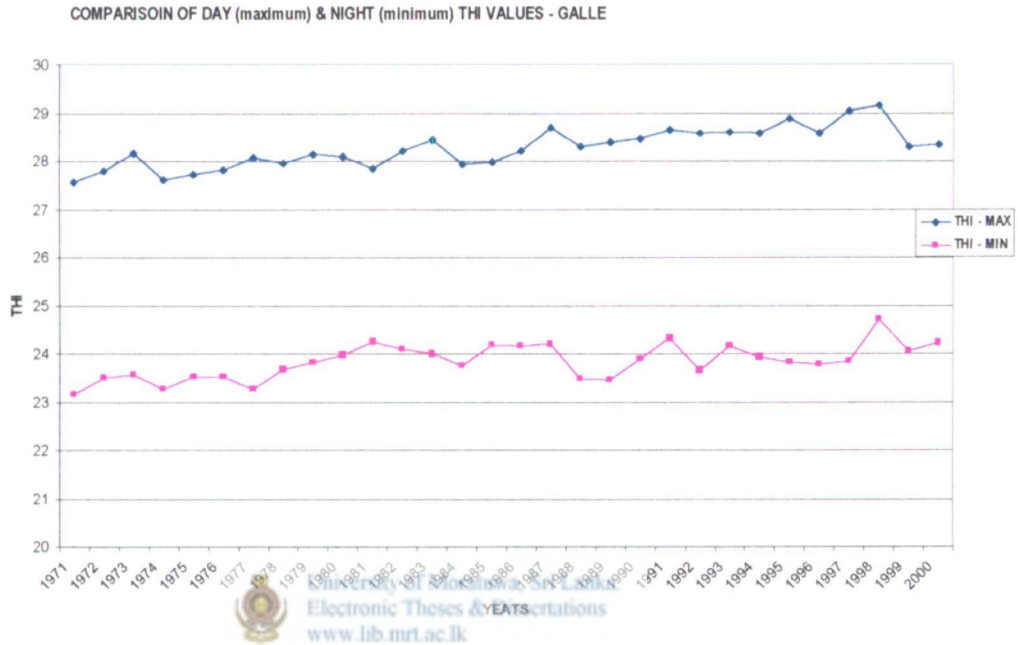
5.0 CHAPTER FIVE

RESULTS OF THE RESEARCH STUDY

PART ONE

5.1 GALLE

Thermal Comfort Change



City	DaytimeTHI Variation	Air Temperature Variation	Relative Humidity	Thermal Comfortability
Galle	increased by .7 (28.3 – 27.6)	increased by .6^{0}C (29.7^{0}C – 29.1^{0}C)	increased by 4.5% (77.8% - 73.3%)	100% population in discomfort

City	Night timeTHI Variation	Air Temperature Variation	Relative Humidity	Thermal Comfortability
Galle	increased by .9 (24.2 – 23.1)	increased by .9^{0}C (24.8^{0}C –23.9^{0}C)	increased by 3.9% (88.3% - 84.6%)	100% population in comfort

In the Galle meteorological station day time THI values has increased by .7 (27.6 - 28.3) and night time by 1.1 (24. 2 – 23.1) during the last 30 years. During the same period (from 1971 – 200) day time air temperature (dry bulb) increased by .6^{0}C (29.1^{0}C – 29.7^{0}C) and night time temperature increased by .9^{0}C (23.9^{0}C – 24.8^{0}C), while maximum relative humidity (early morning)

increased by 3.7% (88.3% - 84.6%) and minimum relative humidity increased by 4.5 % (77.8 % - 73.3%)

When considering them nighttime THI values, maximum THI value holds by the year 1998, which is 25.3. In this years 1982, 83, 85, 86, 87, 91, 93, 92 and onwards THI values were only in the range of 50% population comfortable. All the other years THI values indicate that Galle is was in 100% population comfortable range during the nighttime.

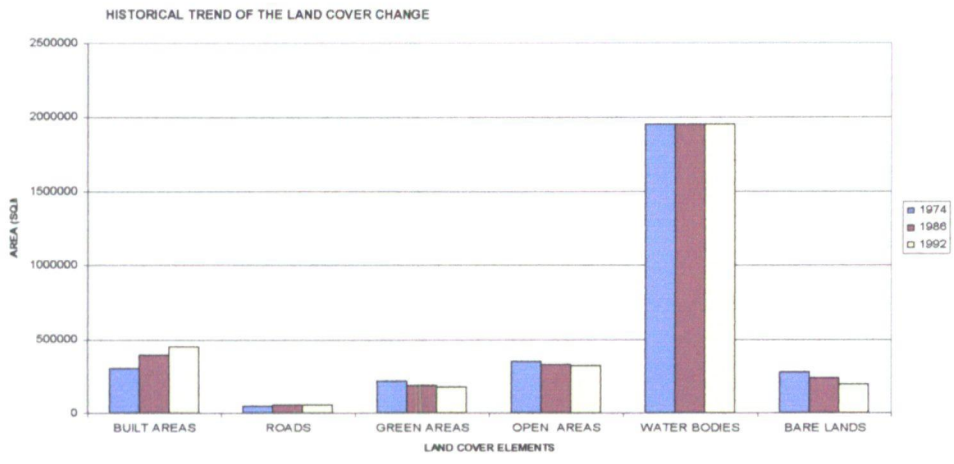
When comparing the THI variation of day and night in Galle, it was decreased during the research period. In 1971 variation of day and night THI was 14.5 and in 2000 it was 4.1. And the daytime THI variation .7 (1971 – 2000) throughout the research period, Galle was in 100% population uncomfortable range.

When comparing with the THI values of other two stations, Trincomalee also in the 100% population uncomfortable range in the daytime during the period of 30 years taken for the research and it is so vital, comparing with Galle. Because THI values stated from 28.7 (in 1971) and ended up by 30.4 (in 2000)

Considering the monthly THI averages of last3 decades Galle was in 100% population uncomfortable range throughout every year arid in the night time form October to March 100% population comfortable range. Form April to end of September it was 50% population in comfortable range.

According to the graph prepared by average temperature variations though out the study period for Galle, indicates .6°C decrease from 1971 upto 2000; which indicates a potential to having urban heat island; even recently Galle slightly affected by an urban heat island effect.

Land Cover Change



Land Cover Change in Galle

	BUILT AREAS	ROADS	GREEN AREAS	OPEN AREAS	WATER BODIES	BARE LANDS
1974	302400	50054	214330	349303	1950000	276770
1986	390200	53200	185450	327007	1950000	237000
1992	446250	57200	174700	320000	1950000	194707

Land Cover Values (in Square meters)

Land Cover Change of Galle seems very little changes when comparing with Nuwara Eliya. According to the graph built areas were increased and bare lands were decreased. Area calculations indicate that the roads and open areas had almost small variations.

Figure 58. Traced Arial Photograph of the Galle City (1986)

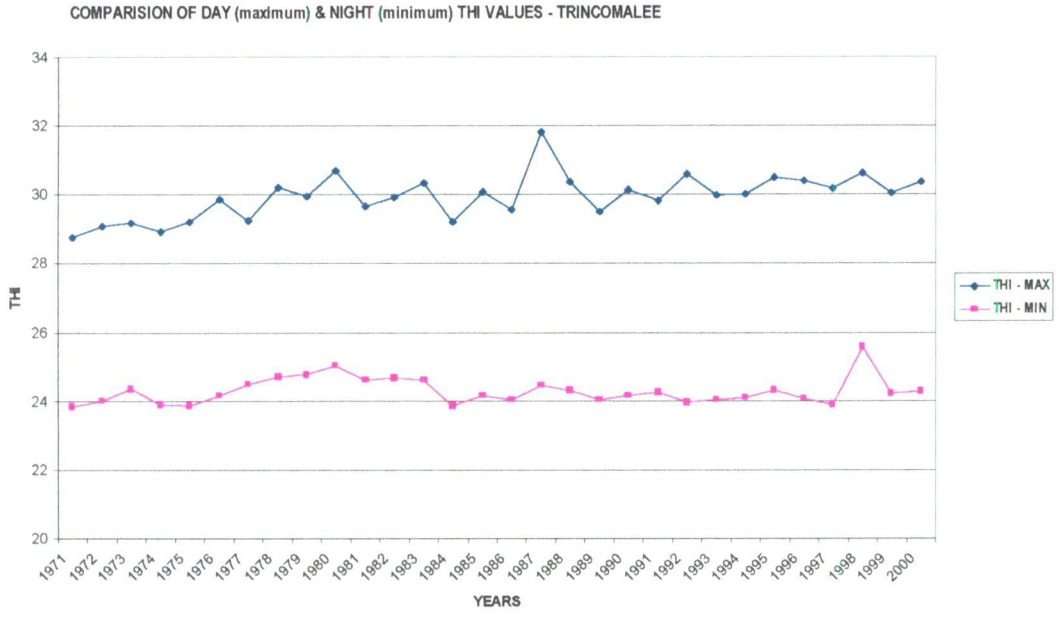
PART TWO

TRINCOMALEE

PART TWO

5.2 TRINCOMALEE

Thermal Comfort Change



City	DaytimeTHI Variation	Air Temperature Variation	Relative Humidity	Thermal Comfortability
Trincomalee	increased by 1.7 (30.4 – 28.7)	increased by 1.7^{0}C (32.7^{0}C – 30.0^{0}C)	increased by .4% (63.8% - 63.4%)	100% population in discomfort

City	Night timeTHI Variation	Air Temperature Variation	Relative Humidity	Thermal Comfortability
Trincomalee	increased by 1.7 (24.3 – 23.8)	increased by .2^{0}C (24.9^{0}C – 24.7^{0}C)	increased by 5.8% (86.6% - 80.8%)	50% population in comfort

In the Trincomalee meteorological station from the start (1971) up to the end (2000) of the research period, daytime THI values increased by 1.7 (30.4 – 28.7) and night time THI values increased by .5 (24.3 – 23.8). Daytime air temperature increased by 1.7^{0}C (32.7 ^{0}C – 31.0^{0}C) and night time temperature increased only by .1 ^{0}C (24.9 ^{0}C – 24. 8 ^{0}C). The maximum humidity variation was 5.8% (86.6% - 80.8oC) and minimum was .4% (63.8% - 63.4%)

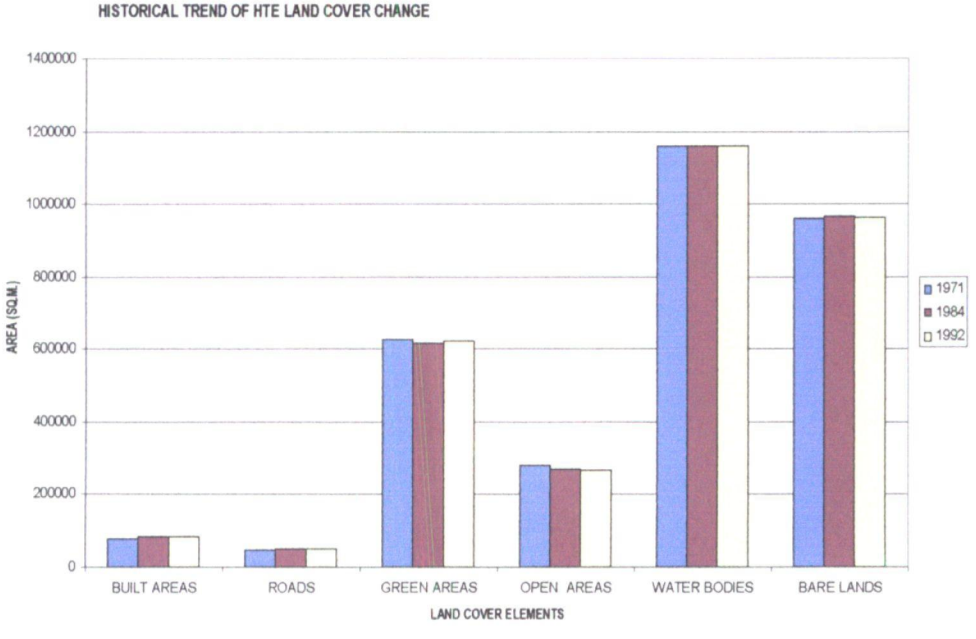
When considering the daytime THI values shown in the graph. Trincomalee was in 100% population uncomfortable range throughout the research period. From the monthly averages of THI values of the 30 years, the result was same 100% population uncomfortable during the year.

