CHAPTER 2

LITERATURE REVIEW

2.1 Urban Heat Island Phenomenon

Urban developments induce the changes in the atmospheric properties of a region. It involved the transformation of radiative, thermal, moisture and aerodynamic characteristics. This leads to a set of distinction in the natural energy and hydrological balances (Oke, 1987).

Urban heat island effect is one phenomenon of urban climate modification, which varies in time, meteorological, location and urban characteristics. This effect is categorized into local climate as shown in Figure 1 (Hidore and Oliver, 1993; World Meteorological Organization, 1997).

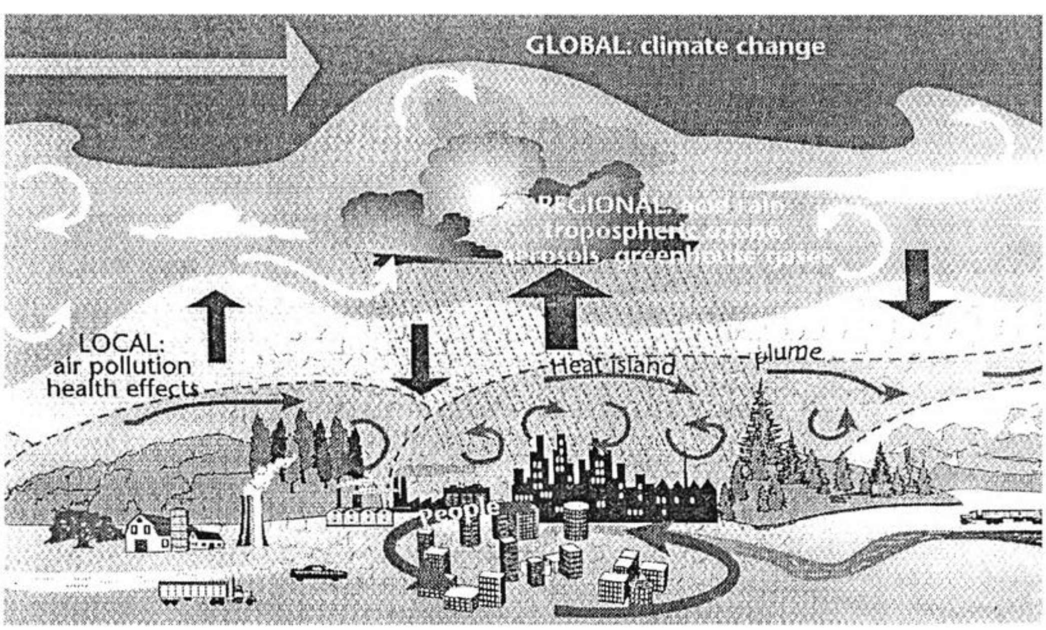

Figure 1: Interaction between local, regional and global atmospheric pollution process (World Meteorological Organization, 1997)

The obvious demonstration of this phenomenon is shown in Figure 2. Where air temperature varies along the distance crossing from the countryside to the center of an urban area under the condition set out above.

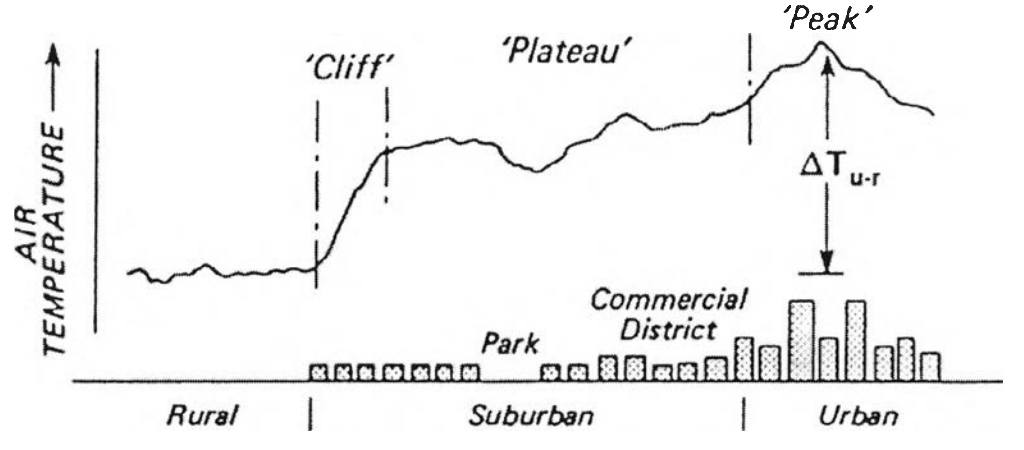

Figure 2: Generalized cross-section of a typical urban heat island (Oke, 1987)

As displayed in Figure 2, variation of the temperature curve is a geomorphic analogy of an island, since the relative warmth of the city projects distinctly out of the cool 'sea' of the surrounding landscape. The rural/urban boundary exhibits a steep temperature gradient, or 'cliff' to the urban heat island. Much of the rest of the urban area appears as a 'plateau' of warm air with a steady but weaker horizontal gradient of increasing temperature towards the city center. The uniformity of the 'plateau' is interrupted by the influence of different intra-urban land use. The urban cores show a 'peak' to the heat island where the urban maximum temperature is found. The difference of this temperature and the rural temperature defines the urban heat island intensity (Oke, 1978).

