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Urban Heat Island Study Based on Remote Sensing and Geographic Information System: Correlation between Land Cover and Surface Temperature

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Abstract. Significant changes in urban environmental characteristics such as altered land use and a higher population density contribute to the formation of the urban heat island (UHI) phenomena. Remote sensing technology and Geographic Information Systems (GIS) have now become effective tools for analysing the UHI phenomenon. This research uses the literature review method. The objectives of this study were to review: 1) General studies of the UHI phenomenon, 2) UHI studies in the context of remote sensing and GIS, and 3) Application GIS and remote sensing to examine the connection between surface temperature and land cover in the context of urban heat island effects. The UHI is formed related to the change in urban structure and land cover, such as an increase in building and road surfaces and a reduction in green open areas. The UHI phenomenon has significant impacts on thermal comfort, air quality and energy efficiency in urban areas. UHI measurements can be made by analyzing Land Surface Temperature (LST). LST can giver information on change in time and space of the Earth's surface temperature. This review can offer a more thorough comprehension of the variables influencing UHI. and its impact on the urban environment as well as a collection of technical remote sensing and GIS methods that can be applied to map the UHI phenomenon.

1 Introduction

When temperatures in urban areas are often higher than those in neighboring rural areas, this phenomenon is known as an urban heat island (UHI). The main causes of UHI are changes in urban structure and land cover, such as the increase of building surfaces, roads, and the reduction of green open areas. The UHI phenomenon has a significant impact on thermal comfort, air quality and energy efficiency in cities. Both natural and human factors are among the many causes of UHI, the core cause of which is land use change [1]. Two categories exist for UHI. The initial two are Atmospheric Urban Heat Island (AUHI) and Surface Urban Heat Island (SUHI). SUHI represents the difference in radiant temperature between impermeable and natural surfaces. While AUHI refers to the effect on the canopy layer or air boundary

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layer, in other words, the measurement of AUHI must involve the measurement of air temperature [2], [3]. Because heat from impermeable surfaces releases more slowly after sunset, surface temperature is more constant after sunset than air temperature. The UHI phenomenon can be described as follows:

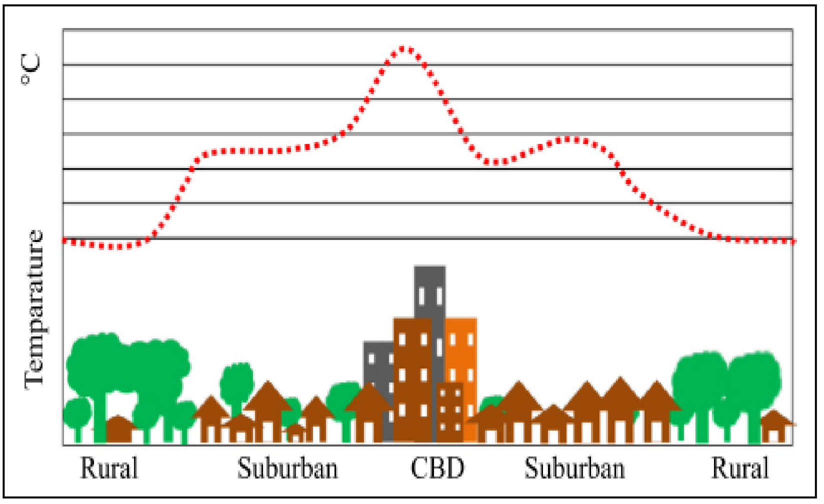

Fig. 1. Illustration of Urban Heat Island.

Susca et al. in 2011 examined the UHI phenomenon at four points in New York City found that there was an average difference of about 20C between the most and least vegetated areas with the warmest areas around the University of Colombia and the coldest areas in Fieldston Region [4]. In addition, another study conducted by Liao et al. in 2017, which examined the impact of energy consumption for nighttime light use on the SUHI in 32 Chinese major cities found the. The fact that consumption of energy is positively correlated with SUHI at night but not with SUHI during the day [5]. So it can be said that cities with a greater amount of energy use intensity have a much greater impact on SUHI at night.