Night time THI values of the research period shows slight increase but other than the years of 1971, 74, 75, 84 and 97 the rest of the years within only the 50% population comfortable range. Above indicated years only Trincomalee and TH1 values of 100% population comfortable range; which is below the THI = 24.

Night time temperature averages throughout the 12 months of the year shows slight different comparing with night time monthly averages. From November to February it was in the 100% population comfortable range and rest of the months 50% population in comfortable range. According to the graph the most uncomfortable month was May to the year. December and January are the comfortable months to Trincomalee.

When comparing with other cities, THI variation and temperature variation is very small in Trincomalee. This means that urbanization happened in Trincomalee is very less comparing with other two cities. Major reason for that is the civil war, which has 20 years history between LTTE terrorists. And the development of the eastern provinces of the country badly effected by this war, throughout last 20 years. Minimum urbanization of Trincomalee them expressed the minimum changes in the microclimate.

Land Cover Change



Land Cover Change in Trincomalee

	BUILT AREAS	ROADS	GREEN AREAS	OPEN AREAS	WATER BODIES	BARE LANDS
1971	78057	45600	625000	278200	1157000	959000
1984	83250	48147	617800	270000	1157000	966660
1992	85172	49900	622500	265605	1157000	962680

Land Cover Values (in Square meters)

Figure 59. Traced Arial Photograph of Trincomalee City (1971)

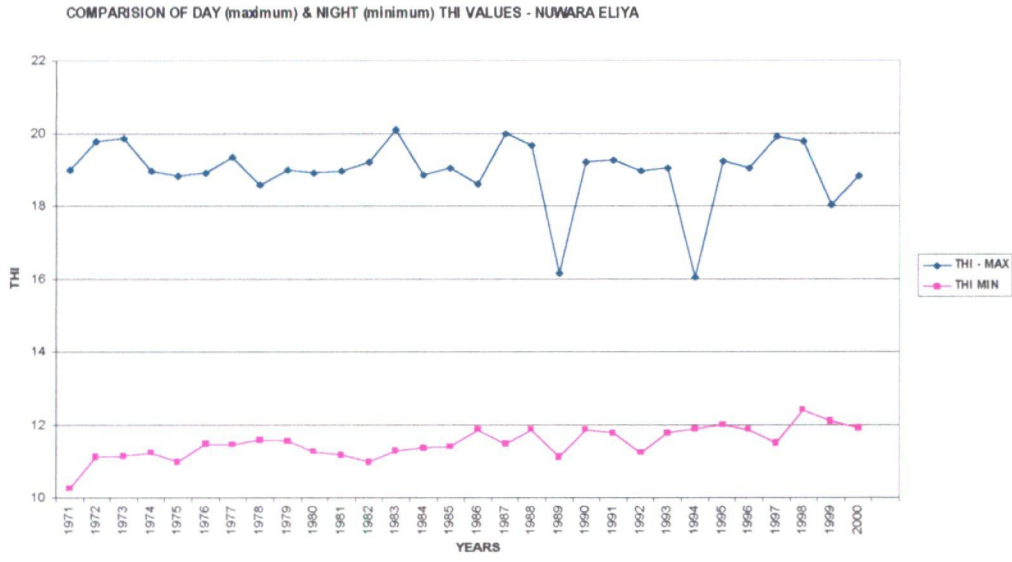
PART THREE

NUWARA ELIYA

PART THREE

5.3 NUWARA ELIYA

Thermal Comfort Change



City	Daytime THI Variation	Air Temperature Variation	Relative Humidity	Thermal Comfortability
Nuwara Eliya	decreased by.2 (18.8 – 19.0)	decreased by .3°C (19.6°C – 19.9°C)	increased by 2.4% (78.8% - 76.4%)	100% population in comfort

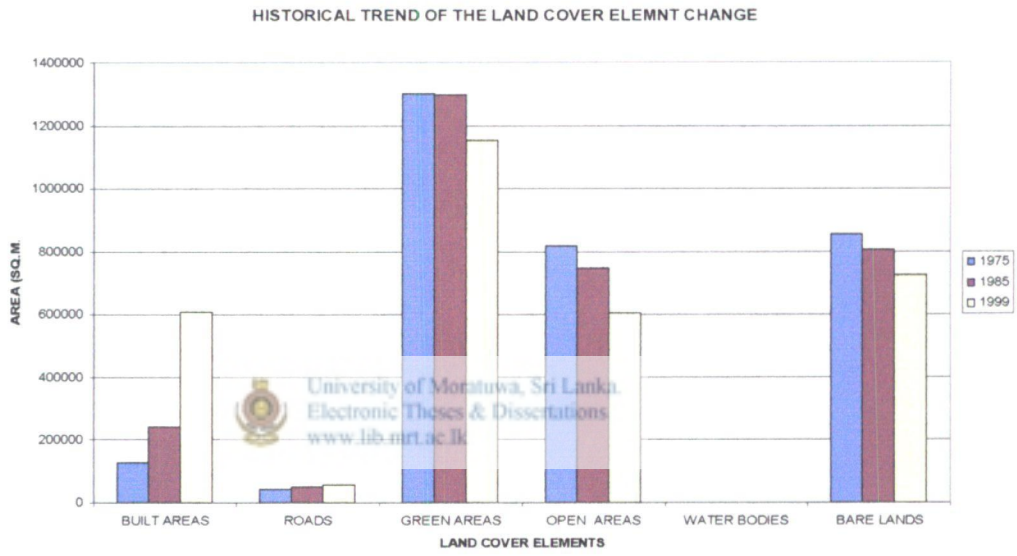
City	Night time THI Variation	Air Temperature Variation	Relative Humidity	Thermal Comfortability
Nuwara Eliya	increased by 1.7 (11.9 – 10.2)	increased by1.7 °C (12.1°C – 10.4°C)	increased by .4% (90.4% - 90.0%)	100% population in comfort

In Nuwara Eliya Meteorological station from the beginning of the research study to the end (1971 – 2000) daytime THI values showed a decrease of .2 (18.8-19) and night time THI values increased of 1.7 (11.9- 10.2) Daytime air temperature varies from the beginning to the end by .3°C (19.6°C – 19.9°C)and night time temperature increased by 1.7 °C(12.1°C – 10.4°C). the maximum relative humidity variation was .4% (90.4% - 90.0%) and minimum, by 2.4% (78.8% - 76.4%). Comparing day time THI values Nuwara Eliya showed very significant decrease. This is not only for the THI, but for the day time temperature also. Nuwara Eliya was within 100% population in

comfortable zone within day and night throughout the research period, but it is important that graph of day and night temperature variation which showing a heat island effect in the city.

Land Cover Change

According to the figures calculated by using Arial photographs Nuwara Eliya showed a significant development then other cities, taken for the research study. Due it increasing tourism related activities this new development occurred during the last three decades. clearly Can see the decrease of green areas, open areas and bare lands within the selected area.



Land Cover Change in Nuwara Eliya

	BUILT AREAS	ROADS	GREEN AREAS	OPEN AREAS	WATER BODIES	BARE LANDS
1975	127000	44200	1300200	816857	0	854600
1985	242400	49477	1296900	747920	0	806160
1999	606507	55100	1151900	604750	0	724600

Land Cover Values (in Square meters)

Figure 60. Traced Arial Photograph of the Nuwara Eliya City (1985)

PART FOUR

SUMMERY OF FINDINGS

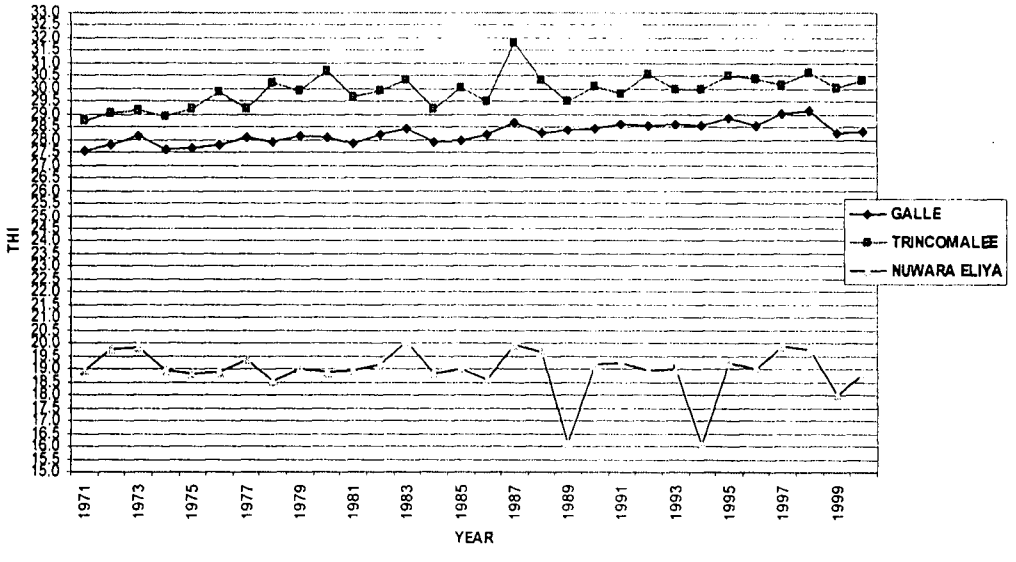
PART FOUR

5.4 SUMMERY OF FINDINGS

During the study period Nuwara Eliya showed significant changes in both urban physical environment and thermal comfort. Land use data indicates that the built area roads and paved areas changed also an increasing trend. Higher built area change also shown from Nuwara Eliya, then Galle and Trincomalee. Development around the Galle meteorological station was restricted during last decades because of the fort of Galle. The fort first built by Portuguese and then it was captured and rebuilt by the Dutch and then the British's; therefore I have higher historical value and is one of the UNESCO world heritage sites. Other than conservations and reuses new constructions are strictly prohibited inside the fort of Galle. But the city area shows a rapid development. Unlike in other two cities Trincomalee showed less urbanization throughout the research period. First reason for it was the civil war continued from 80's up to 2000; which made drew back of development of the largest city in the eastern province of Sri Lanka. The second reason was the Trincomalee meteorological station was situated somewhat away from the city canter.

Decrease of bare lands is higher in Nuwara Eliya than the other two cities. The research resulted that the effect of vegetation makes less impact for the thermal comfort of a city. The vegetation cover was not largely changed in Galle and Trincomalee during the period of study, but it showed a significant deference in Nuwara Eliya.

COMPARISION OF DAY TIME (maximum) THI VALUES OF THE CITIES



Statistical analysis of data of day and night THI variation in two cities namely Galle and Trincomalee were gradually increased during the last 30 years. But Nuwara Eliya shows a fluctuation of THI values during the research time, but considering 1971 to 2000 it shows a decrease of THI value of about 0.2. The graph shows except Nuwara Eliya other two cities were in 100% population in uncomfortable range in the daytime through out the study period. (According to Thom, 1956, Discomfort Index).

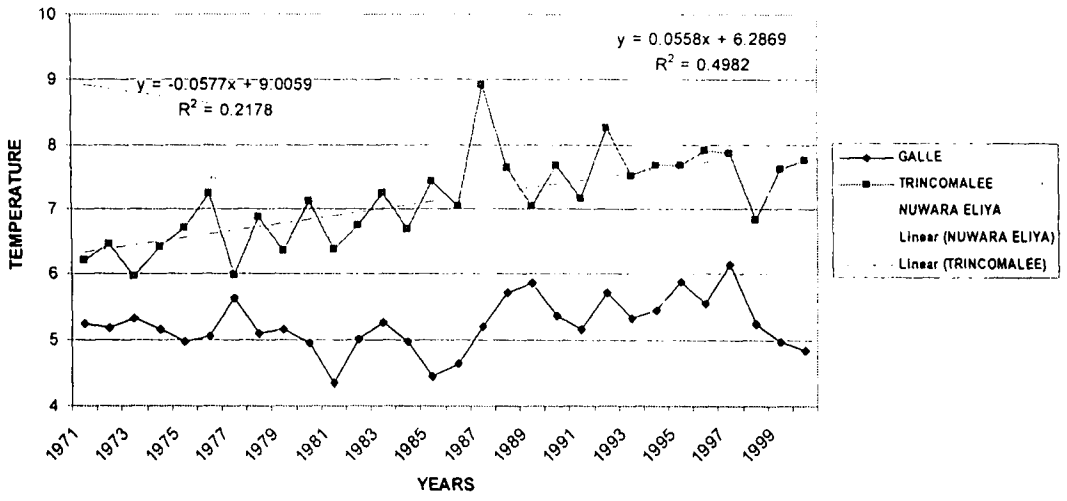
Results of Galle showed THI variation of .7 and temperature variation of .6°C during 1971 – 2000 in the daytime. Trincomalee indicated daytime THI and temperature variations as 1.7 and 1.7°C respectively. Nuwara Eliya showed a speciality of decreasing daytime THI and temperature variations within the study period of .3 and .2°C.