Cities tend to be warmer than the surrounding non-urban environment, can be considered as follows:

Sensible heat storage increasing

The materials of the urban landscape generally have low volumetric heat capacities, such as street and building materials (Oke, 1978; Marsh, 1991; Hidore and Oliver, 1993). This means that urban surface reach a higher temperature with the absorption of a given quantity of radiation and, inturn, heat the overlying air faster. During the day, the urban surfaces absorb heat more readily and then become a radiating source after sunset that raises night temperatures. Table 4 shows thermal properties of some common earth materials.

Table 4: Thermal properties of some common earth materials (Marsh, 1991)

Substance	*Thermal Conductivity*	*Volumetric Heat Capacity*
Air		
Still (at 10 °C)	0.025	0.0012
Turbulent	3,500-35,000	0.0012
Water		
Still (at 4 °C)	0.60	4.18
Stirred	350.00 (approx.)	4.18
Ice (at –10 °C)	2.24	1.93
Snow (fresh)	0.08	0.21
Sand (quartz)		
Dry	0.25	0.9
15 percent moisture	2.0	1.7
40 percent moisture	2.4	2.7
Clay (non organic)		
Dry	0.25	1.1
15 percent moisture	1.3	1.6
40 percent moisture	1.8	3.0
Organic Soil		
Dry	0.02	0.2
15 percent moisture	0.04	0.5
40 percent moisture	0.21	2.1
Asphalt	0.8-1.1	1.5
Concrete	0.9-1.3	1.6

Evapo-transpiration decreasing

Rain falling on urban and non-urban areas is quite different disposing as shown in Figure 3 (Hidore and Oliver, 1993). Some of water on building-free or rural surfaces is retained as soil moisture. Plants use this source and return the moisture to the air through transpiration. At the same time, standing water and soil moisture evaporate directly. Both transpiration and evaporation processes require solar energy. In the city, green areas are limited with the dense urban constructions thus the transpiration is minimal. Moreover, these urban surface prohibit entry of water into the soil by drains it off quickly passes to sewer system, greatly reducing the water available for evaporation. Since both evaporation and transpiration amounts are decreased, the solar energy available for this process give rise to the surface heating (Goulding *et al.*, 1992; Hidore and Oliver, 1993).

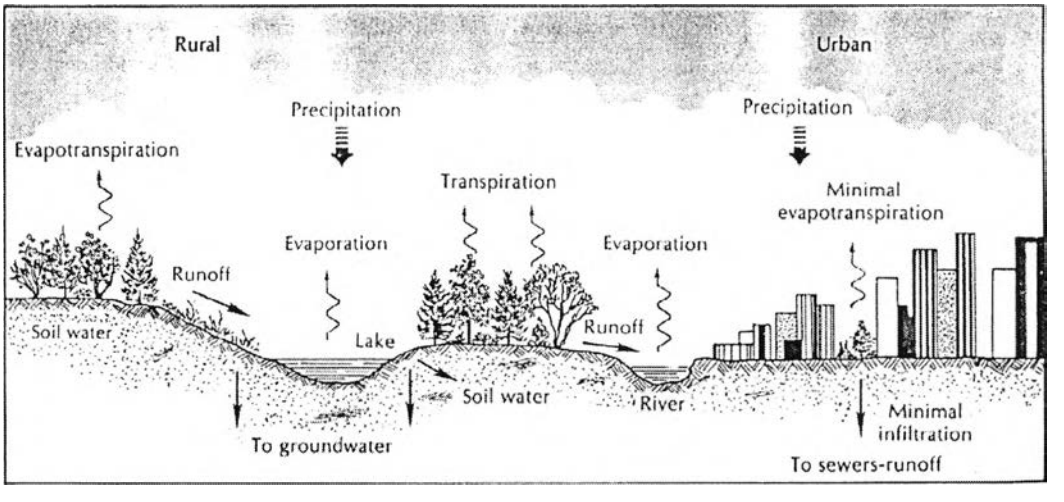

Figure 3: The disposal of precipitation on rural and urban surfaces (Hidore and Oliver, 1993)

Anthropogenic heat source

In areas of high activities, there are high energy consumption for the purposes of manufacturing, lighting, transportation, etc. These areas conduct exceeded heat energy and subsequently release to the atmosphere. The released energy is a form of heat waste generation, which increasing urban's warmth (Oke, 1987).

Air pollution and green house gases effect

Combustion of fossil fuels causes cities to have high air pollution level, particularly the green house gases such as carbon dioxide, which retain more heat (Hidore and Oliver, 1993; Kubo, 1996). Some incoming solar radiation is reflected back to space by gaseous particles, at the same time, these particles can absorb energy and re-emission to the atmosphere. In addition, the poor air quality can increase cloudiness, which reflect the long wave energy back to earth surface as shown in Figure 4 (Goulding, 1992; Hidore and Oliver, 1993).

