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RELATIONSHIP BETWEEN DEFORESTATION AND LAND SURFACE TEMPERATURE ACROSS AN ELEVATION GRADIENT USING SATELLITE IMAGERY IN CAMERON HIGHLANDS, MALAYSIA

DARREN HOW JIN AIK

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By

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Chairman : **Professor Gs. Ts. Mohd Hasmadi bin Ismail, PhD**
Faculty : **Forestry and Environment**

The Cameron Highlands has experienced multiple land encroachment activities and repeated deforestation, leading to extensive land-use and land-cover change (LULCC) during the past six decades. The recent deforestation has possibly contributed to the warming and increased LST. On the other hand, the rise in LST could be directly linked to deforestation due to the expansion of urban areas, including agriculture. However, deforestation and land cover dynamics and their effect on land surface temperature (LST) in the highland areas are not well known. This study aims to explore the drivers and impacts of deforestation as a direct cause of urbanization and land expansion and its effects on the land surface temperature of the Cameron Highlands between 2009 and 2019 using satellite imagery. The specific objectives were three folds; (i) to detect Land Use and Land Cover Change (LULCC) between 2009 and 2019 in Cameron Highlands, (ii) to evaluate the relationship between Land Use and Land Cover Change (LULCC) and Land Surface Temperature (LST) using Landsat and MODIS imageries, and (iii) to assess Land Use and Land Cover Changes (LULCC) of different forest types across an altitude gradient. Geospatial techniques and remotely sensed data were employed to analyse Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and 8 Operational Land Imager (OLI/TIRS), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Global Digital Elevation Model (GDEM), and Moderate

Resolution Imaging Spectroradiometer (MODIS) 11A sensors. First, land cover classes and detection were identified using an Object-based Image Analysis (OBIA) classification technique on both Landsat 7 and 8 sensors, using a combination of nearest neighbour and multiresolution segmentation algorithm (MSA). Then, for the derivation of LST, a single channel (2009-2012) and Split-Window Algorithm (SWA) (2013-2019) was applied to derive the LST. In order to validate the results, air temperature data were obtained from Met Malaysia and MODIS data. Then this study determined the LULCC across forest types according to the forest type-elevations. Results have shown a significant rise in both agriculture and urban change where LULC change for agriculture nearly tripled in 10 years from 4.93% to 12.63%, while urban development increased from 7.48% to 9.12% between 2009 and 2019. This comes as a cost of a decline in primary forests by 59.44 km^2 (8.87%) of total land area between 2009 and 2019. LST experienced an average increase of 2 °C between 2009 and 2019 for the overall study area, where hotspots were found to concentrate in the main towns of Ringlet, Brinchang and Tanah Rata. Our validation results proved successful as the accuracy of LULC, and LST outputs achieved 94.6% and 80.0%, respectively. The forest type most affected by deforestation is the upper dipterocarp forest, reducing 232.54 km^2 to 207.38 km^2. This is where most urban and agricultural land is located. A further study of LULC on slopes had shown an expansion of agriculture and urban development onto slopes above 35°, prevailing in 2014-2019. The sensitive upper dipterocarp forests saw an interannual temperature variation of +/- 5 °C with a gradual incline until 2019. This study provides a novel and essential fundamental research finding for Cameron Highland. Thus, government bodies, land planners, and environmentalists benefited to understand the impacts of LULC on LST. This study can be helpful in highland planning and development and control deforestation expansion to conserve forests and environmental sustainability in the mountainous region. On the other hand, this study could evaluate to a level where ecosystems and social systems can support the development of the REDD+ policy and approach achieving a low carbon credit value in this country.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

HUBUNGAN ANTARA DEFORESTASI DAN SUHU PERMUKAAN TANAH MELALUI GRADIEN ELEVASI MENGGUNAKAN GAMBAR SATELIT DI CAMERON HIGHLANDS