Climate Oriented Results of the three Cities in the Daytime

City	DaytimeTHI Variation	Air Temperature Variation	Relative Humidity	Thermal Comfortability
Galle	increased by .7 (28.3 – 27.6)	increased by .6°C (29.70C – 29.1°C)	increased by 4.5% (77.8% - 73.3%)	100% population in discomfort
Trincomalee	increased by 1.7 (30.4 – 28.7)	increased by 1.7°C (32.70C – 30.0°C)	increased by .4% (63.8% - 63.4%)	100% population in discomfort
Nuwara Eliya	decreased by .2 (18.8 – 19.0)	decreased by .3°C (19.60C – 19.9°C)	increased by 2.4% (78.8% - 76.4%)	100% population in comfort

COMPARISION OF NIGHT TIME (minimum) THI VALUES OF THE CITIES

COMPARISION OF TEMPERATURE DIFFERENCE (day & night or max - min) OF THE CITIES



Unlike daytime THI variation, nighttimes showed a clear change of thermal comfort variation in the three selected cities. Galle was in 100 % population comfort in the nighttimes except few years 1981,1988, and 1991 up to 1997. There onwards THI increased and it was 50% population in comfort. At the beginning of the research Trincomalee was in the range of 100% population comfort range and gradual increasing of THI brought into 50% population in comfort in the night time almost through out the research period. Nuwara Eliya was within the range of 100% population comfort, but considering the temperature vitiation among the three cities. Clear change of comfort level can find from the graph in the years of 1976 up to 1980 and from 1997 onwards when considering the total research time period.

Climate Oriented Results of the three Cities in the Night time

City	Night timeTHI Variation	Air Temperature Variation	Relative Humidity	Thermal Comfortability
Galle	increased by .9 (24.2 – 23.1)	increased by .9ºC (24.80C –23.9ºC)	increased by 3.9% (88.3% - 84.6%)	100% population in comfort
Trincomalee	increased by 1.7 (24.3 – 23.8)	increased by .2ºC (24.9ºC – 24.7ºC)	increased by 5.8% (86.6% - 80.8%)	50% population in comfort
Nuwara Eliya	increased by 1.7 (11.9 – 10.2)	increased by1.7 ºC (12.1ºC – 10.4ºC)	increased by .4% (90.4% - 90.0%)	100% population in comfort

5.5 SUMMARY OF FINDINGS AND THEIR RELATIONSHIPS

The research study done to find out the effect of urbanization process to a suburban cities, specially for it's micro climate and physical environment within last 3 decades. The data presented showed variations of built areas, roads, and pared built areas, roads and pared areas with time.

Time α An increase of built areas

Time α An increase of roads and pared areas

From this study too, indicate that bare lands in area were inversely changed within the time.

Time α 1 / bare lands

Through the study it was explored that there is an increasing or statistically almost stable situation in green areas in three cities; compared to the general condition of urban areas. However this may be as a result of selected areas, due to reason fore said. Galle was an ancient port city and after colonial period it used as the administrational and commercial center of southern province. After British have captured the fort, the development of the city increased and still continuing.

Trincomalee not showed a significant change throughout the study period but Nuwara Eliya had the highest urbanization comparing with other two cities.

Thermal comfort studies carried out by the research were mainly important and significant not only in the field of architecture but also in other fields like climatologic, town and country planning etc.

Tropical countries have fairly high daytime temperature and low humidity compared to the night time. Here too, this general principle was established. Secondly the daytime THI values were well above the nighttimes values as a result of above phenomenon. But however considering the rate of increase of THI values during the last 30 years and night time indicates a higher increase than the daytime while having increase in both day and night data.

Thirdly when it is comparing with the thermal comfort condition Galle and Trincomalee were in 100 % population discomfort, in daytime and Nuwara Eliya 100 % population in comfort range, yet increasing the THI values. Unlike daytime THI differences Galle went from 100 % population in comfort rang to 50% population in comfort range. Trincomalee within the range of 50% population comfortable in the night time, during the research period. Nuwara Eliya within 100% population comfortable range but clear increasing of THI values. Comparing the day and

night temperature variations, it can clearly visible that Nuwara Eliya subjecting to the urban heat island effect; and Galle also having a growing heat island effect. Very significant observation was gradual increase of day and night temperature variation in Trincomalee. There was an increasing discomfort in thermal comfort condition and both day and night THI values in all three cities. Thus it shows proportional relationship between increase discomfort of particular city and its amount and increase rate of built area, roads and pared areas. Those sounds both built areas; roads and paved areas are having an inversely proportional relationship with thermal comfort.

Day & Night Thermal Comfort α 1 / an increase of built areas roads and paved areas etc.

The increasing comfort may occur due to the results of amount and increasing rate of building density and hard surfaces. And analysing land cover elements statistically during the study period then other two cities Nuwara Eliya had reduced its bare lands significantly.

As mentioned earlier thermal comfort of the three cities became uncomfortable, during last 30 years. Thus there was a relationship between the present of bare land and the increase of discomfort.

But according to the previous studies in this field it is pointed out that the increase of vegetation cover has proportional relationship with the migration of urban heat island effect. Thus it may also have an effect on positive direction to increase of thermal comfort.

Thermal comfort α Vegetation Cover.

But other then Nuwara Eliya tree coverage was almost stable in the other cities within the research period. However in other words according to the research built areas, roads and pared areas have largely effected on thermal comfort in particular cities compared to the effect on vegetation cover.

CHAPTER SIX

Conclusion

6.0 CHAPTER SIX

6.1 CONCLUSION

Back to the question: does urbanization tend to change the prevailing microclimate, thermal comfort and physical environment of particular area? Considering the suburban cities selected from the three climatic zones in Sri Lanka it seems that there considerable impact on microclimate in consequence of increasing urbanization. The most prominent impact on microclimate change was, higher temperature values in highly urbanized areas. It is so vital to thermal comfort condition in a city, and significantly contributes to increase of urban dwellers discomfort.

An emphasis on relationship between urbanization and thermal comfort provided a data based starting point to Sri Lankan studies in this field. Also important decisions related to urban design on an increased application of climatologic to urban designs / planning related to out door spaces, urban renewals and input for the design of new cities, and the optimum use of lands. The study was used Time Rate Change Method to identity the relationship between urbanization and microclimate. Normally in this approach urban to rural temperature difference were categorized over time and urbanization was measured as the population density of the area.

Day and night temperature values were them calculated using maximum (Day time), minimum (Night time) temperature and humidity values. Using discomfort chart by Thom 1956 the study identified the percentage of people in the comfort range over the study period.

An urban areas can be seen as three dimensional sculpture series of Arial photographs at difference intervals provide sequence of physical change over the respective time period. Then analyzed the percentage variation of physical environment changes both in man made (built and natural environment).

For the research selected three suburban cities belongs to three climatic zones of Sri Lanka. They were Galle, Trincomalee and Nuwara Eliya. The research study was carried out in an area of a circle having 1 km radius around the meteorological stations. During study period both urban physical environment (built areas, roads, tree covered areas, green / grown areas, water bodies, and bare lands) and thermal comfort has significant changes.

The statistical data indicate continuous increase to built areas, roads and paved areas in three cities, but it is very small in Trincomalee and high in Nuwara Eliya. Due to fort it is different when considering Galle. Further developments were restricted in and around the fort area because of its antiquity. But the city area seems subjected to rapid urbanization; when examine the

Arial photographs. Increasing of population, expansion and development works of the city and its surrounding land sub division, construction works related to tourism are the main courses happened to Nuwara Eliya. Trincomalee the situation is different. Both northern and eastern provinces of Sri Lanka suffer from a civil war between Sri Lankan Army and LTTE armed garillas asking those provinces as their own territory. Therefore the major city of northern province, Trincomalee has less development within the research period. However it seems bare lands decreasing slightly; which was inversely proportional to the urbanization. Since base land areas calculated as reduction of al other land use, almost all the time it has been reducing and converted to the other categories of land used.

The present research study also revealed that there is almost stable situation in green areas in the three stations. However this may be the result of the peculiarities of selected areas for the study. Vegetation cover of Galle was subjected to less impact during the last 30 years because it is a conserved area. Vegetation cover of Trincomalee area was not significantly changes because of less development of the area due to civil war and the study area belongs to a camp site of the Sri Lanka Air Force. Nuwara Eliya has difference situation. Development of the city occurred very rapidly during the last 3 decades specially is 90's. Residential development was increased due to development of tourism local and foreign.

According to these statistical data presented here Nuwara Eliya has the highest urban growth compared to the other two cities.

On the thermal comfort side, the following principles were established. There is a rapid rise in minimum temperature and slow rise in maximum temperature. Considering minimum temperature Trincomalee shows fewer variations. Secondly the daytime THI values were well above the nighttime values as a result of above phenomenon. But however when consider the rate of increase of THI values during last 30 years night time indicated the higher values than the day time while having an increase in both day and night values.

Thirdly the thermal comfort conditions; Galle and Trincomalee exceeded the THI value of 26 during the last 3 decades, thus during the study period Nuwara Eliya were under 100% population in comfort range.

THI values of nighttime shows Nuwara Elya has increase of THI values throughout the study period but under the 100% population in comfort zone. Galle shows an increase of nighttime THI values form 100 % population in comfort to 50% population comfortable range most of the research period special changes of THI values day and night times can seen in years 1983, 1987 and 1997 in all 3 cities.

Finally this research study points out some of the very important relationships between urban physical element changes and the thermal comfort changes. There is an increase of both

built areas, roads and paved areas, and there is an increasing discomfort of particular city stations. Thus it shows a proportional relationship between increase in discomfort of particular area and an increase of urban physical elements. That is therefore appears both built areas Roads and pared areas are inversely proportional to the urban thermal comfort.

The role of vegetation cover on thermal comfort was not much explored in this study, when carefully analyzed the data. This may be because vegetation is not directly connected to reduction of air temperature, but it reduced the direct radiation coming from the sky.

The study indicates that there is a considerable relationship between urban physical change and thermal comfort change. Thermal comfort is inversely proportional to changes in built areas. It was difficult to predict a relationship between vegetation cover and thermal discomfort.

6.2 LIMITATIONS

As mentioned earlier urbanization trends were analyzed by using climatic data of 30 years and analyzing Arial photographs; of 70's, 80's and 90's. Considering the Arial photographs of Galle, Trincomalee and Nuwara Eliya. They were not taken in same time and same month or year; some times. But the climate data was sequential not even the same year.

Years of Arial Photographs used for the study

Station	Year
Galle	1974, 1986 , 1992
Trincomalee	1971, 1984, 1992
Nuwara Eliya	1975, 1987, 1995

Time Duration's of used Climatic Data for the study

Station	Day		Night	
	Temperature	Humidity	Temperature	Humidity
Galle	1971 – 2000	1971 – 2000	1971 – 2000	1971 – 2000
Trincomalee	1971 – 2000	1971 – 2000	1971 – 2000	1971 – 2000
Nuwara Eliya	1971 - 2000	1971 - 2000	1971 - 2000	1971 - 2000

Difficulty in quantification of urbanization change was another major limitation. Increase of urban masses, directly proportional to the urban heat island effect. Here in the study 3 dimensional building masses calculated as 2 dimensional areas. For calculation the tree cover also same method applied. The plan area of the canopies only calculated as an alternative to the 'volume' of leaves.

Zenith angle of the Arial photographs also different and act as another limitation for the study. When getting the photographs the cameras has not over the area exactly and the Arial photographs traced out to be not plans but partial plan and partial perspective. For the study traced the photographs as plans and might have created mismatch.

In the plan vertical photographs which is taken properly the axis of the camera is perpendicular to the axis of the camera is perpendicular to the horizontal plan of the ground or 3 degrees of the verticals at the time of exposure producing on overhead or plan views (Branch, 1997: 139). According to that plan area must be modified and reinterpreted as an actual area.

Heights of the buildings and other structures shown on the verticals Arial photographs can be seen with the naked eye. If the height of one building is known, the heights of other buildings can fined out by measuring the length of shadows.