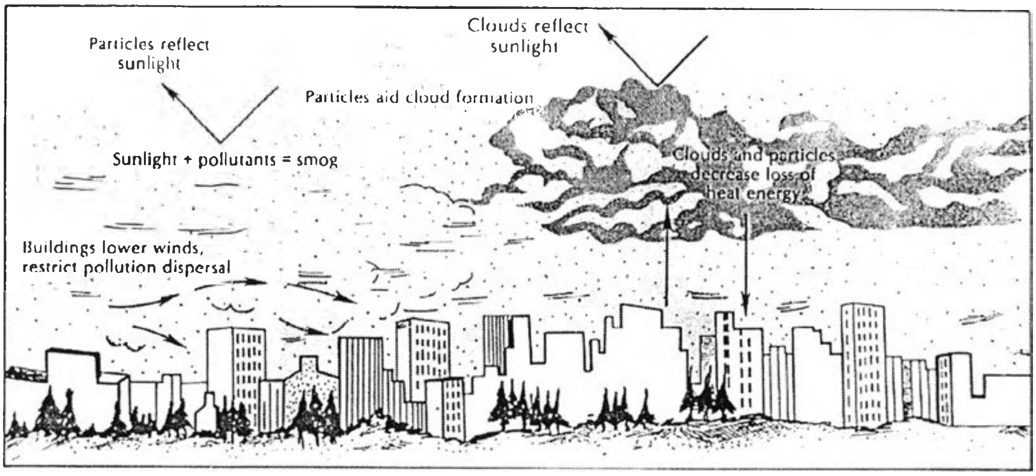

Figure 4: Schematic diagram showing the modified flow energy in an urban environment (Hidore and Oliver, 1993)

Heat loss

The principal controller of heat output or heat losses from the urban atmosphere is wind speed. Cities tend to have much lower wind speeds at ground level than those in open areas because of the roughness of urban geometry (Oke, 1978; Marsh, 1991). Therefore, heated air tends not to be flushed away as readily as it is in rural landscapes.

2.2 Remote Sensing for Urban Heat Island Assessment

Many studies of urban heat island have appeared over the past four decades (Henry *et al.*, 1989). The main techniques employed to measure and predict urban heat excess compared with the surrounding rural environment have been urban-rural meteorological station comparisons, the auto-traverse method, computer modeling approaches, and remote sensing technique.

Henry *et al.* (1989) reviewed and summarized the strengths and the weaknesses of these techniques, which measures or analyzes a different aspect of urban-rural temperature differences. The urban-rural's station comparison approach had the problem of the chosen stations, those are representative of general urban and rural conditions. Additionally, the study of urban heat islands spatial distributions must employ many measuring points to gain an improvement of the method.

The auto-traverse method has facilitated the understanding of the spatial variability of urban heat islands. However, persistent problems with this technique include (1) the auto is confined to roads; (2) it may take several hours if the traverses cover many parts of the city, sometimes require time-standardization techniques when applying the data.

Computer simulation models have also been used to study the effects of urbanized areas on the thermal structure of the atmosphere. Terjung (1976) and Oke (1982), cited in Henry *et al.* (1989) pointed out the advantages of this technique that allows the prediction of the space-time variations of the morphological components of the atmosphere, interfaces, and substrates. However, one problem encountered in most modeling simulations is that of parameterizations, which are simplified approximations of actual conditions. These are usually required because of computer limitations and / or lack of data in regard to certain aspects of the modeling process.

Remote sensing technique is a recent alternative measuring scheme for determining urban heat islands. The capability of satellite-based sensors to provide sun-synchronous, high spatial resolution thermal imagery is potentially very attractive and valuable to the field of urban climatology (Roth, Oke and Emery, 1989). These data overcome many of the problems of the other techniques because they allow averages taken over different portions of the city to be used, are more representative of the urban canopy as a whole, and provide the capability of repeated, synoptic coverage (Henry *et al.*, 1989).

Many urban heat island satellites-based studies have appeared in the following literature.

Balling, Sandra and Brazel (1988) used the NOAA Advanced Very High Resolution Radiometer (AVHRR) thermal data to produce one-kilometer resolution surface temperature patterns of Phoenix, Arizona Metropolitan area. The derived surface temperature covers with incidence of residential, commercial, industrial land use, and vacant land cover. From the data obtained, it was found that the residential and commercial area had over 2°C warmer in the summer afternoon period than the surrounding vacant area. Industrial area was over 5°C warmer than vacant area and about 3°C warmer than the residential or commercial area. The results of the study are being used by a local utility in their analyzes of water and power consumption.

Roth, Oke, and Emery (1989) used NOAA AVHRR infrared data to display the surface temperature patterns of Vancouver, British Columbia; Seattle, Washington; and Los Angeles, California. All are coastal cities of Western North America, which were collected under roughly similar conditions. Surface radiant temperatures derived from satellite were compared to air temperature from mobile heat island surveys. The results indicated that heat island intensities are largest in the daytime and in the warm season. Daytime intra-urban thermal patterns are strongly correlated with land use. The location of the warmest surface areas sensed by satellite is in industrial-commercial zones, whereas vegetated, riverine or coastal zones are coolest. These are also the sites of relatively warm near surface air temperatures from mobile observation.

Gallo, *et al.* (1993) calculated the Normalized Difference Vegetation Index (NDVI) from NOAA-11 AVHRR data for the Seattle, Washington D.C. and compare to observed minimum air temperature from weather observation stations. This study found that the NDVI and surface radiant temperature related significantly to observed minimum temperature. Urban area generally exhibited greater values of surface temperature and lower values of a vegetation index than rural area. The difference in the NDVI between urban and rural area appears to be an indicator of the difference in surface properties, such as evaporation and heat storage capacity between the two environments that are responsible for differences in urban and rural minimum temperatures.