Oleh

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Cameron Highlands telah mengalami pelbagai aktiviti pencerobohan tanah dan kehilangan kawasan hutan berulang kali, yang menyebabkan perubahan penggunaan tanah dan litupan tanah yang luas (LULCC) selama enam dekad yang lalu. Pengurangan kawsan berhutan baru-baru ini mungkin menyumbang kepada pemanasan dan peningkatan suhu permukaan tanah (LST). Sebaliknya, kenaikan LST secara langsung dapat dikaitkan dengan penebangan hutan disebabkan oleh pembukaan kawasan bandar, termasuk pertanian. Walau bagaimanapun, pengurangan kwasan berhutan dan kedinamikan guna tanah dan litupan tanah serta pengaruhnya terhadap suhu permukaan tanah (LST) di kawasan tanah tinggi tidak dapat dipastikan. Kajian ini bertujuan untuk meneroka punca dan kesan pegurangan Kawasan berhutan sebagai penyebab langsung kepada urbanisasi dan pembukaan tanah dan kesannya terhadap suhu permukaan tanah di Cameron Highlands antara tahun 2009 dan 2019 dengan menggunakan imej satelit. Objektif khusus adalah seperti berikut; (i) untuk mengesan perubahan guna tanah dan litupan tanah (LULCC) antara 2009 dan 2019 di Tanah Tinggi Cameron, (ii) untuk menilai hubungan antara pPenggunaan tanah dan litupan tanah (LULCC) dan suhu permukaan tanah (LST) menggunakan imej satelit Landsat dan MODIS dan (iii) untuk menilai perubahan guna tanah dan litupan tanah (LULCC) dari hutan yang berbeza merentasi ketinggian. Teknik geospatial dan penderiaan jaak jauh digunakan untuk menganalisis Landsat 7 Enhanced Thematic Mapper Plus (ETM +) dan 8 Operational Land Imager (OLI / TIRS), Advanced Spaceborne Thermal Emission dan Reflection Radiometer (ASTER), Global Digital Elevation Model (GDEM), dan Sensor Spectroradiometer Pengimejan Beresolusi Sedernaha (MODIS) 11A. Pertama, pengkelasan litupan tanah dan pengesanan dikenal pasti menggunakan teknik pengkelasan imej berasaskan objek (OBIA) ke atas imej Landsat 7 dan 8, menggunakan kombinasi algoritma segmentasi tetangga terdekat dan multiresolusi (MSA). Kemudian, untuk menjana LST, saluran satu (2009-2012) dan Algoritma Split-Window (SWA) (2013-2019) digunakan untuk memperoleh LST. Untuk mengesahkan hasilnya, data suhu udara diperoleh dari data Met Malaysia dan MODIS. Kemudian kajian ini menentukan LULCC merentasi jenis hutan mengikut ketinggian jenis hutan. Hasil menunjukkan peningkatan yang ketara kepada perubahan pertanian dan bandar di mana perubahan LULC untuk pertanian hampir tiga kali ganda dalam 10 tahun dari 4.93% kepada 12.63%. Sementara itu, pembangunan bandar meningkat dari 7.48% kepada 9.12% diantara tahun 2009 dan 2019. Ini berlaku disebabkan kesan penurunan hutan primer sebanyak 59,44 km^2 (8,87%) dari jumlah kawasan antara tahun 2009 dan 2019. LST mengalami kenaikan purata 2 ° C antara tahun 2009 dan 2019 untuk keseluruhan kawasan kajian, di mana kawasan panas didapati tertumpu di bandar-bandar utama Ringlet, Brinchang dan Tanah Rata. Hasil pengesahan kami terbukti berjaya kerana ketepatan LULC, dan output LST masing-masing mencapai 94.6% dan 80.0%. Jenis hutan yang paling banyak dipengaruhi oleh pegurangan hutan adalah hutan dipterokarpa atas, berkurang 232.54 km^2 menjadi 207.38 km^2. Di sinilah kebanyakan tanah bandar dan pertanian berada. Kajian lebih lanjut mengenai LULC di lereng telah menunjukkan pengembangan pertanian dan pembangunan bandar ke lereng di atas 35 °, berlaku pada tahun 2014-2019. Hutan dipterokarp bahagian atas yang sensitif menyaksikan variasi suhu antara tahun +/- 5 ° C dengan kemiringan secara beransur-ansur hingga 2019. Kajian ini membuktikan penemuan asas dan penting bagi Cameron Highlands. Oleh itu, badan kerajaan, perancang tanah, dan ahli alam sekitar mendapat manfaat untuk memahami kesan LULC terhadap LST. Kajian ini dapat membantu dalam perancangan dan pembangunan tanah tinggi dan mengawal pengurangan kawsan berhutan demi untuk memulihara hutan dan kelestarian alam sekitar di kawasan tanah tinggi. Kajian ini juga dapat menilai tahap dimana ekosistem dan sistem sosial dapat membantu membangunkan dasar dan pendekatan ke arah REDD + untuk mencapai nilai karbon kredit yang rendah di negara ini.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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ABP	Backpropagation algorithm
AI	Aggregation index
ALOS	Advanced land observing satellite
ANN	Artificial neural network
AOI	Area of interest
APEX	Airborne prism experiment
ASTER	Advanced spaceborne thermal emission and reflection radiometer
AT	Atmospheric attenuation
ATCOR	Atmospheric correction
AVHRR	Advanced very high-resolution radiometer
AWMPFD	Area-weighted mean patch fractal dimension
BT	Brightness temperature
CART	Classification and regression trees
CASI	Compact airborne spectrographic imager
CBERS	China–Brazil Earth Resources Satellite
CHRIL	Copernicus high resolution imperviousness layer
CMFDA	Continuous monitoring of forest disturbance algorithm
COLD	Continuous monitoring of land disturbance
CORINE	Copernicus land monitoring service
DCNN	Deep convolutional neural networks