Terrain also very important. The nature of terrain effected to the length of the shadows. Due to uneven terrain, building elevation can be vary, when getting heights by using shadows.

For this kind of studies use an equipment to calculate canopy volumes of trees. It indicates the number of leaves on the three and calculates the volume, then its relationships to the study. This method was not used in the study.

Another error is especially due to main calculations of areas of urban physical elements. It results few errors in each elements, built areas, tree covered areas, roads, green or grass areas and water bodies. Multiple errors were presented in the base lands because it was calculate by reducing all the other areas of urban elements form the total study area.

Other than that, there was no direction in this study to analyze the conditions like change of type of activities, air quality etc.

Despite those shortcomings the current research study is very important as data base starting point to the fields not only the architecture but climatology, town and country planning and urban designing and specially it helps and sets the future directions for the field of climatic studies.

6.3 FUTURE DIRECTIONS

This kind of research studies are must for the near future. Because urbanization, seems creating serious effects on microclimate of the cities in Sri Lanka. It is very important to identity, clarify and design a research studies for find out more information about urbanization and its

relationships to many other areas, related to a city, city design, town and country planning, urban climate etc.

Building heights, various characteristics of hard surfaces, should include for future studies; and it is important to follows proper alternative calculation methods to calculate volume of three covered areas. This same study can even do for other suburban cities in Sri Lana, Mahaweli towns, which came up last 2 decades, and for the towns like Anuradhapura and Polonnaruwa to identity the effect of change of urban climate to the monuments belongs to centuries ago. Quality of air, condition of rainwater, also effects for the ancient ruins and even vegetation and bio diversity of an area. It is important if can study the matters related to change of air quality conditions or rainwater in urban areas and there long term effects through similar kind of another studies within Sri Lankan context. Some are not directly related to urbanization and its effects on micro climatic changes of particular area; but have as equal significant impact of changes of precipitation patterns amounts and long term effect on thermal comfort of urban environment; and pattern and speed changes of wind also effects on thermal comfort. By analyzing precipitation data, wind data (speed, direction); also find out the impact of organization on thermal comfortability in urban area.

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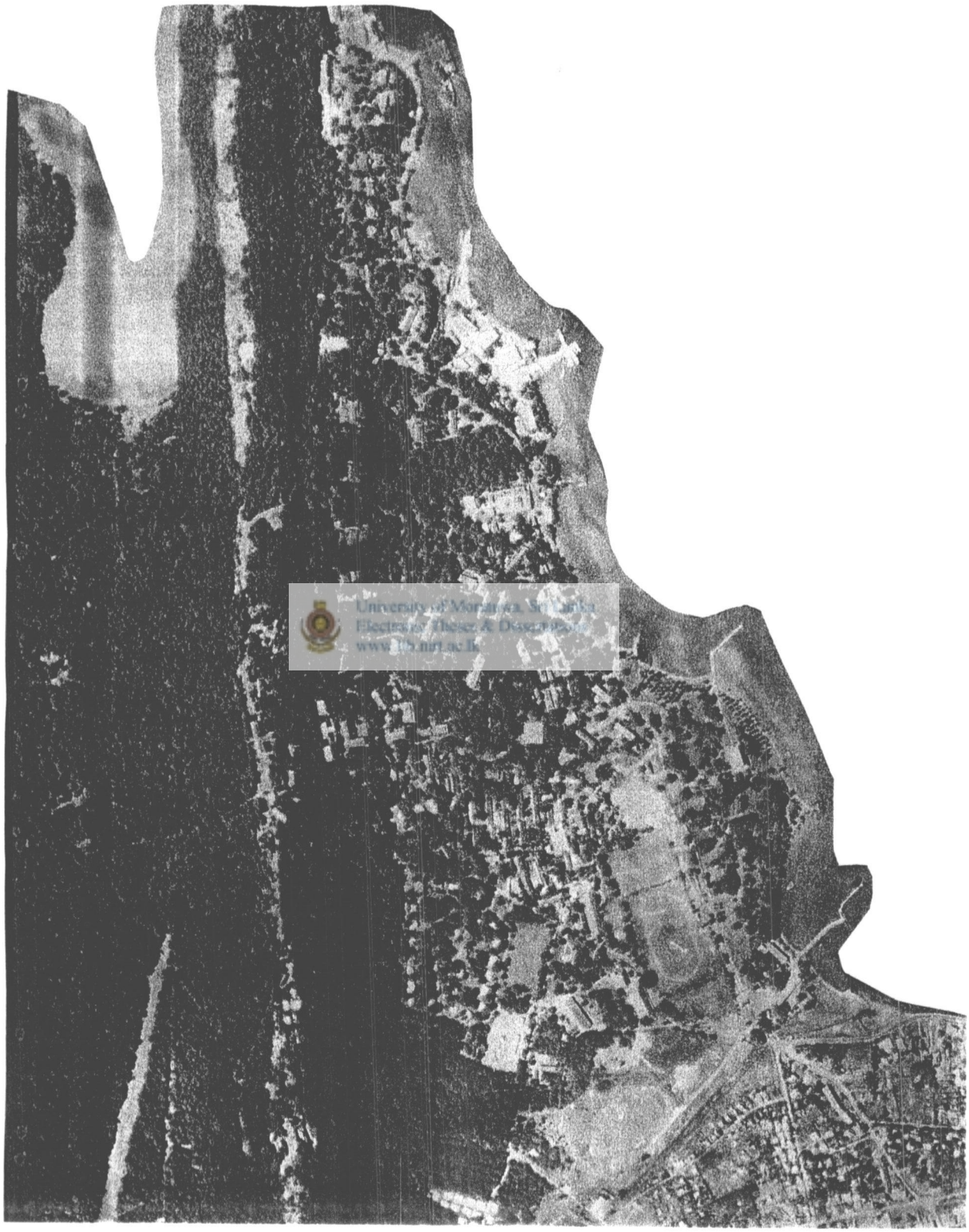
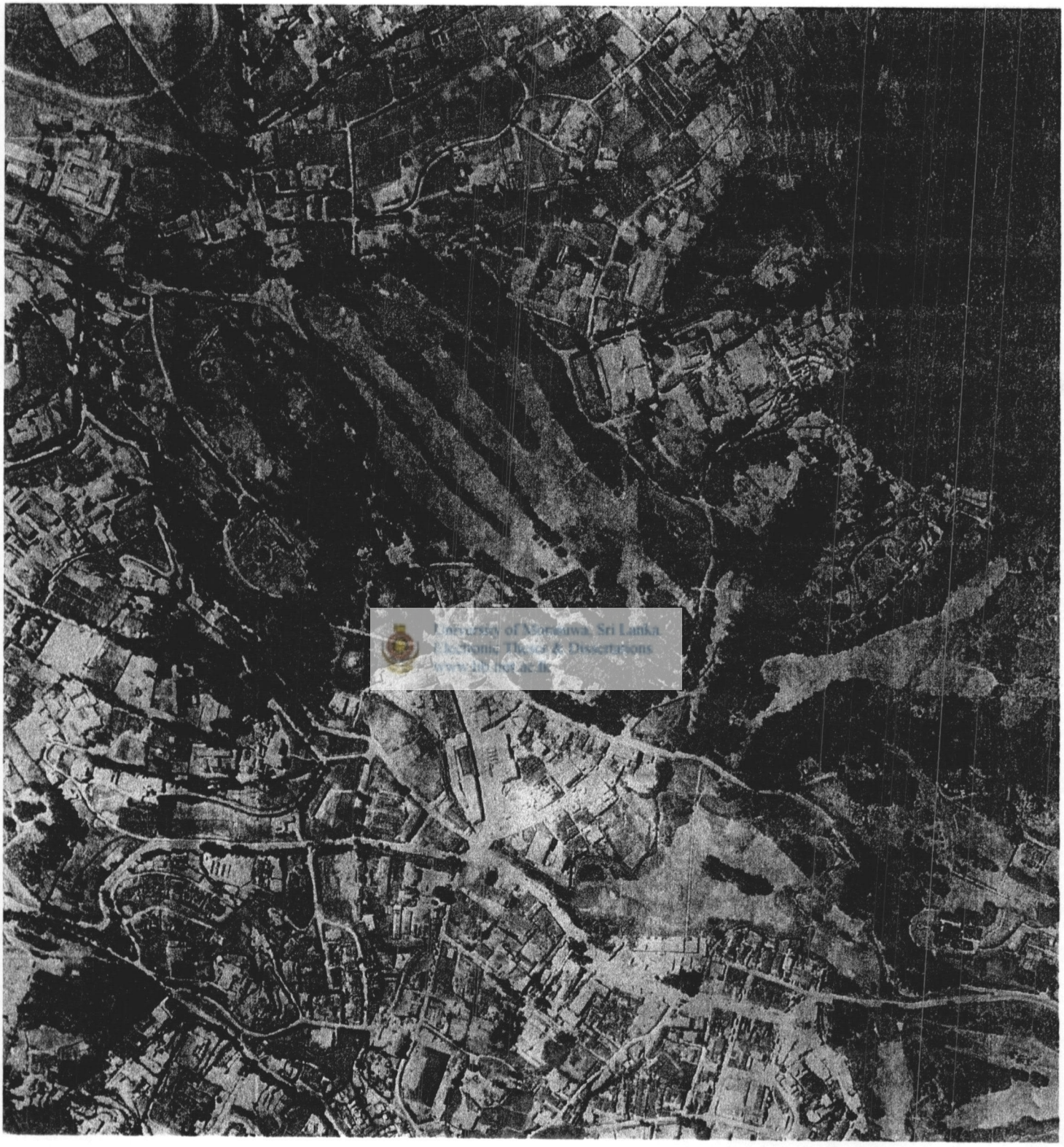
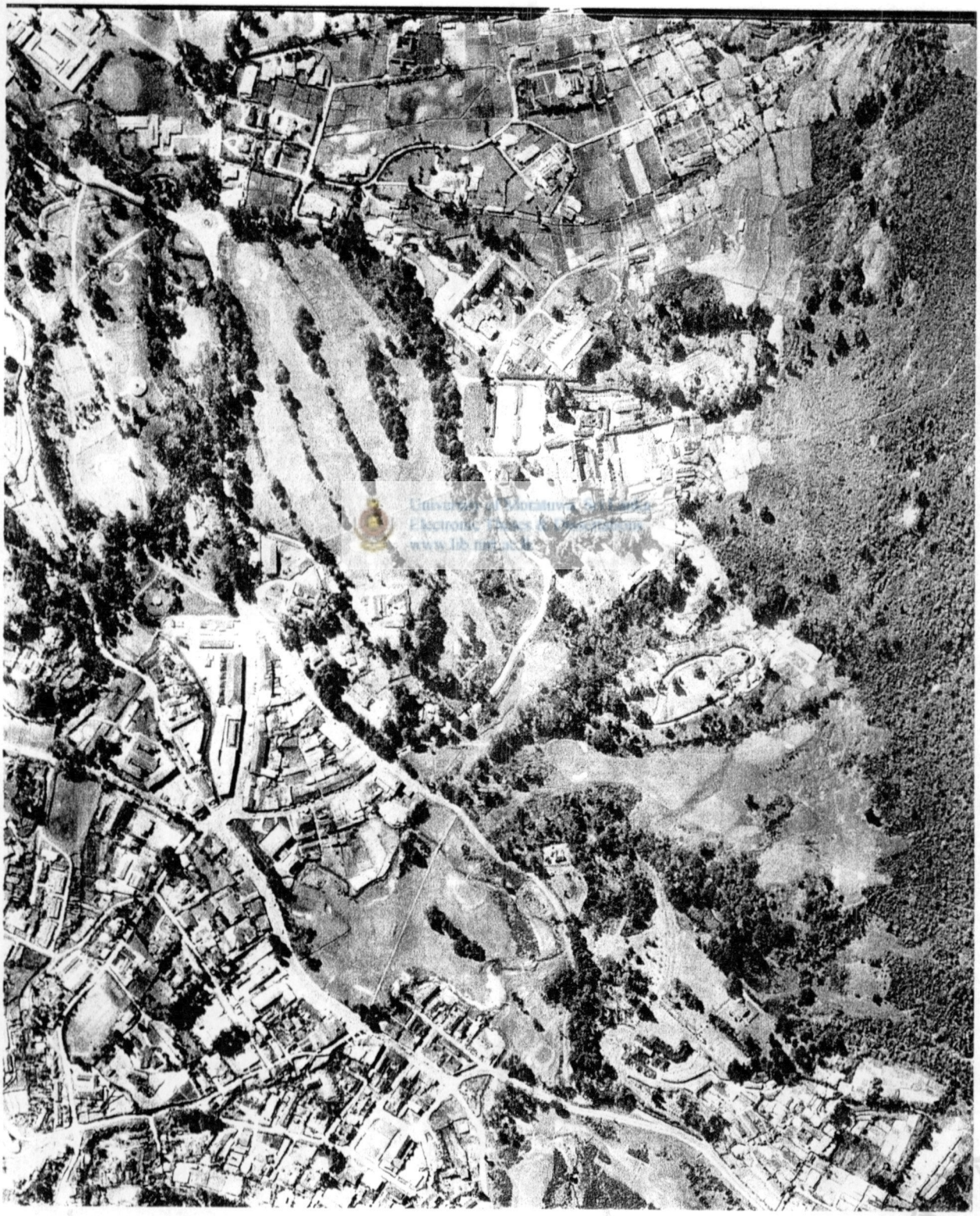
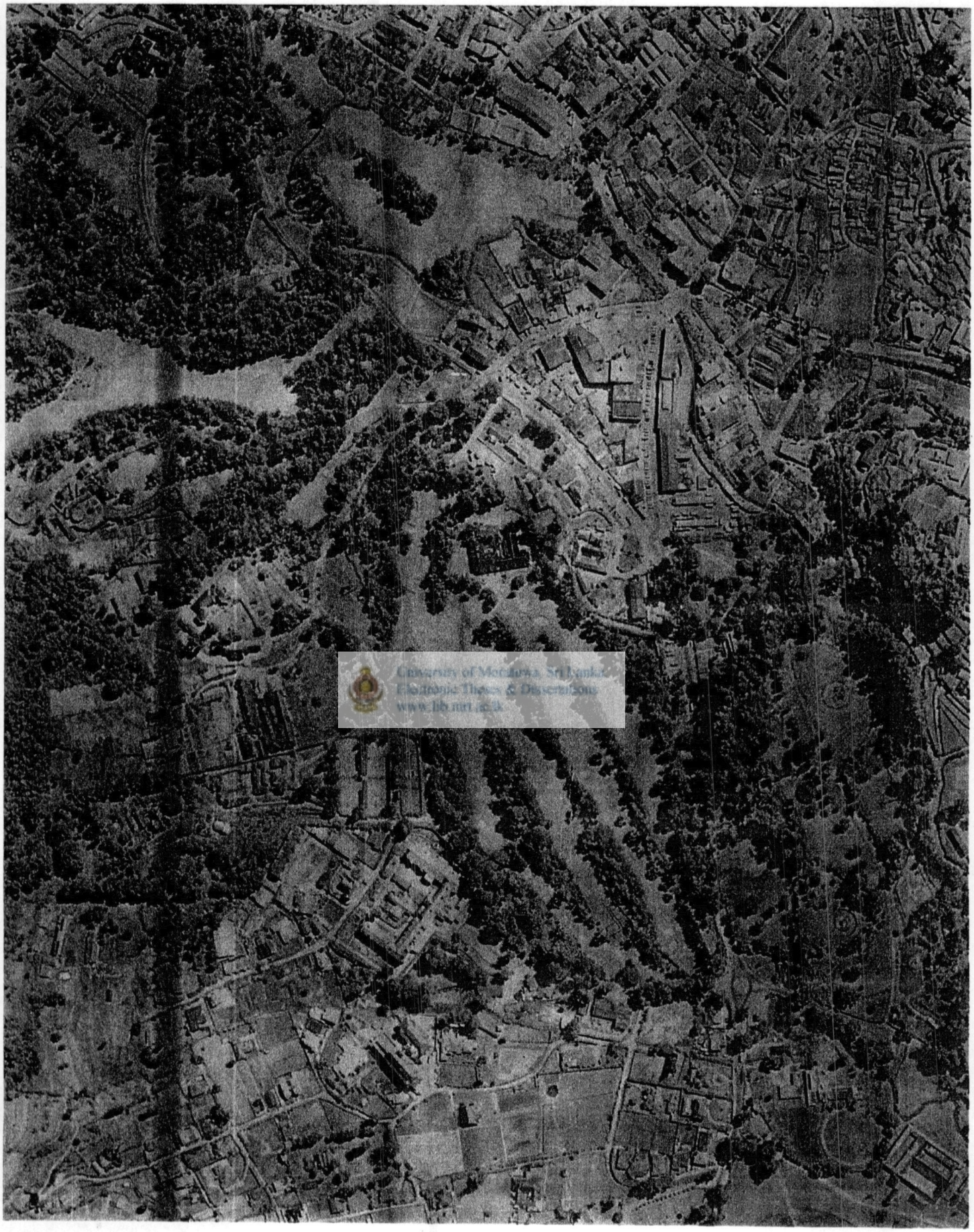
APPENDIX