Nichol (1994) evaluated Landsat Thematic Mapper's thermal band for indicating temperature differences in Singapore's high-rise municipal housing estates. They are located near the center of the island. Atmospheric correction was not carried out because absolute temperature values are not required for the study. Two classes of land cover type, non-vegetated and vegetated area were considered. For all the estates, a close inverse relationship was obtained between surface temperature and vegetation index, indicating that the presence of green biomass may effectively lower temperatures in high-rise residential development.

2.3 Remote Sensing Definition and Theory

Remote sensing is the science and art of obtaining information about object, area or phenomenon, by a device that is not contact with the object, area, or phenomenon under investigation (Howard, 1991; Lillesand and Kiefer, 1994). This technique differs from sensing *in situ*, which sense by physical contact (Buiten, 1993).

Remote sensing for earth observation is being operated from airborne and space borne platforms. Sensor systems acquire the electromagnetic energy, which emit and reflect from various earth surface features, and these data are analyzed to provide information about resources under investigation (Lillesand and Kiefer, 1994). Information about earth's surface and its features can be obtained by detection base on spectral, spatial, and temporal characteristics (Buiten, 1993).

Figure 5 shows the two basic processes involved in electromagnetic remote sensing of earth resources, which consists of data acquisition and data analysis (Lillesand and Kiefer, 1994).

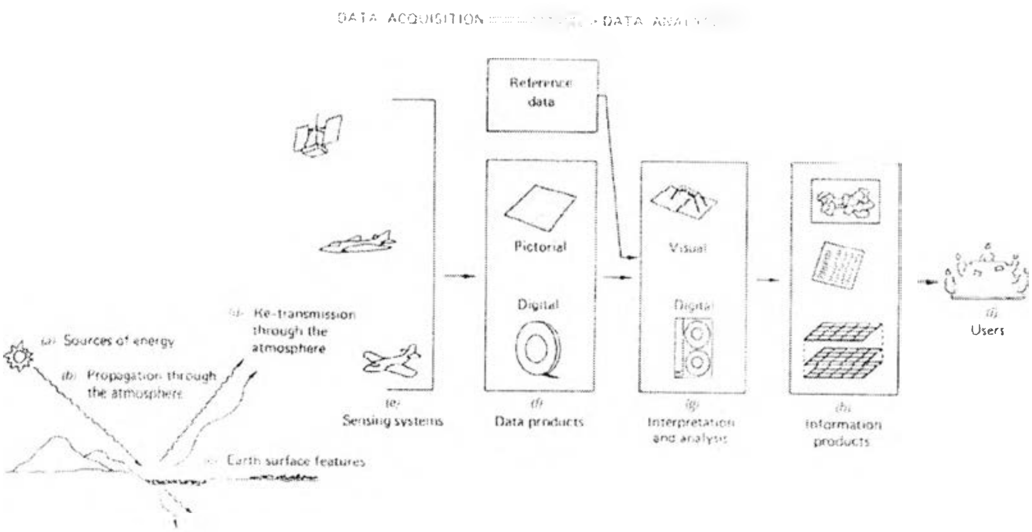

Figure 5: Electromagnetic remote sensing of earth resources (Lillesand and Kiefer, 1994)

2.3.1 Data acquisition

The elements of the data acquisition process are (a) energy sources and radiation, (b) energy interactions in the atmosphere, (c) energy interactions with earth surface features, (d) sensors system, and (e) spectral signature.

(a) Energy sources and radiation

In remote sensing, information transfer from objects to a sensor is achieved by electromagnetic radiation. It is the most important medium for remote sensing, which exhibits great variety in its behavior, and can be utilize by remote sensing in many different ways (Barrett and Curtis, 1992). Electromagnetic waves in remote sensing classified by their wavelength locations within the electromagnetic spectrum, consist of cosmic rays, gamma rays, ultraviolet, visible light, infrared, microwave and radiowave (Lillesand and Kiefer, 1994).

Remote sensing is classified into three types with respect to the wavelength region as shown in Figure 6 (Japan Association on Remote Sensing [JARS], 1994).

- *Visible and reflective infrared regions*

The energy source used in these regions is the sun. Data obtained mainly depends on the reflectance of objects on the ground surface. Therefore, information about objects can be obtained from the spectral reflectance.

-*Thermal infrared regions*

The energy source used in these region is the object itself, because any object with a normal temperature will emit electromagnetic radiation. The spectral signature varies with respect to the reflectance, emittance and temperature of the object.

- *Microwave regions*

There are two types of sensors at microwave regions, passive microwave remote sensing and active microwave remote sensing. In passive microwave remote sensing, the microwave radiation emitted from an object is detected, while the back scattering radiation is detected in active microwave remote sensing.