DN	Digital numbers
DT	Decision tree
ECS	Expert classification system
ED	Edge density
EMR	Electromagnetic radiation
ENND	Euclidean nearest neighbour distance
ERTS	Earth Resource Technology Satellite
ESA	European Space Agency
ETM+	Enhanced thematic mapper plus
FAO	Food and Agriculture Organisation
FCN	Full convolutional networks
FRA	Forest resources assessments
GCM	General circulation models
GDEM	Global digital elevation model
GHG	Greenhouse gases
GIMMS	Global inventory modelling and mapping studies
GIS	Geographical information sciences
GLCM	Grey levels' Coocurrence matrices
HOB	Heart of Borneo
HSR	High spatial resolution
JAXA	The Japan Aerospace Exploration Agency
k-NN	K-nearest neighbour algorithm

KSOM	Kohonen self-organized neural network feature map
Landsat	Land remote-sensing satellite
LD	Land degradation
LM	Levenberg–Marquardt
LPI	Largest patch index
LSE	Land surface emissivity
LST	Land surface temperature
LSWI	Land surface water index
LULCC	Land use and land cover change
LVQ	Learning vector quantization
MASTER	MODIS-Aster
MDC	Minimum distance classifier
MLC	Maximum likelihood classifier
MNDWI	Modified normalized difference water index
MODIS	Moderate resolution imaging spectroradiometer
MR	Multiresolution
MSA	Microwave sensor algorithm
MRSA	Multiresolution segmentation algorithm
MSS	Multi-spectral sensor
MWA	Mono-window algorithm
NASA	National aeronautics and space administration
NDVI	Normalized difference vegetation index

NDWI	Normalized difference water index
NIR	Near infrared
NP	Number of patch
OA	Overall accuracy
OBIA	Object-based image analysis
OLI	Operational land imager
OSM	Open street maps
PALSAR	Phased array type l-band synthetic aperture radar
PCA	Principal component analysis
QN	Quasi-newton
RBF	Radial basis function
RCBD	Randomized complete block design
REDD+	Reducing emissions from deforestation and forest degradation
RF	Random forest
RFE	Recursive feature elimination
RGB	Red green blue
RH	Relative humidity
RMSD	Root-mean square deviation
RMSE	Root-mean-square-error
RNPN	Regional natural park of narbonne
RS	Remote sensing
RTE	Radiative transfer equation

RTK	Real-time kinematics
RUSLE	Revised universal soil loss equation
SAR	Synthetic aperture radar
SD	Spectral difference
SLC	Scan line corrector
SPLIT	Splitting index
SPOT	Satellite Pour L'observation de La Terre/ "satellite for observation of earth
SVM	Support vector machines
SWA	Split-window algorithm
SWIR	Short-wave infrared
TIGR	Tovs initial guess retrieval
TIRS	Thermal infrared sensor
TOA	Top-of-atmosphere
UAV	Unmanned aerial vehicle
UHI	Urban heat island
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VHIR	Very high image resolution
VHR	Very high-resolution
WGS	World geodetic systems

CHAPTER 1

INTRODUCTION

1.1 General background

Highland regions, status, and function: Highland regions are defined as a land above the clouds, located between undulating mountains, and have their own climatic conditions (Beniston et al., 1994). As the highland regions have their very own climatic conditions, they are known to be sensitive to even the slightest change in climate and are susceptible to minor increases in temperature (Hardwick et al., 2015). Highlands are a highly productive ecosystem located in elevations above 600 m and can range between 600 to 2000 m (Barrow et al., 2008). It is a region comprising of numerous ecological sites, both flora and fauna, as well as several forest types. Globally, for centuries, due to their strategic location, highland regions have been known as an area of natural defence against harsh weather and invading enemies. In modern times, similarities can be found, in addition to the location's expansion into tourism. Due to its temperate climate conditions, agriculture is the top land-use type in the area, followed by urban use of living quarters (Empidi et al., 2021).