Arial Photographs









THI values

Time	RH	TEMPERATURE	THI
1971	73.3	29.1	27.6
1972	72.7	29.4	27.8
1973	77.9	29.5	28.2
1974	77.1	28.9	27.6
1975	78.1	29.0	27.7
1976	79.8	29.0	27.8
1977	78.9	29.3	28.1
1978	78.3	29.2	27.9
1979	78.0	29.4	28.1
1980	76.4	29.5	28.1
1981	78.2	29.1	27.8
1982	77.5	29.5	28.2
1983	77.3	29.8	28.4
1984	78.7	29.2	27.9
1985	79.7	29.2	28.0
1986	79.9	29.4	28.2
1987	78.4	30.0	28.7
1988	75.9	29.7	28.3
1989	75.6	29.9	28.4
1990	76.8	29.9	28.5
1991	78.1	30.0	28.7
1992	77.5	29.9	28.6
1993	77.7	29.9	28.6
1994	79.1	29.8	28.6
1995	78.9	30.1	28.9
1996	79.3	29.8	28.6
1997	74.7	30.6	29.0
1998	76.7	30.6	29.1
1999	79.6	29.5	28.3
2000	77.8	29.7	28.3

Galle Relative Humidity, Temperature, THI Maximum Values

Time	RH	TEMPERATURE	THI
1971	84.6	23.9	23.1
1972	84.9	24.2	23.5
1973	88.2	24.1	23.6
1974	89.3	23.8	23.3
1975	89.6	24.0	23.5
1976	90.9	23.9	23.5
1977	91.6	23.7	23.3
1978	91.3	24.1	23.7
1979	90.3	24.3	23.8
1980	88.8	24.5	24.0
1981	90.2	24.8	24.3
1982	91.2	24.5	24.1
1983	89.4	24.5	24.0
1984	90.8	24.2	23.7
1985	89.5	24.7	24.2
1986	88.6	24.7	24.2
1987	88.1	24.8	24.2
1988	89.0	24.0	23.5
1989	89.0	24.0	23.5
1990	87.8	24.5	23.9
1991	90.0	24.8	24.3
1992	88.9	24.2	23.7
1993	90.7	24.6	24.2
1994	90.8	24.4	23.9
1995	90.7	24.3	23.8
1996	89.9	24.3	23.8
1997	88.3	24.4	23.8
1998	87.8	25.3	24.7
1999	90.0	24.5	24.1
2000	88.3	24.8	24.2

Galle Relative Humidity, Temperature, THI Minimum Values

Time	RH	TEMPERATURE	THI
1971	63.4	31.0	28.7
1972	62.2	31.5	29.1
1973	63.6	31.5	29.2
1974	60.1	31.4	28.9
1975	62.4	31.6	29.2
1976	61.9	32.3	29.9
1977	66.9	31.3	29.2
1978	65.3	32.5	30.2
1979	67.5	32.0	29.9
1980	63.8	33.1	30.7
1981	66.8	31.8	29.7
1982	63.1	32.3	29.9
1983	64.2	32.7	30.3
1984	68.8	31.2	29.2
1985	67.4	32.2	30.1
1986	65.8	31.7	29.5
1987	66.3	34.1	31.8
1988	64.1	32.7	30.4
1989	63.3	31.8	29.5
1990	61.8	32.6	30.1
1991	63.1	32.2	29.8
1992	64.2	33.0	30.6
1993	65.1	32.2	30.0
1994	62.7	32.4	30.0
1995	67.3	32.6	30.5
1996	66.3	32.6	30.4
1997	65.8	32.4	30.2
1998	61.9	33.2	30.6
1999	62.3	32.5	30.0
2000	63.8	32.7	30.4

Trincomalee Relative Humidity, Temperature, THI Maximum Values

Time	RH	TEMPERATURE	THI
1971	80.8	24.8	23.8
1972	80.1	25.0	24.0
1973	77.3	25.5	24.3
1974	78.0	25.0	23.9
1975	80.0	24.9	23.9
1976	81.6	25.1	24.2
1977	83.3	25.3	24.5
1978	82.2	25.6	24.7
1979	82.7	25.7	24.8
1980	81.8	26.0	25.0
1981	84.2	25.4	24.6
1982	82.6	25.6	24.7
1983	83.7	25.4	24.6
1984	87.9	24.5	23.9
1985	88.3	24.7	24.2
1986	86.8	24.7	24.0
1987	85.2	25.2	24.4
1988	84.6	25.1	24.3
1989	84.4	24.8	24.0
1990	84.6	24.9	24.2
1991	85.0	25.0	24.3
1992	85.3	24.7	24.0
1993	86.1	24.7	24.0
1994	86.8	24.7	24.1
1995	87.1	25.0	24.3
1996	87.4	24.7	24.0
1997	87.3	24.5	23.9
1998	85.3	26.3	25.6
1999	87.3	24.9	24.2
2000	86.6	25.0	24.3

Trincomalee Relatiove Humidity, Temperature, THI, Minimum Values

Time	RH	TEMPERATURE	THI
1971	76.4	19.9	19.0
1972	75.0	20.8	19.8
1973	76.8	20.8	19.8
1974	78.2	19.8	18.9
1975	79.5	19.6	18.8
1976	76.7	19.8	18.9
1977	80.9	20.1	19.3
1978	80.7	19.3	18.6
1979	79.8	19.8	19.0
1980	76.9	19.8	18.9
1981	75.9	19.9	19.0
1982	76.3	20.2	19.2
1983	71.1	21.3	20.1
1984	78.9	19.7	18.8
1985	78.4	19.9	19.0
1986	78.3	19.4	18.6
1987	75.7	21.0	20.0
1988	76.0	20.6	19.7
1989	75.8	17.0	16.1
1990	77.5	20.1	19.2
1991	76.0	20.2	19.3
1992	74.7	20.0	18.9
1993	76.9	20.0	19.0
1994	79.1	16.8	16.0
1995	78.8	20.1	19.2
1996	77.9	19.9	19.0
1997	78.5	20.8	19.9
1998	76.8	20.7	19.8
1999	79.3	18.8	18.0
2000	78.8	19.7	18.8

Nuwara Eliya Relative Humidity,
Temperature THI Maximum Values

Time	RH	TEMPERATURE	THI
1971	90.0	10.5	10.2
1972	89.3	11.4	11.1
1973	87.8	11.4	11.1
1974	88.3	11.5	11.2
1975	89.9	11.2	11.0
1976	87.8	11.8	11.5
1977	88.9	11.7	11.4
1978	91.8	11.8	11.6
1979	90.8	11.8	11.5
1980	90.5	11.5	11.3
1981	87.7	11.5	11.2
1982	89.4	11.2	11.0
1983	84.6	11.6	11.3
1984	91.8	11.6	11.4
1985	91.1	11.6	11.4
1986	90.1	12.1	11.9
1987	88.9	11.7	11.5
1988	89.5	12.1	11.8
1989	86.3	11.4	11.1
1990	88.4	12.1	11.8
1991	89.3	12.0	11.8
1992	85.5	11.6	11.2
1993	87.0	12.1	11.8
1994	88.7	12.2	11.9
1995	90.1	12.2	12.0
1996	89.2	12.1	11.8
1997	85.7	11.8	11.5
1998	88.8	12.7	12.4
1999	89.7	12.4	12.1
2000	90.4	12.2	11.9