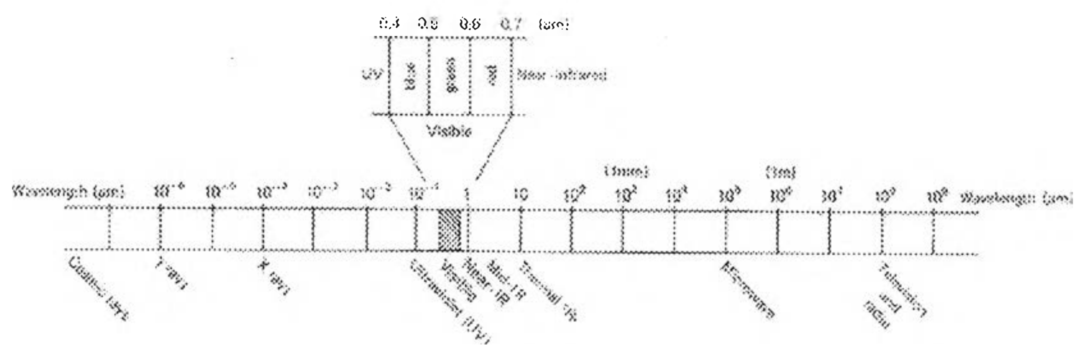

Figure 6: The electromagnetic spectrum (Lillesand and Kiefer, 1994)

The sun is the most important source of electromagnetic radiation. However, all materials with a temperature above absolute zero (0 K) generate and emit energy in radiant form (Barrett and Curtis, 1992; Buiten, 1993; Lillesand and Kiefer, 1994). Thus, terrestrial objects are also sources of radiation, which have differences in magnitude and spectral composition.

(b) Energy interactions in the atmosphere

The solar radiation is absorbed or scattered by the atmosphere during transmission to the ground surface, while the reflected or emitted radiation from the objects are also absorbed or scattered by the atmosphere before it reaches a sensor. Hence, remote sensors sense the electromagnetic energy unequal the real reflected or emitted energy from the objects on earth surface. This atmospheric effect varies with the difference in path length, the magnitude of energy signal being sensed, the atmospheric condition present, and the wavelengths involved (JARS, 1994; Lillesand and Kiefer, 1994).

(c) Energy interactions with earth surface features

When electromagnetic energy is incident on any earth surface features, it can occur three phenomenon; reflection, absorption and transmission. The principles of energy conservation are applied for interrelationship between these three energy interaction.

Proportions of energy reflected, absorbed, and transmitted will vary for different earth surfaces, depending on their material type and condition, whereas any feature type will vary at different wavelength. Reflected radiation is the most important for remote sensing technique because many observing systems base upon it (Barrett and Curtis, 1992; Lillesand and Kiefer, 1994).

The sun is the obvious source of electromagnetic radiation for remote sensing. However all objects at temperatures above absolute zero (0 K or –273 $^{\circ}$C) continuously emits electromagnetic radiation. Thus, terrestrial objects are also sources of radiation. The intensity and spectral composition of object's radiation are a function of the material type involved and the temperature of the object under consideration.

(d) Sensors system

Sensors are devices that measure electromagnetic radiation, cameras and scanners are examples of remote sensors. They can be classified into passive and active sensors base on radiation sources type (Buiten , 1993).

Passive sensors do not have their own radiation source. They sense the radiation from a natural origin, the principal is the sunlight, or the earth surface emission. The multispectral scanner and thermal scanner are the examples of passive sensors. Active sensors have a built-in source of radiation. These sensors detect reflected responses from object, which are irradiated from artificially generated energy sources such as radar.

(e) Spectral signature

Spectral reflectance is different with respect to the type of land cover. This is the principle that in many cases allows the identification of land covers with remote sensing by observing the spectral reflectance from the objects on earth surface.

Figure 7 shows typical curves of spectral reflectance for three basic types of earth surface, vegetation, soil and water. As seen in the figure, vegetation has a very high reflectance in the near infrared regions, but there are three low minima due to absorption. Soil has rather higher values for almost all-spectral regions, whereas water has almost no reflectance in the infrared regions.