UHI measurements can be done in two ways. The first is insitu measurement using field survey techniques. Second, patterns of variations in the distribution of surface temperatures can be found using data from remote sensors, which can be used to observe the UHI phenomenon [6]. Urban Heat Island can be obtained from Land Surface Temperature (LST) analysis [7]. At both local and global stages, In the physical processes of surface water and energy balance, LST is an essential metric. Understanding LST gives information about changes in the equilibrium state of the Earth's surface throughout time and space [8], [9]. LST can be obtained using the channel wavelength of space-based thermal sensors. After the LST value is obtained, UHI analysis is performed by establishing the UHI threshold using the LST mean and standard deviation. Once the threshold is obtained from UHI, field measurements are required to analyse the validation the LST data obtained.

Thus, the aim of this research is to analyse the link between the cover of land and temperature on surface area in the context of UHI by combining the use of remote sensing and GIS. The focus of this research is to understand how changes in urban land cover, such as increased building surfaces or reduced green areas, can affect surface temperature in urban areas. The goal of this study area is to advance knowledge of the variables influencing UHI and its effects. With the ultimate goal of establishing a more comfortable and sustainable urban environment for its citizens, the study's findings are anticipated to be a significant source of information for decision-making in the management and design of sustainable urban areas.

1.1 Bibliography Data

Google Scholar is one of the platforms that provides access to a variety of complete bibliographic data sources. Through Google Scholar, users can search and access various types of scientific publications from various sources, such as journals, conferences, theses, books, and other scientific articles. The diversity of data sources available in Google Scholar makes it a legitimate and reliable source in the search for scientific information [10]. Google Scholar can be a valuable reference source for researchers and students in compiling their bibliography. During the data gaining on this research, Google Scholar is used as a tool to acquire information for bibliographic data in conjunction on monitoring the phenomena of urban heat islands using GIS and remote sensing. The advantage of using Google Scholar is the simple interface and wide access to relevant literature.

1.2 Methods

This research uses a literature review approach with research steps that involve reading, understanding, evaluating, and synthesising various reference sources relevant to the research topic. Literature review, also known as literature review, is an activity carried out to review various literature that has been published by academics or previous researchers related to the topic being researched. [11]. This process involves steps such as selecting relevant reference sources, reading carefully and critically, taking relevant quotes or summaries, and organising and presenting information obtained from various sources. Researchers conducted a search for scientific publications, especially journal articles both at the national and international levels, through the Google Scholar database using the keywords "Urban Heat Island Study", "Remote Sensing", and "GIS". Based on the titles, abstracts and keywords, articles were selected that showed the utilization of GIS and remote sensing for urban heat island phenomenon.

2 Results and Discussion

2.1 Overview of the Urban Heat Island (UHI) Concept

2.1.1 Definition and characteristics of UHI,

Urban Heat Island (UHI), is a condition where at some areas, normally urban area, have warmer surface temperatures than the neighboring areas [12]. UHI is formed when the surface that should absorb heat from the sun is reflected back into the air and trapped in the urban area. Increased heat reflection on the surface results from the conversion of vegetation to pavement, concrete, buildings with multiple floors, and other infrastructure. used to accommodate the needs and increase in population [13]. The primary source of UHI effect is the heat energy absorbed by urban structures and radiated back to the surrounding environment. Because of this gradual release of heat, urban areas experience greater temperatures than rural ones [14].

This UHI phenomena can changethe pattern of wind in local area, promote the formation of clouds and fog, higher frequency of lightning strikes, increase rainfall, and affect local and worldwide weather and climate conditions. Additionally, poor air quality brought on by rising energy consumption can negatively impact human health and cause discomfort for people with asthma or other respiratory conditions [6]. Two types of urban heat island according to Bhargava et al., 2017 [15] have been identified, namely (1) Surface Urban Heat Island (SUHI) is the term used to describe the differential in radiative temperature between natural and impermeable surfaces. Though it is typically present day and night, surface urban heat island tends to be the most highest one during the day when the sun shines. Between urban and rural areas, the average difference in surface temperature during the day is 18 to 27°F (10° to 15°C), whereas the average difference during the night is 9° to 18°F (5° to 10°C).