Nuwara Eliya Realative Humidity,
Temperature, THI MinimumValues

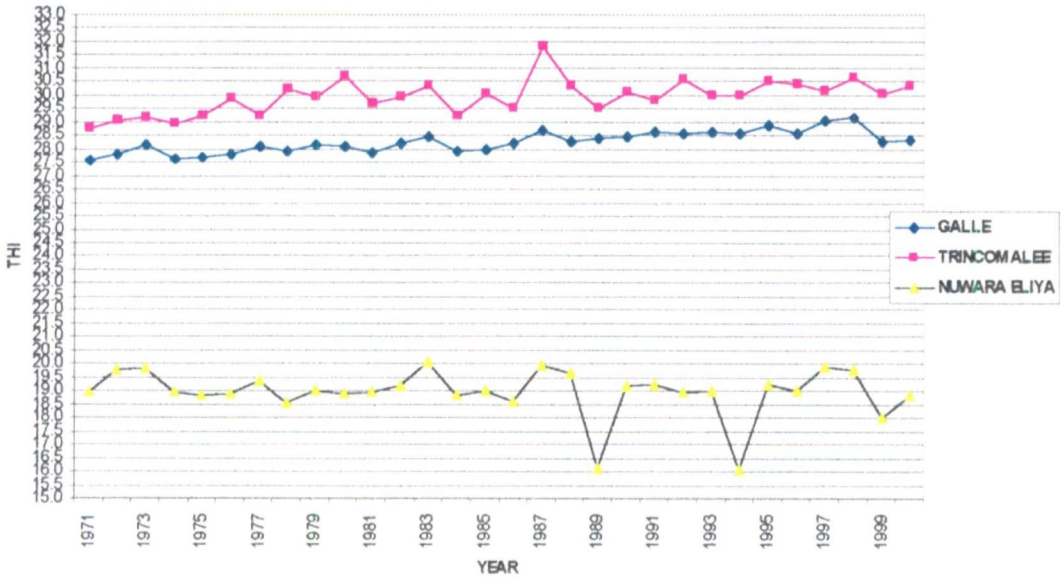
TEMP MAX				TEMP MIN			
	GALLE	TRINCOMALEE	NUWARA ELIYA		GALLE	TRINCOMALEE	NUWARA ELIYA
1971	29.1	31.0	19.9	1971	23.9	24.8	10.5
1972	29.4	31.5	20.8	1972	24.2	25.0	11.4
1973	29.5	31.5	20.8	1973	24.1	25.5	11.4
1974	28.9	31.4	19.8	1974	23.8	25.0	11.5
1975	29.0	31.6	19.6	1975	24.0	24.9	11.2
1976	29.0	32.3	19.8	1976	23.9	25.1	11.8
1977	29.3	31.3	20.1	1977	23.7	25.3	11.7
1978	29.2	32.5	19.3	1978	24.1	25.6	11.8
1979	29.4	32.0	19.8	1979	24.3	25.7	11.8
1980	29.5	33.1	19.8	1980	24.5	26.0	11.5
1981	29.1	31.8	19.9	1981	24.8	25.4	11.5
1982	29.5	32.3	20.2	1982	24.5	25.6	11.2
1983	29.8	32.7	21.3	1983	24.5	25.4	11.6
1984	29.2	31.2	19.7	1984	24.2	24.5	11.6
1985	29.2	32.2	19.9	1985	24.7	24.7	11.6
1986	29.4	31.7	19.4	1986	24.7	24.7	12.1
1987	30.0	34.1	21.0	1987	24.8	25.2	11.7
1988	29.7	32.7	20.6	1988	24.0	25.1	12.1
1989	29.9	31.8	17.0	1989	24.0	24.8	11.4
1990	29.9	32.6	20.1	1990	24.5	24.9	12.1
1991	30.0	32.2	20.2	1991	24.8	25.0	12.0
1992	29.9	33.0	20.0	1992	24.2	24.7	11.6
1993	29.9	32.2	20.0	1993	24.6	24.7	12.1
1994	29.8	32.4	16.8	1994	24.4	24.7	12.2
1995	30.1	32.6	20.1	1995	24.3	25.0	12.2
1996	29.8	32.6	19.9	1996	24.3	24.7	12.1
1997	30.6	32.4	20.8	1997	24.4	24.5	11.8
1998	30.6	33.2	20.7	1998	25.3	26.3	12.7
1999	29.5	32.5	18.8	1999	24.5	24.9	12.4
2000	29.7	32.7	19.7	2000	24.8	25.0	12.2

Maximum and Minimum Temperature Values of Galle, Trincomalee, Nuwara Eliya

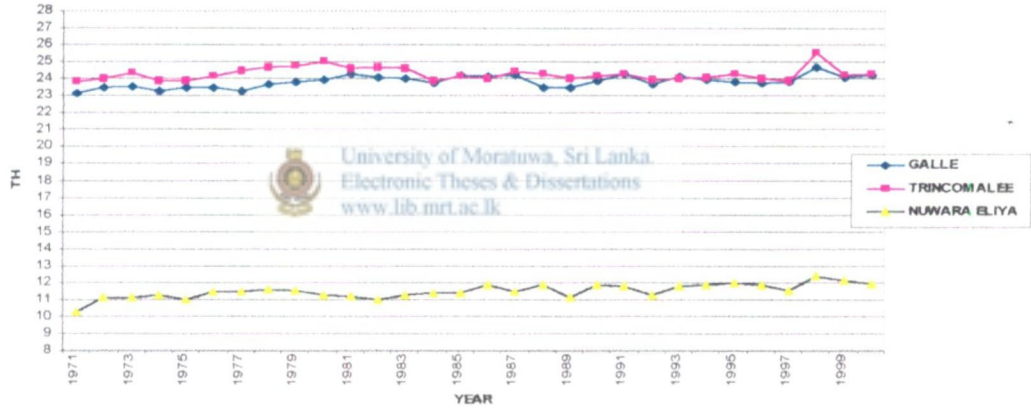
TEMP MAX - MIN			
	GALLE	TRINCOMALEE	NUWARA ELIYA
1971	5.2	6.2	9.5
1972	5.2	6.5	9.4
1973	5.3	6.0	9.4
1974	5.2	6.4	8.3
1975	5.0	6.7	8.4
1976	5.1	7.3	8.1
1977	5.6	6.0	8.4
1978	5.1	6.9	7.6
1979	5.2	6.4	8.0
1980	5.0	7.1	8.3
1981	4.4	6.4	8.5
1982	5.0	6.7	8.9
1983	5.3	7.3	9.7
1984	5.0	6.7	8.1
1985	4.5	7.4	8.3
1986	4.7	7.0	7.3
1987	5.2	8.9	9.3
1988	5.7	7.6	8.5
1989	5.9	7.0	5.5
1990	5.4	7.7	8.0
1991	5.2	7.2	8.2
1992	5.7	8.3	8.4
1993	5.3	7.5	7.9
1994	5.4	7.7	4.6
1995	5.9	7.7	7.9
1996	5.6	7.9	7.8
1997	6.2	7.9	9.0
1998	5.2	6.8	8.1
1999	5.0	7.6	6.5
2000	4.8	7.8	7.5

Maximum – MinimumTemperature Values of Galle, Trincomalee, Nuwara Eliya

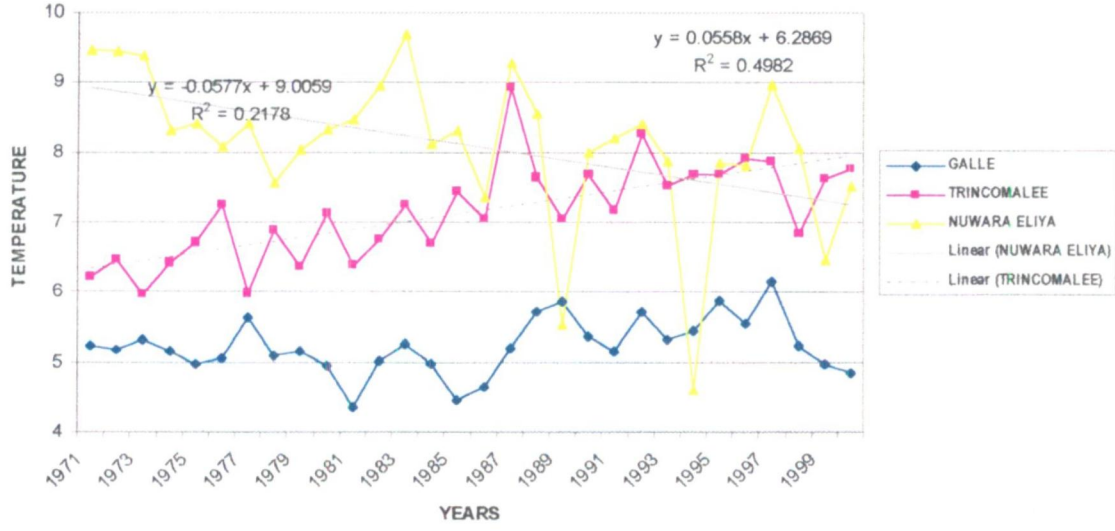
COMPARISION OF DAY TIME (maximum) THI VALUES OF THE CITIES



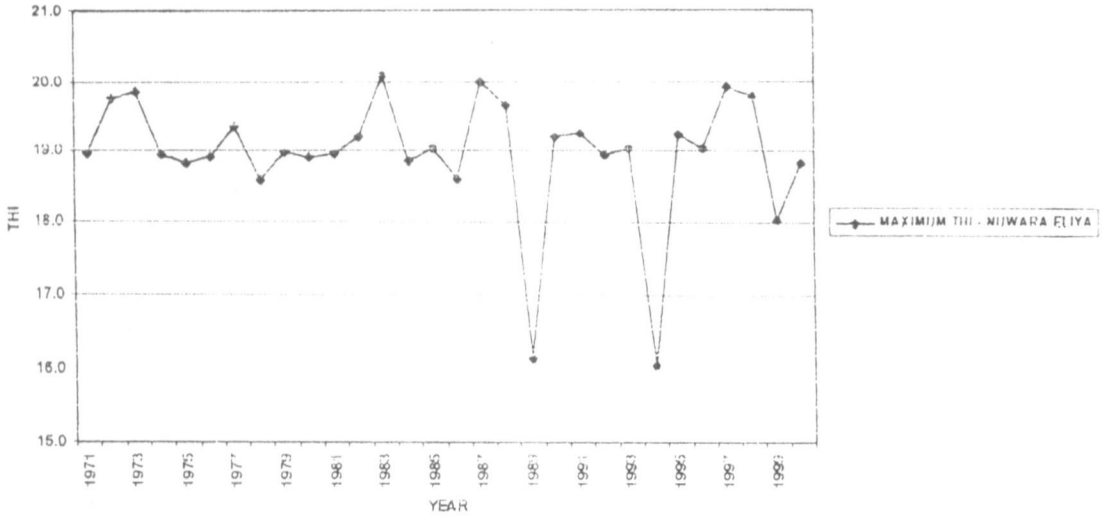
COMPARISION OF NIGHT TIME (minimum) THI VALUES OF THE CITIES



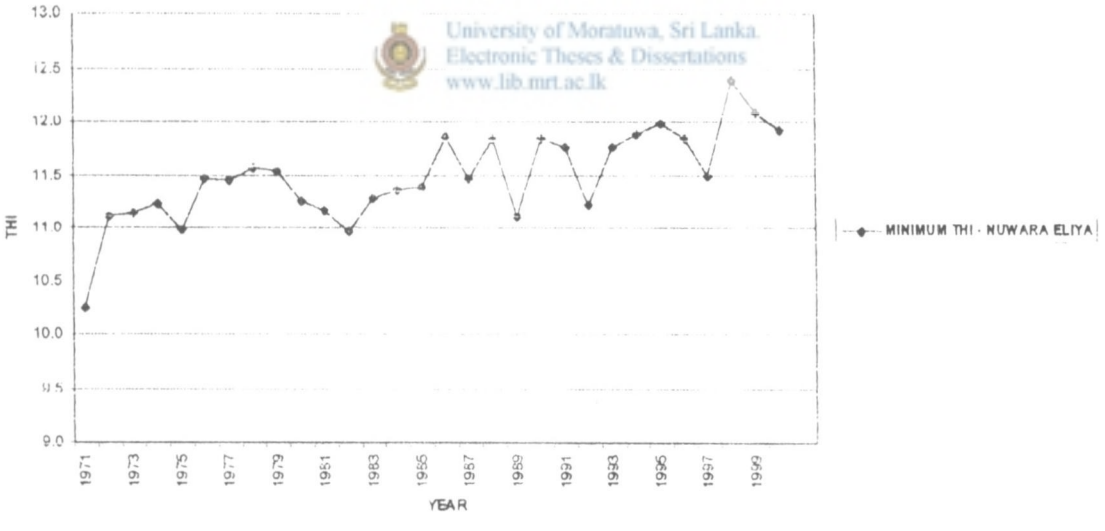
COMPARISION OF TEMPERATURE DIFFERENCE (day & night or max - min) OF THE CITIES