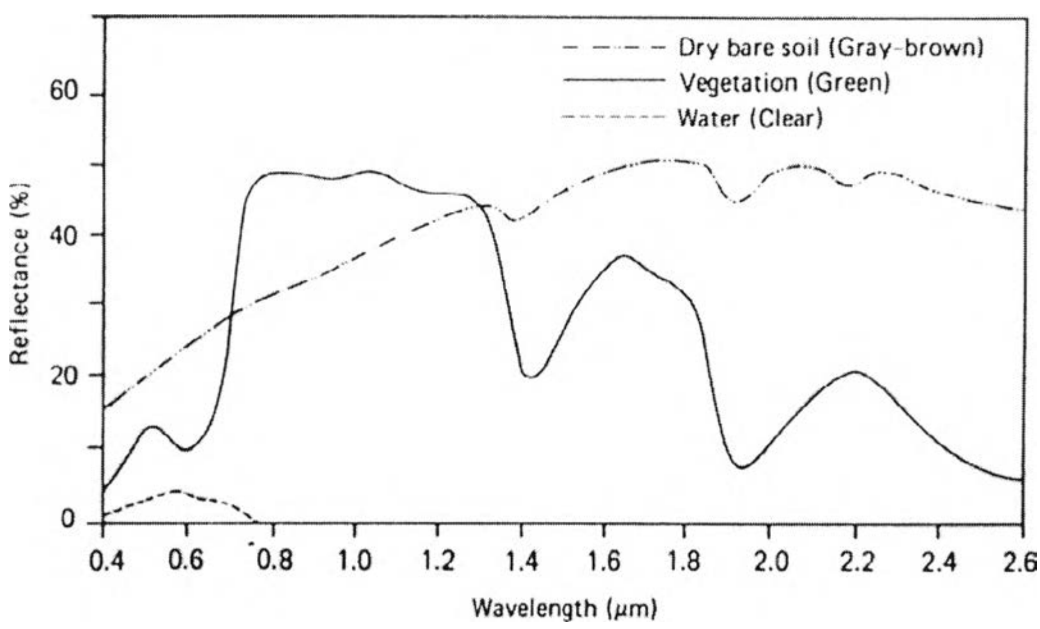

Figure 7: Typical spectral reflectance curves for vegetation, soil, and water

(Lillesand and Kiefer, 1994)

2.3.2 Data analysis

The investigation of information about an object, area or phenomenon in remote sensing is called information extraction. It can be categorized into five types, which is shown in Table 5.

Table 5: The category of information extraction information of remote sensing (JARS, 1994)

Type of information extraction	Description	Examples
1. Classification	Type of categorization of image data using spectral, spatial and temporal information	Land use / land cover type. Vegetation types
2. Change Detection	The extraction of change between multi-date images.	Land use / land cover changes
3. Extraction of physical quantities	Corresponds to the measurement method.	Temperature measurement, atmospheric constituents, elevation and so on
4. Extraction of indices	The computation of newly defined index.	Vegetation index
5. Identification of specific feature	Identification method	Disaster, lineament, archaeological and other features

Information extraction can be made by human or computer methods. Information extraction by human is the visual interpretation of pictorial image data, whereas the use of computer-assisted technique is the digital image data analysis.

Digital image processing

Remotely sensed data are usually digital image data. Therefore data processing in remote sensing is dominantly handled as digital image processing. The following stages are the digital image analysis procedures (Barrett and Curtis, 1992; JARS, 1994; Lillesand and Kiefer, 1994)

(1) Data preparation

As previous-mentioned, the objects on earth surfaces interact with the electromagnetic energy in different regions of spectrum or bands. Therefore, it is important to select the appropriate bands for data investigation. For example, TM data has seven bands, but the optimum bands for land use / land cover studies are bands 2, 3, 4 and 5 (Kunya Tisayakorn, Tanomsri Rungsikunpum and Jatuporn Pornprasertchai, 1993).

Generally, compositions of three selected multi-band images are used for color image viewing. Color display of remote sensing data is important for effective visual interpretation. There are two color display methods: color composite; by generating color with multi-band data and pseudo-color display, and color look up tables; by assigning different colors to the grey scale of a single image (JARS, 1994).

(2) Data pre-processing

- Image rectification and restoration

The raw remote sensing data are not always optimal quality, depending on such things as the instrument design, altitude of the platform, and performance of the recording equipment. Thus pre-processing operations are necessary to correct distorted or degraded image data from the image acquisition process, by create a more accurate representation of the original image. These procedures contain the geometric correction, radiometric correction, atmospheric correction and noise removal (Barrett and Curtis, 1992).

- Image enhancement

Image enhancement involves techniques for increasing the visual distinctions between features in a scene, in order to more effectively display data for subsequent image interpretation. The common procedures include density slicing (divided DNs into a series of DNs intervals or slice), edge enhancement (image sharpening), contrast stretching (increasing the range of image tones), etc (Barrett and Curtis, 1992; Lillesand and Kiefer, 1994).

(3) Data analysis and interpretation (Image classification)

These operations are the quantitative techniques for identification of features and group features with homogeneous characteristics in a scene, base on statistically decision rules. The decision rules are based solely on spectral, spatial or temporal characteristics. The spectral characteristics are preferable to classification method because of their highly informative.

Classification procedures are categorized into *supervised classification* method and *unsupervised classification* method. The former; the known or supervised pixels of image are selected to be representative spectral sample sites of each feature type, called training areas. Then each pixel of image is compared to each category of training areas and labeled with the name of category it most closely likeness. The common techniques of supervised classifications include Parallelepiped classifier, Minimum distance to means classifier, and Maximum likelihood classifier (Barrett and Curtis, 1992; JARS, 1994; Lillesand and Kiefer, 1994).

The latter method does not use training data as the basis for classification. Instead, it uses algorithm to examine the unknown pixels in an image and aggregate them into the number of classes base on the natural spectral groups present in the image. Then specified the class type of each spectral group in classified image from reference data such as maps or field data.

2.4 Thermal Radiation Principles

The temperature of a body that measures by an *in situ* device is called *kinetic temperature*. It is the true or internal temperature of a body. Whereas the temperature that measures by the remote sensing device is called *radiant temperature*. It is the external object's energy state, which radiate as a function of object's temperature.