Being a valuable ecological and economic site, the Cameron Highlands continue to be used as an important site in both agriculture and tourism. It serves as nursery grounds for migratory birds and as a breeding site for many important reptiles and mammals (Cong & Brady, 2012). The dynamic forests of the highlands support over 700 species of flora, of which 20% are endemic to the Cameron Highlands (Kumaran & Ainuddin, 2004). The fauna profile denotes over 300 species of mammals, birds, reptiles, and amphibian species collectively (Kumaran & Ainuddin, 2004). The Cameron Highlands serves as a refuge for several faunal species that are endemic to Peninsular Malaysia. In the Cameron Highlands, the agriculture scene is dominated by tea plantations, followed by vegetables, flowers, and small-scale gardens owned by small shareholders. It is estimated that roughly 1/5 of the total area size is designated for agriculture use (Suppiah et al., 2020). It is a significant place where a complex process involving energies fluxing in between air, earth, surface and living organisms, provides the energy to support numerous environmental processes.

In forested highland regions globally, and as such to the Cameron Highlands, the forests are a renewable source of wood and act as a forest carbon sequestration. The importance of these forests in collecting carbon is to ensure the balance in earth's carbon balance (Knight & Harrison, 2012). These forests have moderated climate change by absorbing carbon emissions emitted by human activities, such as burning of fossil fuels and land-use changes (Nasidi et al., 2021). Despite their relatively small surface area, mountains are well understood to be an integral part of the climate system (Knight & Harrison, 2012; Hardwick et al., 2015). A further understanding of the climatic characteristics of mountain regions is limited by a lack of observations adequately distributed in time and space.

Land Use and Land Cover Changes (LULCC): LULCC due to deforestation, rapid growth in urbanisation, and agriculture have led to a heightened alteration in global landscapes. Land use practices may differ from one to another depending on location, socio-economic practices, and ideologies, however, the resultant aim is the same regardless of their differences in practices. As most land-use changes occur without clear and logical planning, environmental factors and their thereafter effects are not taken into consideration. Thus, LULCC alteration in a natural ecosystem is among the life-threatening issues inducing various implications of land cover, such as forest degradation, loss of habitat and wildlife, erosion as a result of forest uprooting, and climate change (Jun-Lang & Wei, 2009). The relationship between land use and climate change is complex and multidirectional. Land-use change has been demonstrated to influence the climate and at local, regional, and global scales.

Land Surface Temperature: Deforestation and land cover dynamics, and their effect on land surface temperature (LST) especially in the highland areas are not well known. Advancements in geospatial technological tools - Remote Sensing (RS) and GIS techniques have grown to provide an effective and efficient tool to analyze environmental patterns of change globally; as demonstrated by numerous researchers (Rendana et al., 2015; Ogunode, 2017: Kumari et al., 2018; Al Kafy et al., 2020) in various fields of studies. It also provides complete coverage for last surface temperature retrieval in areas where accessibility is limited (Gomis-Cebolla et al., 2018; Lu et al., 2018). Thus, RS enables a variability of guidelines and applications for sustainable highland monitoring of land use and management (Mohammadi et al., 2019a; Razali et al., 2018).

There are several types of space-borne data used for LST mapping, they are optical, radar, and microwave. Optical sensors rely on surface reflectance of sunlight whereby different surfaces provide a different digital number, whereas radar-based sensors, also known as Synthetic Aperture Radar (SAR), actively emit microwave energy onto their targets. Both sensors have their pros and cons, however, the optical sensor is more popular due to its ease of use and the readily available access to satellites. Optical sensors such as Landsat, IKONOS, and MODIS have been widely used to conduct LST retrieval studies on numerous locations with high accuracies. The usage of the sensors is paired with various LST retrieval methods as well, these include the single-channel algorithms, split-window algorithm (SWA), MODIS day/night algorithm and multichannel algorithms amongst several more. In the highland regions of the world, it is recommended for radar sensors to be used due to their penetrative ability to ignore clouds, however, due to its inaccessibility of cost-effective data sets, the optical sensor is used. Through the use of good image corrections, the data set can also reach a similar potential as the radar sensor (Holmes et al., 2018; Prakash et al., 2018; Sun et al., 2019).