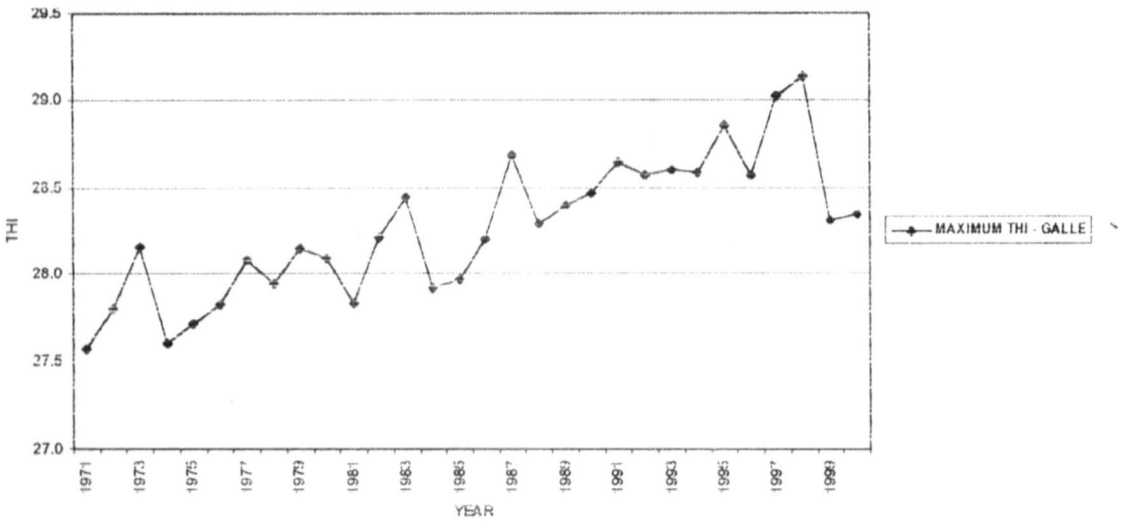
DAY TIME (maximum) THI VALUES - NUWARA ELIYA



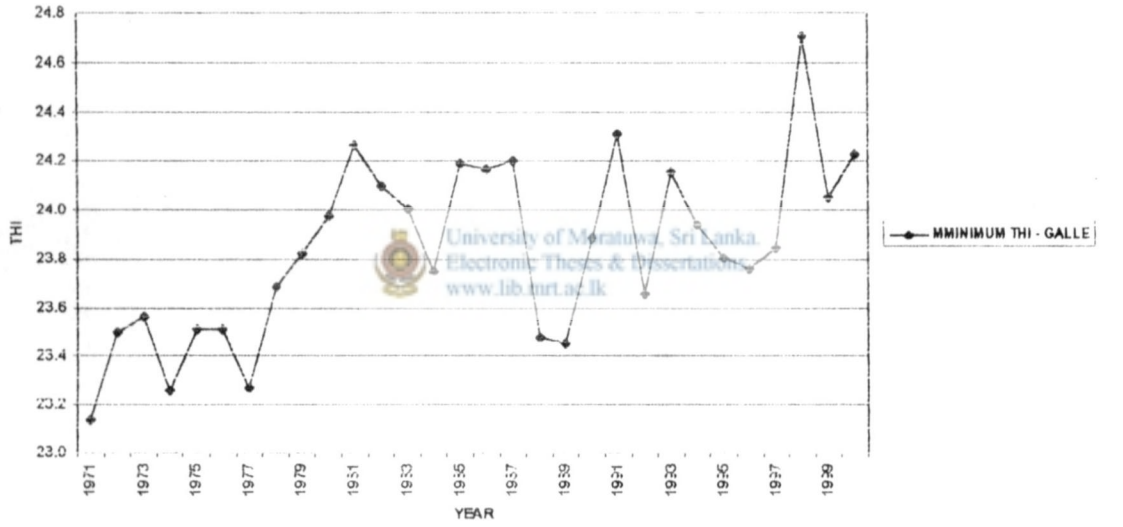
NIGHT TIME (minimum) THI VALUES - NUWARA ELIYA



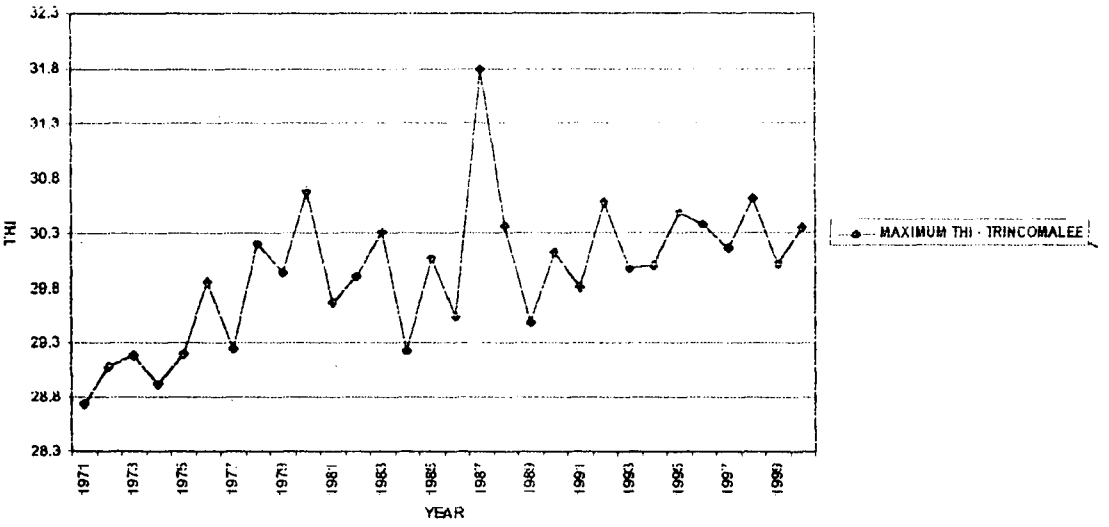
DAY TIME (maximum) THI VALUES - GALLE



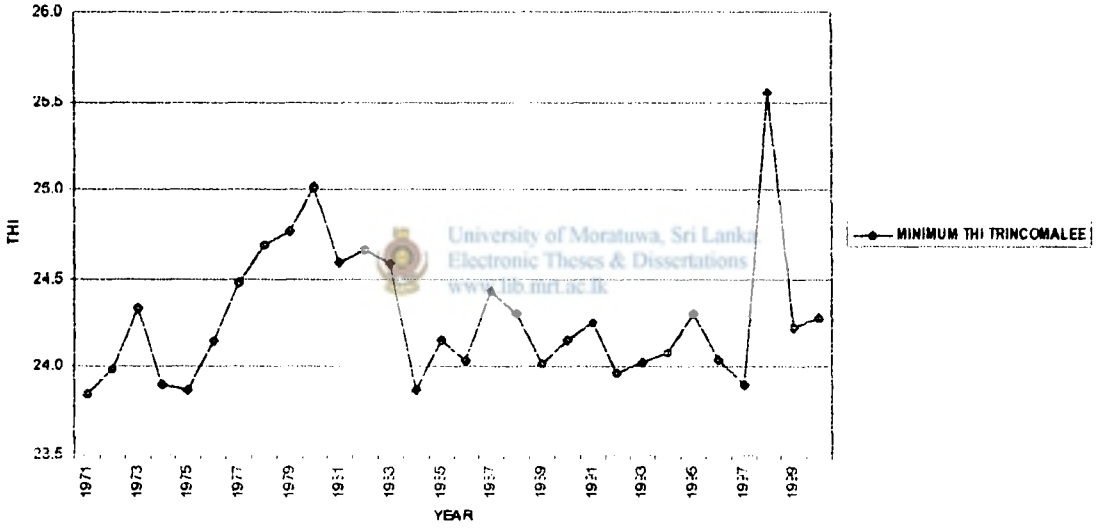
NIGHT TIME (minimum) THI VALUES - GALLE



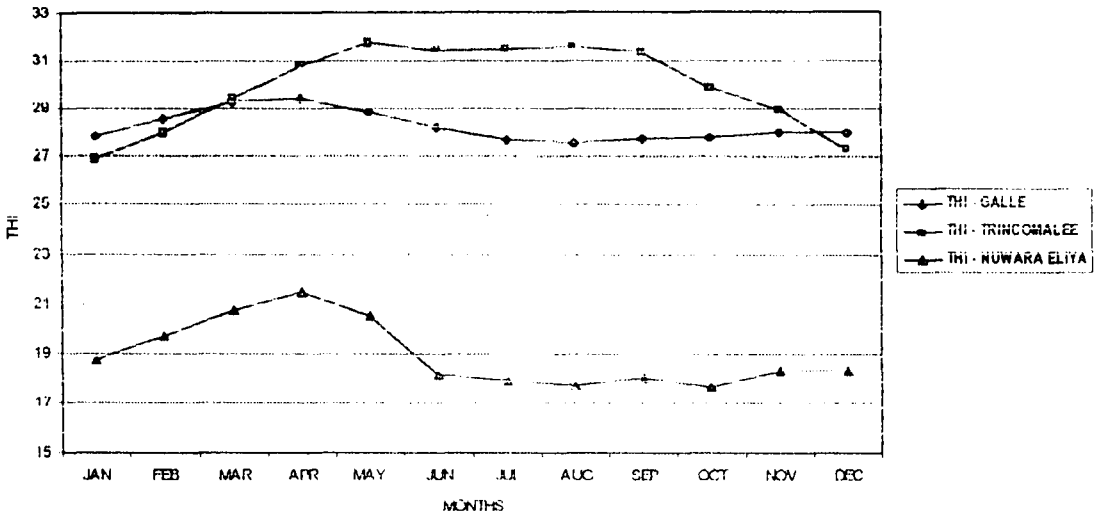
DAY TIME (maximum) THI VALUES - TRINCOMALEE



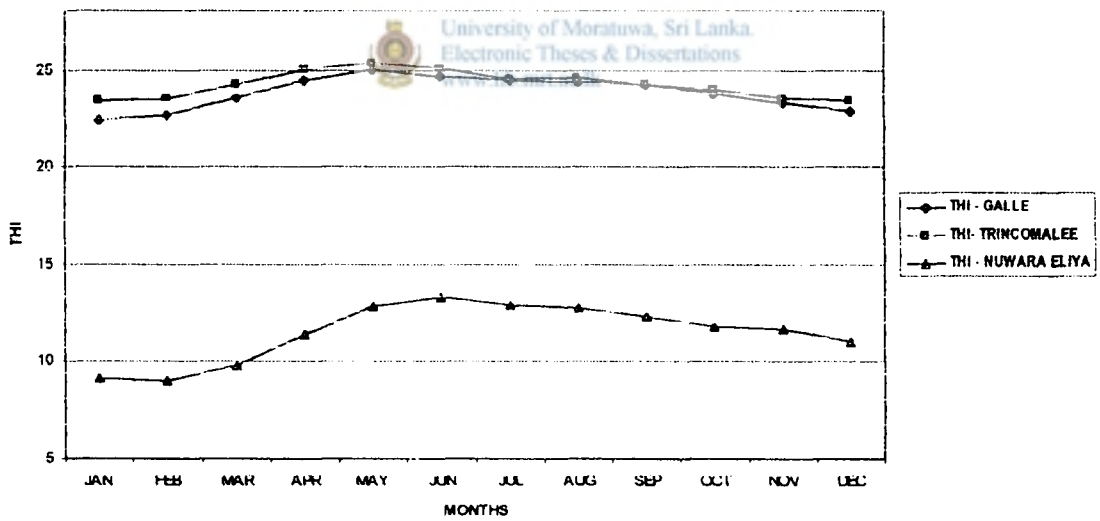
NIGHT TIME (minimum) THI VALUES - TRINCOMALEE