As previously described, the objects with temperature above absolute zero temperature (0 K or –273 °C) generate and emit energy in radiant form whose intensity and spectral composition vary depending on the temperature and object type. The amount of any object radiate energy is a function of the surface temperature of the object. The *Stefan-Boltzmann's law* expresses this property.

$$M = \sigma T^4$$

where M = total radiant emittance from the surface of material , Wm^{-2}

σ = *Stefan-Boltzmann constant* (5.6697×10^{-8} $Wm^{-2}K^{-4}$)

T = absolute temperature (K) of the emitting material

It shows that the total energy emit from an object is proportional to the fourth power of absolute temperature. Therefore, it increases very rapidly with increases in temperature. This law is expressed for an energy source that behaves as a blackbody. The blackbody is an ideal object, which absorbs all energy and reemits all energy incidents upon it.

In case of grey body, object will emit only a proportion of the energy the blackbody could. In this case the *Stefan-Boltzmann's law* can be modified with an emissivity (ε). Hence the equation becames

$$M = \varepsilon \sigma T^4$$

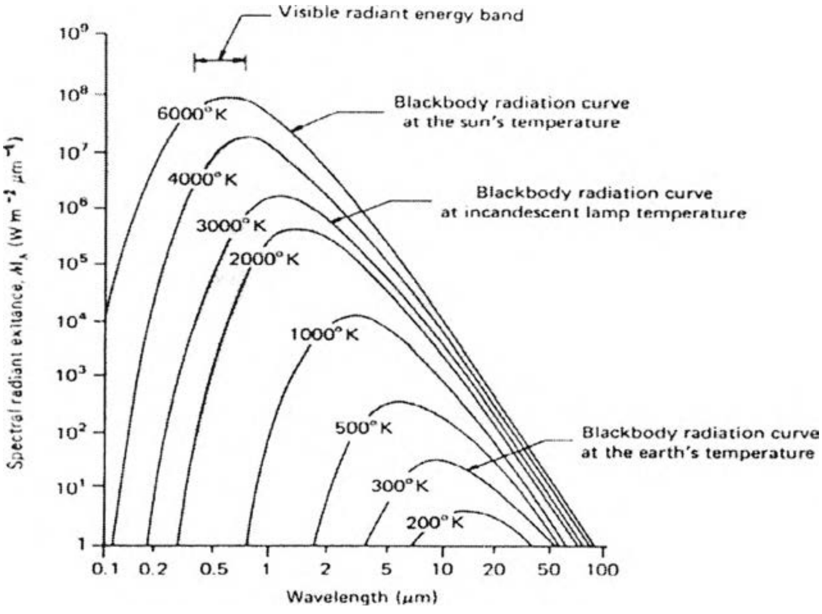

Figure 8: Spectral distribution of energy radiated from blackbodies of various temperatures (Lillesand and Kiefer, 1994)

In addition to the total emitted energy from the object varies with temperature, the spectral distribution also varies as shown in Figure 8. This property can be expressed by the *Planck's law* as a function of temperature and wavelength.

$$M(\lambda) = C_1\lambda^{-5} / [e^{C_2\lambda / T} - 1]$$

where $M(\lambda)$ = the emitted energy of an object , $W.m^{-2}.sr^{-1}.\mu m^{-1}$

C_1 = $2hc^2 = 3.74 \times 10^{-16}\ W.m^2$

C_2 = $hc/k = 1.44 \times 10^{-2}\ mK$

T = temperature

λ = wavelength, μm

h = light's velocity ($2.998 \times 10^2\ m.s^{-1}$)

c = *Planck's constant* (6.62×10^{-34} J.s)

k = *Boltzmann constant* ($1.380 \times 10^{-23}\ JK^{-1}$)

(Barrett and Curtis, 1992; Lillesand and Kiefer, 1994)

2.5 Relation of vegetation index and surface temperature

Green areas in urban area are limited with the built-up construction, this conduct to minimize the evaporation and transpiration process, which is the one cause of urban warming. Vegetation indices derived from satellite data can be used as an indicator of the presence and density of green vegetation and have been used successfully to monitor seasonal vegetation activity (Goward etal., 1985; Malignreau, 1986; Gallo and Flesch, 1989, cited in Gallo *et al.*, 1993).

Several studies (Smith and Choudhury, 1990; Gallo *et al.*, 1993; and Gallo and Tarpley, 1996) have documented that the vegetation index have significantly relation with the minimum temperature. They also found the difference in the vegetation index between urban and rural area appears to be an indicator of the difference in surface properties between two environments that are responsible for differences in urban and rural minimum temperatures.

The vegetation index can be calculated from the infrared-red differences and ratios. The normalized difference vegetation index is the common vegetation index, which can be expressed as:

$$\text{NDVI} = \frac{\text{IR band} - \text{Red band}}{\text{IR band} + \text{Red band}}$$

Its sensitivity to green vegetation is based on the radiance reflected in the red band being related to the amount of chlorophyll, and the radiance in the IR band being related to the density of green leaves (Barrett and Curtis, 1992; Lillesand and Kiefer, 1994).

Due to the differing sensors, the other forms of data transformations have been developed for vegetation monitoring. For Landsat TM, the Transformed Vegetation Index (TVI) was employed to avoid impracticable negative values (Clevers, 1993; Crist and Cione, cited in Lillesand and Kiefer, 1994). The TVI is computed as :

$$\% TVI = \left[\left[\frac{IR - Red}{IR + Red} \right] + 0.5 \right]^{1/2} * 100$$

where IR and red band correspond to the digital number in bands TM4 and TM3, respectively.