1.2 Problem statements

In history, Cameron Highlands district was declared as a reserve for deer in 1958 and subsequently expanded in 1962 for the safekeeping of all animals and birds (Gazette Notification 442). However, in February 1962 (De-gazettement Notification No.66), the protected area was legally struck off (Kumaran & Ainuddin, 2004). In one fell stroke, the protected montane forest situated at an elevation of 900 m above sea level got reduced down to 80% (Davison, 1996). In the year 2000, the forest is estimated to occupy roughly 50,778 ha (71%) of the Cameron Highlands District (Forestry Department Pahang, 2001).

A study by Akmar and Hasmadi (2010) has found that forest decline occurred particularly from 2005 – 2010. Approximately 2% of the forest cover in Cameron Highlands had been lost in 10 years, and a proportion of the remaining forests degraded as a result of agricultural practices. In 1990, the forest area in Cameron Highlands was numbered approximately 62,991 ha then declined to 58,535 ha in 2006 (Ministry of Agriculture, 2007). Land use in the area has given rise to irreversible effects on LST on the ecosystem of the natural mountain forest landscape. As the study covering LULCC in Cameron Highlands was in 2015, there is a need for an updated LULCC map and database for recent years. In that study, Rendana et al. (2015) had discussed the land cover change in Cameron Highlands to change by a further 3.66% by 2020. It was also mentioned that a heightened change in land cover would occur when a rise in population is experienced in the area, further destabilising the soil integrity, which leads to frequent land erosion occurrences; this statement is supported by UI Mustafa et al. (2019) as well. He added that urbanisation continues to grow with the increasing tourism demand of the area. However, such a rapid development will only cause a demise for the geology of the highlands – leading to a rise in temperatures as well as destabilising soil patterns (Empidi et al., 2021).

The Cameron Highlands, Malaysia is situated in high elevation with an average temperature recorded at Tanah Rata is 18 °C, while the minimum temperature is 15°C and a daily deviation between 5 to 7 °C (Kumaran and Ainuddin, 2004). This value is old and dated, given that the data was provided for the year 2006 before the changes in land use and land cover boom from 2009 onwards. Between 1965 – 2002, the temperature was steadily increasing since the mid-1970s (Kumaran and Ainuddin, 2004). The warmest year was 1998 and 2002 was recorded as the second highest. The recent deforestation has possibly contributed to the warming and increased LST. LST is related to surface energy balance and the integrated thermal of the atmosphere within the planetary boundary layer (Jin, 2004; Kamal et al., 2021). It was noted that the recent average temperature in the highlands is between 24 and 28 °C; the difference between the current and previous temperature is only in 15 years, but the rate of temperature rise is shocking (Met Malaysia, 2021). The rise in LST could be a direct relationship between deforestation due to the expansion of urban zones and/or the overall global surface temperature rise from the decline of our ozone layer. The Cameron Highlands is seen to have its microclimate, a local atmospheric zone that is unique and differs from that of the surrounding area. As deforestation continues, this microclimate would cease to exist causing an imbalance of energy fluxes of the surrounding atmosphere and within. Irregular atmospheric pressure and climatic condition would occur as a result (Kemarau et al., 2021).

Recent studies of climate change (Suppiah et al., 2020; Nasidi et al., 2021) and disaster studies through climate-induced factors (Soh et al., 2021) have found an updated climatic condition of the highlands. It was found that the migratory birds that cross the Titiwangsa range have not been showing up in recent months, as the Cameron Highlands are along its route towards the south of Asia (Soh et al., 2021). The climate factors of storms and increase patterns of heat wave-induced rain are named as the primary cause for such a diversion of these migratory birds. Moreover, as these birds mainly reside in the upper dipterocarp forests, it was found that the majority of forest areas in this forest region are either deforested or close to urban zones (See & Chan, 2020). This would mean that the decline in species richness of grazing sites and a lower proportion of species to feed on are the major contributors to montane bird species reduction. Soh et al. (2021) conclude that climate change is the most likely factor that has impacted the montane bird communities; in addition to the larger cause that is deforestation.