The magnitude of the UHI at the surface varies with the season because to variations in weather, land cover, and the amount of sunlight. Because of these fluctuations, summertime typically sees the highest surface Urban Heat Island intensity. Since previous studies on UHI utilizing remote sensing have only examined surface UHI, this research focuses on surface UHI. (2) Airborne/atmospheric Urban Heat Island, also known as Atmospheric Urban Heat Island (AUHI), AUHI refers to the effect on the canopy layer or air boundary layer, in other words, the air temperature must be measured as part of AUHI. Warmer air in urban areas compared to cooler air in neighboring rural areas is known as an atmospheric urban heat island. The urban infrastructure's delayed release of heat causes atmospheric urban heat islands to become increasingly noticeable after sunset. They are typically low intensity in the morning and throughout the day. But the characteristics of the rural and urban surfaces, the time of year, and the weather all affect when these peaks occur.

2.1.2 Factors that influence the formation of UHI

The development of an urban heat island is influenced by a number of elements. One of the main outcomes of urbanization is UHI, which transforms the natural spatial arrangement into an artificial one. This modifies the radiative, heating, roughness, and humidity characteristics of the surface and adjacent atmosphere [7], [25]. Urban buildings have an important role in absorbing and storing heat from sunlight. Materials with high thermal density, such as concrete and asphalt, can retain heat and elevate temperatures in urban areas [21],[30].

In addition, land cover change from green open land to dense urban areas also contributes to the formation of UHI. Reduced vegetation reduces nature's ability to regulate temperature through the process of evapotranspiration. Urban regions experience an increase in temperature as a result. In addition, the albedo effect also plays a role in UHI, where dark surfaces tend to absorb more solar energy and increase temperatures [21]. The urban canyon effect also plays an important role, where tall, dense buildings create narrow passageways that impede air circulation and prevent natural cooling. Human activities also contribute, such as heat emissions from motor vehicles, industry and energy use, which create additional heat sources in urban areas. All these factors together play a role in shaping the UHI phenomenon.

2.2 Remote Sensing and Geographic Information System (GIS) in UHI Analysis

2.2.1 Utilisation of Remote Sensing in UHI Analysis

Remote sensing is the process of collecting details data about objects or phenomena on the Earth's surface using sensors located on aircraft or satellites. Remote sensing technology will be appropriate enough to obtain data on the Earth's surface that is increasingly complex and with a large enough study area [16]. Thermal infrared sensors aboard satellites can be used for remote sensing in the context of UHI to provide quantitative data about surface temperatures related to the type of land cover [2]. Remote sensing uses sensors that can record electromagnetic radiation that surface-level objects emit or reflect. This electromagnetic radiation can cover a wide range of wavelengths, including thermal wavelengths associated with object temperature.

For the UHI analysis, surface temperature data is obtained using thermal infrared sensors that can measure thermal wavelengths emitted by the Earth's surface. This data is used to map the temperature distribution in urban areas and compare it with the surrounding areas. In addition, remote sensing is also used to obtain urban land cover data. Different forms of land cover, such as buildings, roads, parks, and other green open areas in metropolitan settings, can be identified and mapped using a variety of remote sensing techniques, such as object analysis and picture classification. This land cover information is important in understanding the influence of urban structures on surface temperature.

Spatial and temporal analysis can be performed using remote sensing data to map changes in urban land cover over time, compare surface temperatures in various metropolitan locations, and find UHI patterns. Analysis of remote sensing data can yield important new information on how land cover, surface temperature, and the UHI are related.

