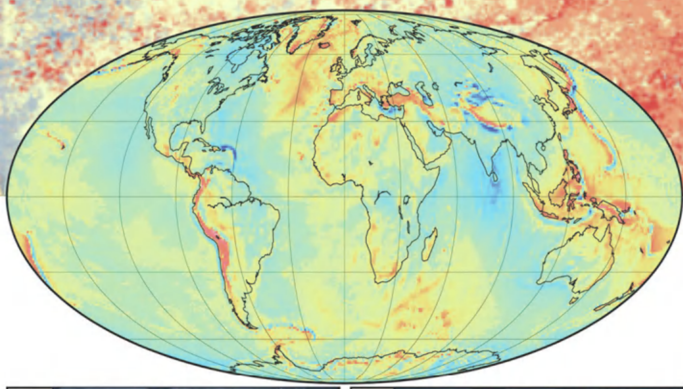
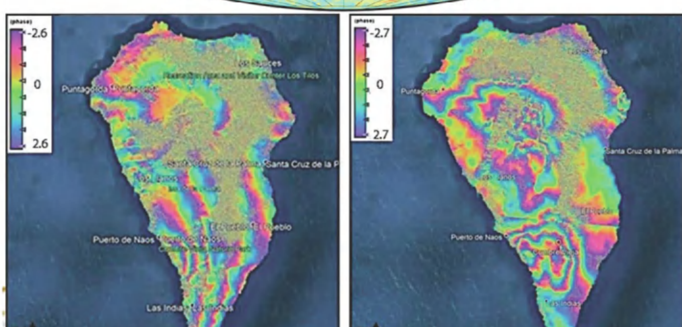
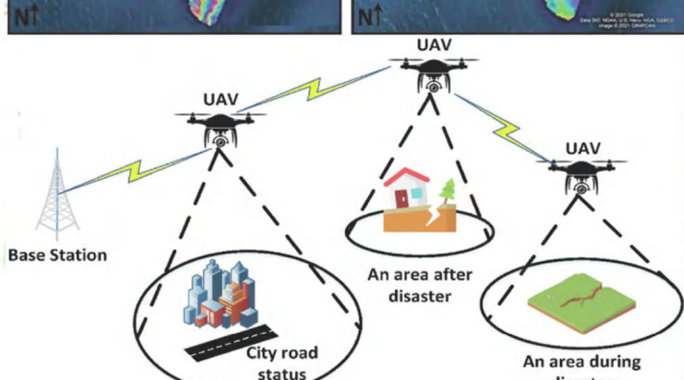
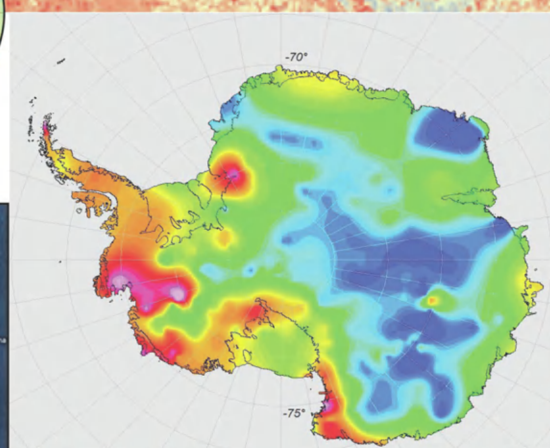
REMOTE SENSING FOR GEOPHYSICISTS

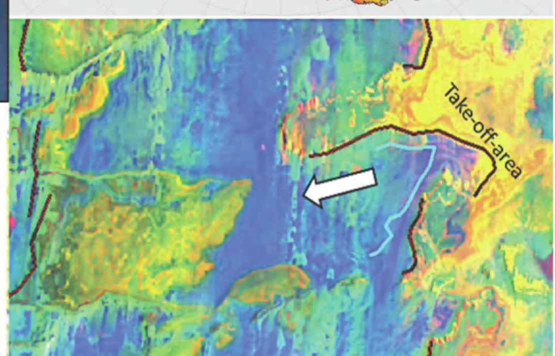
EDITED BY **MUKESH GUPTA**











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Remote Sensing for Geophysicists

Geophysical exploration methods are very expensive and invasive methods for surveys. Remote sensing methods are non-invasive and much cheaper for investigating the Earth's surface. This book bridges this gap and aims to integrate exploration geophysics with remote sensing as a cost-effective method which is easy to implement for prospecting in different areas. It provides exploration geophysicists with the necessary information to use advanced remote sensing technology in the exploration of oil and gas, minerals, and groundwater. It describes the integration of remote sensing in each of the nine exploration methods based on over 11 case studies from different countries across the globe.