The latest prediction models using climate GCMs as researched by Nasidi et al. (2021) have found heightened rainfall to occur more frequently, and paired with corrosive elements in the atmosphere to generate more acid rains. The climate studies projection timescales reach as far as 2050 and 2080, where the climate of the highlands is predicted to reach extreme temperatures of 36 - 40°C if the rate of climate change is constant. Previous studies by using satellite observations indicate that tropical deforestation results in warmer and drier conditions at the local scale (Chan et al., 2021; Soh et al., 2021). A study conducted by Suppiah et al. (2020) simulated precipitation for the highlands between 2018-2069. The purpose of this study was to assess the disaster risks that are incurred by historic deforestation and climate change, using the regional climate model (RCM). Results show that the effects of daily precipitations effects paired with toxic atmospheric content generated from urban areas, such as cars, factories, and the continuous burning of waste are the main attributes of the disaster risks. In a model scenario, the relationship between climate change, hazards, and deforestation was found to have a positive correlation. It provides an increasingly serious prediction whereby constant floods and landslides are expected to occur in the coming years (Suppiah et al., 2020; Nasidi et al., 2021). Moreover, serious implications are expected on the highlands agricultural sector as noted by Entezari et al. (2021) and Nishizawa et al. (2021).

The forests of the highlands have been put under severe pressure in the last decade, primarily due to the rise in the development of urban areas as a result of urbanization. As urban areas grow, so does the needs of those populations; hence, deforestation occurs at a higher rate than before (Rendana et al., 2015). Many forested areas, predominantly in the central areas, such as Tanah Rata and Brinchang have been cleared to make way for development processes. The development of the Ulu Jelai Hydroelectric plant is another cause of concern for both water dynamics and geological structures. As the location it is built upon is carved out of metamorphic rock, it is more susceptible to landslides occurring than other areas of the highlands covered in an area of convexities (Samy et al., 2014). Ching et al. (2020) adds that the highlands can meet sustainability requirements as there are many challenges but local support outweighs weaknesses. In the matter of forestry clearing and urban development, Ching confirms that the policies in reducing environmental damages in the highlands are slow to be enforced, though there is some work laid on the ground in 2020.

As the highlands are known for their massive array of biodiversity, amounting to 700 flora and 300 faunae; it has seen massive threats over the last five decades. Numerous areas of conservation are under constant threat by illegal logging, land encroachment, unauthorised construction, and many other threats are noted too (Chan et al., 2021). Using spatial imagery, a threat assessment was underdone in areas of high conservation properties in Malaysia, one of those areas is Cameron highlands. Chan et al. (2021) notes the weakened endemism, phylogenetic and evolutionary distinctiveness of the highlands to be under constant threat due to the expansion of land use as a result of forest clearing and illegal hunters/ gatherers. It was found from his spatial study where the seriousness of this issue matters the most in Cameron Highlands. It requires the highest conservation policy due to the endangerment of flora and fauna, whereby the number of sightings of local animals; the striped deer, and speckled green forest are at an immense low. This is the result of severe environmental degradation and inadequate protection sites. He adds that the lack of governance and care towards the ecosystem has led to an imbalance in the overall ecology and biophysical balances of the highlands, as agreed by Maideen et al. (2021) too.

Landslides have become a common occurrence in the Cameron Highlands ever since the development boom in 2009 (Abdulkadir et al., 2020). It is related to the loosening of soil due to the larger cause, that is deforestation and land clearing. It has been found that landslides and erosions are happening on slopes surrounding Cameron Highlands. While the land use is unknown in those areas, as to why these landslip occurrences are happening, it can be labelled as a manmade induced disaster. While there have been many studies relating to landslide susceptibility modelling using remote sensing and GIS techniques, most of the studies do not take into account, the type of land use grown in that area (Kadir et al., 2020; Al-Najjar et al., 2021). Those studies conducted regarding the landslide issue in Cameron Highlands have merely taken into account the DEM, stream features, slope inclination, and permeability of rock structures (Samy et al., 2014; Shahabi & Hashim, 2015; Tien Bui et al., 2018; Nhu et al., 2020).

1.3 Research questions

With all the issues stated earlier, the following research questions are asked:

1. What is the current state of land use/land cover in Cameron Highlands, and to what state has the deforestation led to in 10 years between 2009 and 2019?
2. What is the change in land surface temperature that is caused by deforestation as a result of expansion through urbanization?
3. In which forest region according to the elevation is at the highest risk of deforestation and how will this issue be tackled?

1.4 Aim and objectives

The general objective of this study is to assess the relationship between deforestation and land surface temperature using satellite imagery and remote sensing techniques between 2009 and 2019 in Cameron Highlands, Malaysia. The specific objectives are as follows:

1. To assess Land Use and Land Cover Change (LULCC) between 2009 and 2019 in Cameron Highlands
2. To assess the relationship between Land Use and Land Cover Change (LULCC) and Land Surface Temperature (LST) using Landsat and MODIS imageries.
3. To assess Land Use and Land Cover Changes (LULCC) of different forest types across a topographical gradient.