2.2.2 Utilisation of GIS in UHI Analysis

GIS are crucial to the analysis of UHI. In the context of UHI, GIS can integrate various spatial data such as surface temperature, land cover, elevation and other data, and perform in-depth spatial analyses to better understand the UHI phenomenon. The utilisation of GIS in UHI analysis is very diverse. First, GIS can be used for UHI mapping by mapping the surface temperature distribution in urban areas and visually analysing UHI patterns. In addition, GIS also enables the analysis of land cover in urban areas, so that the relationship between land cover type and surface temperature can be identified.

Furthermore, GIS can assist in the analysis of urban structure by mapping tall buildings, road networks, and population density that can affect surface temperature. GIS can also be used to identify UHI-prone areas by identifying areas with high surface temperatures and urban structure characteristics that could potentially amplify UHI effects. In addition, GIS can be used in sustainable urban simulation and planning by modelling UHI mitigation scenarios, such as increased green land cover or the use of smarter building materials. Thus, GIS makes a significant contribution to UHI analysis and can be used as an effective tool in making more sustainable urban planning decisions.

2.3 Assessment of the Correlation between Land Cover and Surface Temperature

2.3.1 Classification and Characterisation of Urban Land Cover

Classifying and characterizing urban land cover is a crucial initial step in the research of the link between land cover and surface temperature in the context of UHI. First, remote sensing data, such as satellite images or aerial images, should be collected to cover the urban area to be analysed with sufficient spatial resolution such as NOAA-AVHRR with 1.1 km spatial resolution, Landsat TM and ETM+ with 120 m and 60 m spatial resolution respectively, TERRA MODIS with 250m, 500m, 1000m spatial resolution, ASTER with 90 m spatial resolution and Landsat 8 with 100 m spatial resolution [1], [17]-[20]. Next, image segmentation techniques are used to divide the image into homogeneous units based on land cover characteristics, and then image classification algorithms are applied to classify the image pixels into different land cover categories.

The most accurate techniques for classifying land cover can be applied in a number of ways. The maximum likelihood classification method, also known as supervised classification, was employed by Senanayake et al. (2013) to classify the land cover types in the city of Colombo [21]. Many other studies have also utilised supervised classification methods for urban land cover analysis [22] - [25]. However, these methods may have shortcomings that cause image misinterpretation. The Geographic Information System (GIS) algorithm was used to analyze the hybrid-supervised/unsupervised classification method, as in the study by Ogashawara & Bastos (2012). This was done because the supervised maximum likelihood classification method has significant issues due to spectral confusion, which causes areas of vacant land to be incorrectly classified as urban and vice versa [24]. Classification results need to be validated to ensure accuracy and consistency, by comparing the classification results with field data or other reference data.

Analyzing the connection between temperatures at the surface and the land cover comes next once land cover has been classified and characterised. The present study may employ statistical methods such as regression or correlation analysis to assess the association between a specific type of land cover and the surface temperature recorded [5], [26]. Furthermore, the results of these analyses are interpreted to understand how certain land cover types affect surface temperature. In some studies, high surface temperatures tend to be positively correlated with more built-up land, indicating that there is a strong relationship between rising surface temperatures and growing amounts of built-up land [27]-[29]. Important factors such as building material type, covered area, or building density can be identified as major contributors to the increase of surface temperature in urban areas [30]. Thus, the analysis of land cover classification and characterisation in combination with the analysis of the relationship with surface temperature is an important step in understanding the dynamics of UHI and the development of effective mitigation strategies such as physical modifications to buildings that involve the use of high albedo materials, such as roofs and walls that reflect more sunlight, and implementing the concept of green walls, green roofs, and planting vegetation around parking areas and along roads [29]. These efforts aim to increase the amount of vegetation and green areas around buildings, thereby helping to reduce the UHI effect and create a cooler and more sustainable urban environment.

2.3.2 Extraction of surface temperature information

The process of extracting surface temperature information involves the use of remote sensing data, such as thermal imagery or multispectral imagery with thermal channels. The general steps in this process start with obtaining remote sensing data that includes thermal channels with sufficient resolution. One of the most crucial variables in the physical processes of surface energy and water balance at local and global scales is land surface temperature (LST). Understanding LST gives information on changes in the equilibrium state of the Earth's surface throughout time and space [8], [9].