2.6 Landsat Thematic Mapper Data

Characteristics of the Landsat TM system

Landsat thematic mapper (TM) data provide land surface information from 1984 to the present. The current Landsat 5 platform operates from a sun-synchronous, near-polar orbit, imaging the same 185 km (115 miles) ground swath every 16 days. The TM data are received directly from Landsat 5 by a network of 16 worldwide ground station. Table 6 shows the characteristics of the Landsat System

Table 6: Characteristics of the Landsat System

Characteristics	Landsat TM
Mission Objective	Monitor natural and cultural resources
Owner	USA
Launch Date	1984
Altitude	705 km
Recurrent Period	16 days
Instruments	Thematic Mapper (TM) 7 channels
Swath Width	185 km
Current Status	Operational

Spectral Range

The TM sensor is an advanced, multispectral scanning, Earth resources instrument designed to achieve higher image resolution, sharper spectral separation, improved geometric fidelity, and greater radiometric accuracy and resolution than the MSS sensor. The TM data are scanned simultaneously in seven spectral bands. Band 6 scans thermal (heat) infrared radiation.

Spatial Resolution

A Landsat-5 TM scene has an instantaneous field of view (IFOV) of 30 meters by 30 meters (900 square meters) in bands 1 through 5 and band 7, and an IFOV of 120 meters by 120 meters (14,400 square meters) on the ground in band 6.

Data Characteristics

Landsat satellites have provided repetitive, synoptic, global coverage of high-resolution multispectral imagery. The characteristics of the TM bands were selected to maximize detecting and monitoring different types of earth resources.

Typically, TM Bands 4, 3, and 2 can be combined to make false-color composite images where band 4 represents the red, band 3 represents the green, and band 2 represents the blue portions of the electromagnetic spectrum. This band combination makes vegetation appear as shades of red, brighter reds indicating more vigorously growing vegetation. Soils with no or sparse vegetation range from white (sands) to greens or browns depending on moisture and organic matter content. Water bodies will appear blue. Deep, clear water appears dark blue to black in color, while sediment-laden or shallow waters appear lighter in color. Urban areas appear blue-gray in color. Clouds and snow appear bright white. Clouds and snow are usually distinguishable from each other by the shadows associated with clouds. Table 7 summarizes the spectral range of bands, spatial resolution and data characteristics of Landsat TM.

Table 7: Spectral range of bands, spatial resolution and data characteristics of Landsat TM (http://userservices.nrct.go.th/Satellite/index.html and http://edcwww.cr.usgs.gov/glis/hyper/guide/landsat_tm#tm8)

TM	Wavelength (micrometers)	Resolution (meters)	Data Characteristics
Band 1	0.45-0.52	30	penetrates water for bathymetric mapping along coastal areas and is useful for soil-vegetation differences and for distinguishing forest types
Band 2	0.52-0.60	30	detects green reflectance from healthy vegetation
Band 3	0.63-0.69	30	design for detecting chlorophyll absorption in vegetation
Band 4	0.76-0.90	30	ideal for detecting near-IR reflectance peaks in healthy green vegetation and for detecting water-land interfaces
Band 5	1.55-1.75	30	useful for vegetation and soil moisture studies and for discriminating between rock and mineral types
Band 6 (thermal-IR band)	10.40-12.50	120	design to assist in thermal mapping, and is used for soil moisture and vegetation studies
Band 7	2.08-2.35	30	useful for vegetation and soil moisture studies and for discriminating between rock and mineral types

2.7 Study area description

Bangkok Metropolis

Bangkok Metropolis is situated at 13 ° 45′ north latitude, 100 ° 29′ east longitude, in the lower central region of Thailand. The Chao Phraya river flows through the Bangkok Metropolis area from the north to the Gulf of Thailand. Its total area of 1568.737 square kilometers (Nopanant Tapananont, 1996) has 1.5 meters average height above mean sea level (Pollution Control Department, 1993). The city has been developed as the dominant center for national administration, economic activities, industrialization, telecommunications, social services and public welfare. Urban development is dense in this area of the country and undergoing rapid expansion.

Pathum Thani

Pathum Thani province is located along the Chao Phraya river between Phra Nakhon Sri Ayutthaya and Nonthaburi provinces. It covers an area of 1,528 square kilometers and is approximately 28 kilometers to the north of Bangkok Metropolis. The major land use is paddy field and orchard.

Nonthaburi

Nonthaburi province covers an area of 624 square kilometers in the Chao Phraya river flood plain. It has agriculture area from Amphoe Pak Kret in the north to Amphoe Muang Nonthaburi and Amphoe Bang Kruai in the south.

Samut Prakan

Samut Prakan province is located at the downstream end of the Chao Phraya river, approximately 25 kilometers from Bangkok. It covers an area of 890 square kilometers in the river flood plain. The southern area of the province, along the coastline, has both industrial and agricultural zones. Recently, there have been gradual increases in population and industrial development in this area, while community, commercial and industrial areas are clustered in Amphoe Muang.

Samut Sakhon

Samut Sakhon is located in the flood plain of the Tha Chin river. It covers an area 851 square kilometers adjacent to the shore of the Gulf of Thailand. Most of the area is utilized for agriculture, aqua-culture, salt production and industrial activity.