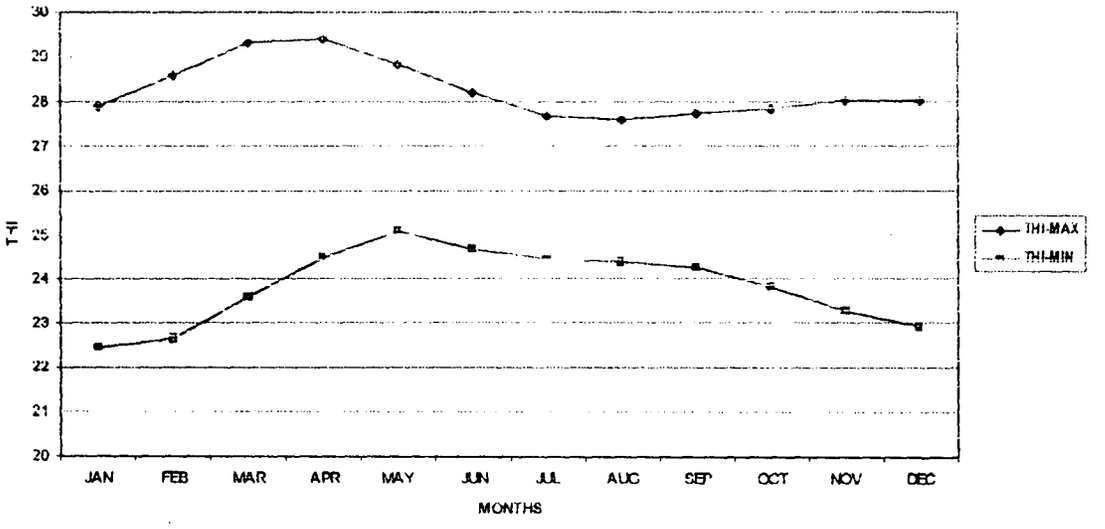
COMPARISION OF DAY TIME (maximum) THI VALUES OF THE CITIES



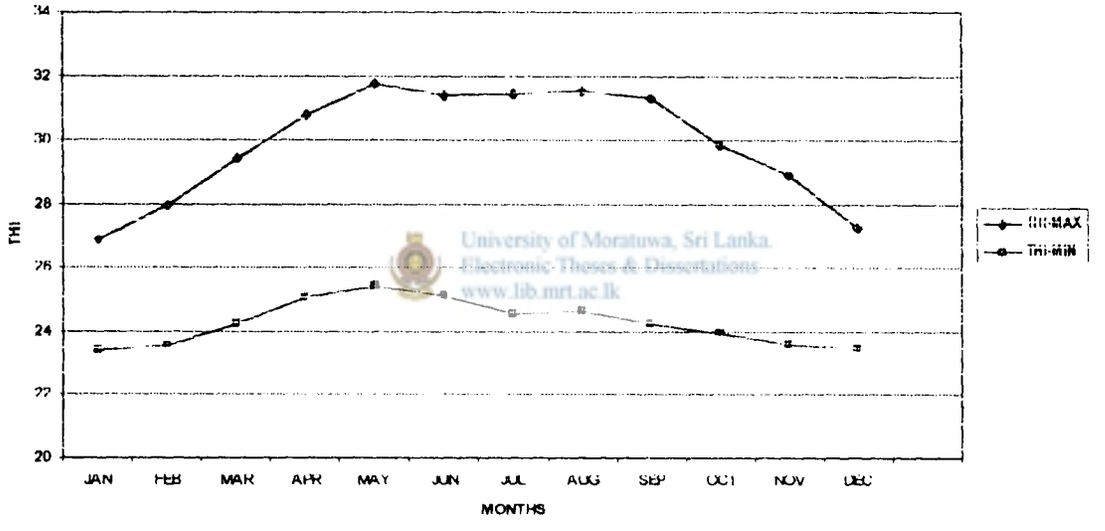
COMPARISION OF NIGHT TIME (minimum) THI VALUES OF THE CITIES

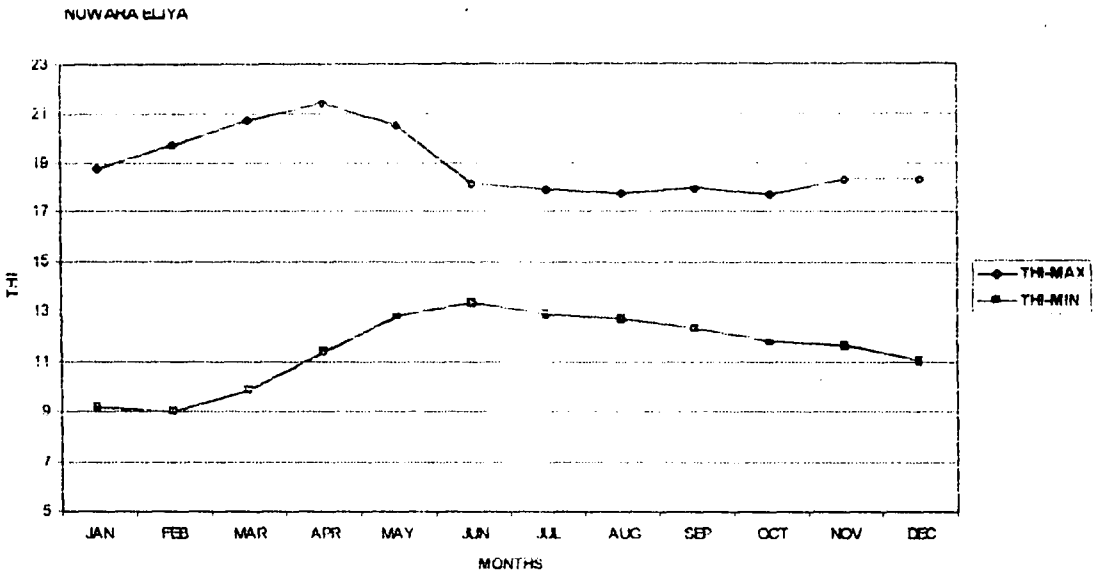


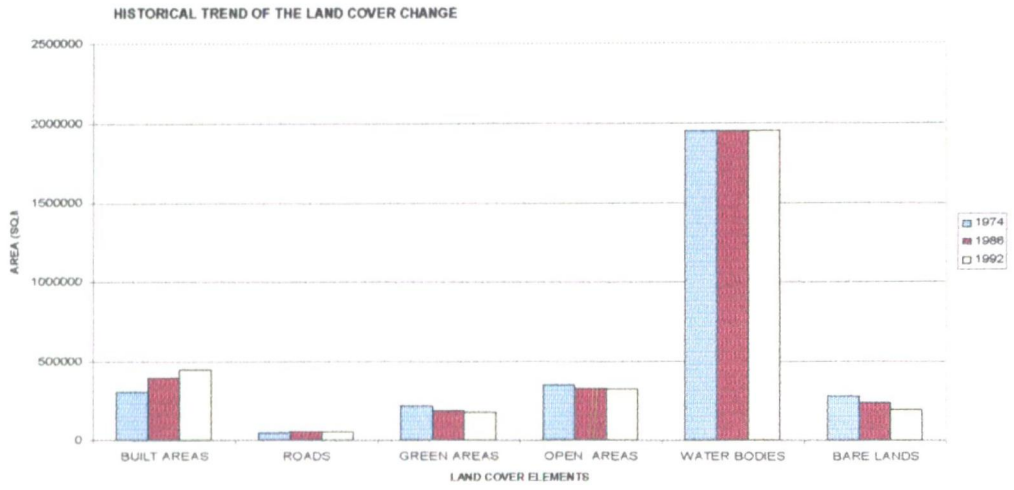
GALLE



TRINCOMALEE



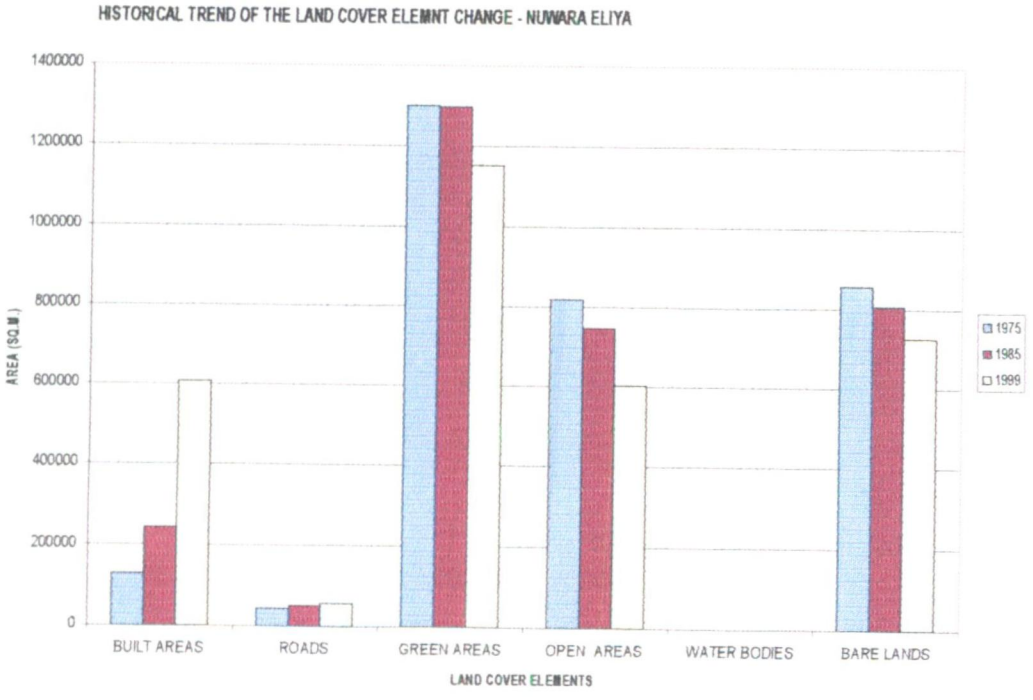




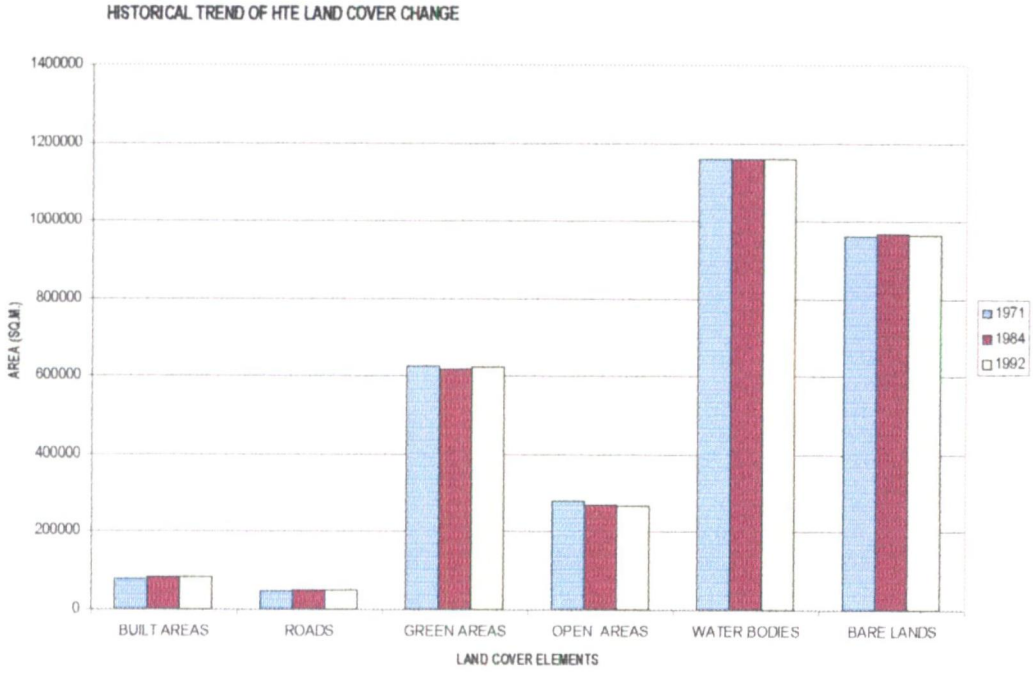
Land Cover Change in Galle

	BUILT AREAS	ROADS	GREEN AREAS	OPEN AREAS	WATER BODIES	BARE LANDS
1974	302400	50054	214330	349303	1950000	276770
1986	390200	53200	185450	327007	1950000	237000
1992	446250	57200	174700	320000	1950000	194707

Land Cover Values (in Square meters)



Land Cover Change



Land Cover Change in Trincomalee

	BUILT AREAS	ROADS	GREEN AREAS	OPEN AREAS	WATER BODIES	BARE LANDS
1971	78057	45600	625000	278200	1157000	959000
1984	83250	48147	617800	270000	1157000	966660