The first step involves the conversion of pixel values into spectral irradiance values using the scale replacement constant (ML), pixel value (QCAL), and addition constant (AL) specific to each image band. This conversion allows the calculation of spectral irradiance above the atmosphere.

$$L\lambda = ML \ x \ QCAL + AL \quad (1)$$

Furthermore, the brightness temperature of the satellite is determined using a thermal infrared sensor (TIRS) in a specific wavelength range. By comparing the object's emission with blackbody radiation, the brightness temperature of the object on Earth can be calculated using the calibration constants (K1 and K2) and the previously obtained spectral irradiance values.

$$\mathrm{T} = \frac{K2}{In(\frac{K1}{\mathrm{L}\lambda}+1)} - 273.15 \quad (2)$$

Depending on the kind of imagery used, different bands are used to generate the Standardized Difference Vegetation Index (NDVI), which is used to evaluate the extent of vegetation. The NDVI formula compares near infrared and red reflectance values, providing a numerical representation of vegetation cover on the Earth's surface.

$$\mathrm{NDVI} = \frac{Near\ Infrared - Red}{Near\ Infrared + Red} \quad (3)$$

The Proportional Vegetation Index (PVI) is then calculated as the ratio of the projected vegetation area to the total vegetation area. PVI is derived from NDVI values, and helps in measuring the proportion of vegetation.

$$\mathrm{Pv} = (\frac{NDVI - NDVImin}{NDVImax - NDVImin})^2 \quad (4)$$

The PVI value is used to calculate Land Surface Emissivity (LSE), a metric that determines Land Surface Temperature (LST). The soil surface's emissivity level is described by LSE.

$$e \ = \ 0.0004Pv + 0.986 \quad (5)$$

Finally, the LST is calculated by inputting the brightness temperature value and the ground surface emissivity value. This formula involves Planck's constant, Boltzmann's constant, speed of light, and wavelength to calculate the Land Surface Temperature.

$$\mathrm{LST} = \frac{BT}{1} + W \ x \ \left(\frac{BT}{P}\right) x \ In(e) \quad (6)$$

To extract UHI based on LST values, the mean surface temperature (Tmean), mean LST (μ), and standard deviation of LST (α) were used. The mean surface temperature was subtracted from half the standard deviation and the mean LST to get the UHI distribution.

$$\mathrm{UHI} = Tmean - (\mu + \frac{\alpha}{2}) \quad (7)$$

Next, the extracted surface temperature data are interpreted and further analysed. Surface temperature patterns and distributions are understood, and relationships between surface temperature and other factors, such as land cover, urban structure, or other variables relevant in the context of UHI, are identified. These steps contribute to a deeper comprehension of the UHI phenomena and the creation of practical mitigation plans.

3 Conclusions

This research used a literature review to examine the relationship between land cover and temperature on surface area in Urban Heat Island (UHI). The research method involved searching for relevant reference sources through Google Scholar, then reading, understanding, evaluating and synthesising information from various relevant sources. The phenomenon known as UHI occurs when temperatures inside urban areas are greater than those outside in rural areas, caused by changes in urban structure and land cover such as an increase in buildings and a reduction in green open areas. Several UHI-related studies have been conducted, such as the temperature comparison between vegetated and unvegetated areas in New York, as well as the impact of energy use on SUHI in major cities in China.

Analysing UHI can be done by measuring the LST through sensing technology. LST offers data on the spatial and temporal fluctuations of the Earth's surface temperature. The purpose of this research is to integrate remote sensing and GIS to understand the relationship between land cover and surface temperature for UHI analysis. According to certain studies, there seems to be a substantial positive correlation between more urban areas and greater surface temperatures. This implies that there is a direct relationship between rising surface temperatures and increasing built-up land area. A greater understanding of the variables influencing UHI and its effects on the urban environment is anticipated as a result of this research. It is anticipated that the findings of this research will significantly impact the choices made about sustainable urban management and planning.

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