1.5 Hypothesis

A hypothesis is a statement of assumption and/or prediction concerning research problems. To be able to achieve the right direction of a study, the research needs to develop hypotheses. Hence, in this study, regarding land-use change and its relationship with land surface temperature, the following hypotheses are developed:

1. There is a change (reduction) of primary forests and an increase in other land use classes during the last 10 years (between 2009 and 2019);

2. There is a relationship between deforestation and land surface temperature;
3. There are changes associated to the land cover in the multiple forest types.

1.6 Scope of the research

This study was conducted to assess the relationship between deforestation of land surface temperature. It is formed from the initiative to understand what has happened between 2009 and 2019 in terms of land cover change, and how has this change affected land surface temperature. The main area of change is known to be in the hotspots of Cameron Highlands, namely Brinchang, Tanah Rata, and Ringlet. As these areas are the most densely populated, land surface temperatures emitted from these areas are higher than in other areas. Expansion of land cover change is higher due to the increase in population, resulting in clearing of land, deforestation of primary forests and along the upper slopes of the region. Thus, determining the land cover change is the first critical step in determining the growth change patterns of these areas; additionally, determining the land surface temperature rate annually will enable the authors to understand the activities occurring there, hence the focus of this study.

1.7 Significances of the research

Cameron Highlands is an important region that houses many florae and fauna that are not available in the lower elevation areas of Malaysia. It is rich in biodiversity, with dense primary forests as well as rare crops that are only suitable for its climate. The local community has been living off the natural produce of the area and greatly depends on its low and cool climate for their livelihoods.

Currently, there haven't been any updated studies regarding land-use and land cover change in the Cameron Highlands in the past 3 years. Additionally, classification techniques used in previous studies are basic, with the common method used – Supervised classification. Hence, in this study, we performed classification using the Object-Based Image Assessment (OBIA) method by grouping pixels into the form of shapefiles. This method also combines the use of ground-based points for truthing and to improve classification accuracy. Through this method, we can fully understand the land use effectively in this region. Additionally, land surface temperature (LST) was also conducted, we have found a significant change in temperature that has affected the entire climate of the region. From the years 2009 to 2019, we found a heightened rise in temperature that has altered the growth of flora and fauna. Through this assessment, we can fully understand the sensitivity of biodiversity through the slightest change in temperature and how it would benefit the local population in crop growth and yield.

Finally, this study used digital elevation models (DEM) for assessing land cover changes across an elevation gradient. There are no studies that show the use of DEM on to classifications of the various forest types in Cameron Highlands. Hence, this assessment will allow the local government to fully understand where deforestation is occurring and to what extent over the past 10 years. The study, which focuses on the effects of deforestation and the climate change of forest type classifications is the novelty of the thesis.

1.8 Limitations of the research

The study area is situated in a mountainous region paired with its temperate climate, there are known fluctuations in the weather. Such effects have brought a change in wind patterns, extreme cloud cover, and undulating patterns of land surface temperature. It was hoped that higher resolution imagery was available for the dates chosen, however, as there were none, we settled for the usage of moderate resolution remote sensing data.

For the calculation of land surface temperature, we had used Landsat 8 and MODIS sensors, plus air temperature for validation. This would mean, an average of ground air temperature at certain hotspots is not being available as another means of validation.

1.9 Research framework

This study conceptualised that both deforestation and land surface temperature is increasing mainly, due to a diversity of anthropogenic factors (both land use and land cover change factors as well as socioeconomic factors). The framework of the study is visualized below in Figure 1.1:

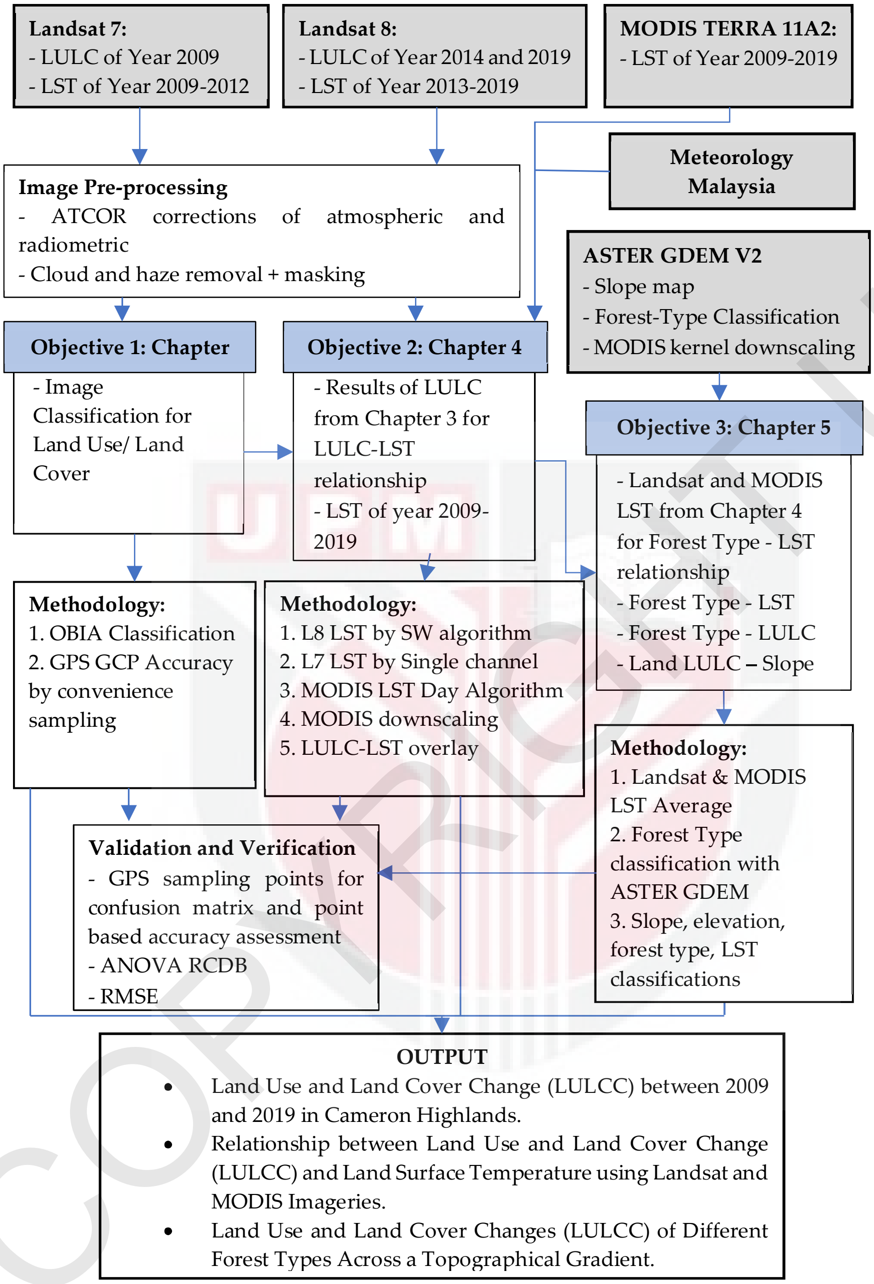

Figure 1.1 : Framework flowchart of the research study

1.10 Organization of the thesis

In this thesis, there are 6 chapters hence it is organized as below:

Chapter 1 is the introduction describing the background of land-use changes and climate change that has occurred in the history of Cameron Highlands. It also discusses the use of remote sensing and GIS technologies to tackle these issues. The problem statement, research questions, significance, and objectives are also discussed in this chapter.

Chapter 2 comprises the literature review, in which previous research works are discussed in regards to using remote sensing for forest change analysis. The discussion also leads to the assessment of climate change (causes and effect) in other mountainous regions of the world along with the impacts of change onto the individuals living along these sensitive regions.

Chapters 3 to 5 are organized as a series of article papers related to the scopes and objectives of the study. All papers have been submitted to reputable journals and are published. The articles are explained further as follow in Table 1.1:

Table 1.1 : Progress of papers submitted to journals

Chapter	Title	Journal	Status during thesis submission
3	Assessing Land-use and Land-cover Change (LULCC) between 2009 and 2019 using Object-Based Image Analysis (OBIA) in Cameron Highlands, Malaysia	IOP Conference Series: Earth and Environmental Sciences, Vol. 540, 012002	Published
4	Land Use/Land Cover Changes and The Relationship with Land Surface Temperature using Landsat and MODIS Imageries in Cameron Highlands, Malaysia	(Land, ISSN: 2073-445X, Vol. 10, Issue 9, 2020	Published
5	Evaluating The Impacts of Land Use/Land Cover Changes Across Topography Against Land Surface Temperature in Cameron Highlands	PLOS ONE (ISSN: 1932-6203, Vol. 16, Issue 5, e0252111, 2021	Published

Finally, Chapter 6 summarizes the overall findings and concludes the study. Future recommendations of use of classification techniques of the land use of other forests in Malaysia are also included.

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