Features:

- Describes the geophysical exploration methods that geophysicists frequently use, along with suitable remote sensing techniques.
- Offers a well-structured one-stop guide for finding a suitable remote sensing technique for a specific geophysical exploration method.
- Provides case studies on the exploration of oil, gas, and groundwater with step-by-step instructions using remote sensing technology.
- Serves as a practical field book for exploration geophysicists who have never used or rarely use remote sensing.
- Enables exploration geophysicists to understand and interpret remote sensing data for the assessment of complex explorations.

This book is an excellent resource for professionals, researchers, academics, and students with a background in remote sensing across many disciplines in Earth sciences, such as geology, hydrology, petrology, mining, geography, geosciences, etc.

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Dedication

To the women (past, present, and future):

Your unwavering pursuit of truth, relentless drive for excellence, and courageous fight for freedom have illuminated the darkest corners of our world.

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PART III Remote Sensing in Seismic Methods

PART IV Remote Sensing in Electrical Methods

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PART IX Remote Sensing in Integrated Geophysical Problems

Preface

AIMS AND SCOPE

This comprehensive book aims to explore the critical role of remote sensing techniques across various geophysical methods. It seeks to provide researchers, professionals, and students with an in-depth understanding of how remote sensing technologies enhance and expand the capabilities of traditional geophysical exploration and monitoring techniques. The book aims to bridge the gap between traditional geophysical methods and modern remote sensing technologies, highlighting their complementary nature and the advantages of integrated approaches. It provides case studies, practical examples, and discussions on future trends and challenges in remote sensing applications for geophysics.

The need for this book arises from several key factors in the current geophysical and remote sensing landscape. Rapid developments in satellite technology, sensors, and data processing techniques have significantly expanded the capabilities of remote sensing in geophysical applications. There is a growing trend towards integrating traditional geophysical methods with remote sensing techniques. Remote sensing often offers a more cost-effective and efficient approach to large-scale geophysical surveys. Remote sensing methods are often less invasive than traditional ground-based surveys, aligning with increasing environmental concerns. Remote sensing allows for consistent data collection over large and often inaccessible areas, which is crucial for global-scale geophysical studies. The book demonstrates how remote sensing in geophysics has applications across various fields, including geology, hydrology, environmental science, and natural hazard assessment. There is a need for a comprehensive resource that bridges the gap between geophysics and remote sensing for students, researchers, and professionals. With growing interest in remote sensing applications across the world, this book serves as a valuable guide for capacity building. It provides insights into future directions and challenges in the field, helping professionals stay ahead of the curve.

The motivation behind this book stems from several important factors. More than two decades ago, geophysics and remote sensing were considered disparate subjects. Until a few years ago, it was difficult for a student to opt for remote sensing alongside geophysics. Many geophysicists may not be fully aware of the latest remote sensing capabilities, while remote sensing specialists might not fully understand geophysical applications. To bridge the knowledge gaps, this book connects traditional geophysical methods with modern remote sensing techniques. The rapid advancement of remote sensing technologies has outpaced existing literature. This book can provide an up-to-date resource on the latest developments and their applications in geophysics. With more open-access satellite data becoming available, the book guides geophysicists on how to effectively use these resources in their work. The book aims to foster collaboration between geophysicists, remote sensing specialists, and data scientists, promoting a more integrated approach to Earth science research. This book highlights important remote sensing applications to address global issues like climate change, natural hazard assessment, and resource management. There is growing industry demand for professionals who can integrate remote sensing with traditional geophysical methods, motivating the need for a comprehensive resource on this topic. As the world moves towards more sustainable practices, the book provides motivation to show how remote sensing can offer less invasive alternatives to traditional geophysical surveys. By exploring emerging trends and potential future developments, the book aims to prepare professionals for the evolving landscape of geophysics and remote sensing.

The book integrates decades of research conducted by leading scientists in applied geophysics (geophysical exploration) and remote sensing across the world. It promotes a synergistic and multi-disciplinary approach among scientists. Potential readers may come from a wide spectrum of scientific backgrounds and expertise, such as agricultural sciences, archaeology, architecture and planning, artificial intelligence (AI), atmospheric sciences, big data analytics, civil engineering, computing, ecology, electrical engineering, environmental sciences, geodesy, geography, geology, hydrology, machine learning, meteorology, mineralogy, and oceanography. The preparation for the book was possible because of contributions from interdisciplinary experts from all over the world. The book can be used for teaching and research alike because of its sectioned structure, which meets the specific needs of different readers. The chapters can also be perceived as independent units suitable for combining with other materials if required.

The editor extends heartfelt appreciation to all contributing authors who, despite their demanding commitments, generously dedicated their time and expertise to this book. My deepest gratitude goes to the reviewers, whose insightful comments and valuable suggestions significantly enhanced the quality and depth of this book. Finally, the editor extends sincere appreciation to Taylor & Francis and their staff, Irma Shagla Britton, Isobel Brink, Indhumathi Kuppusamy and Chelsea Reeves, for their unwavering support and patience throughout the book's preparation, which were instrumental in bringing this work to fruition.

SYNOPSIS OF THE BOOK

This book is divided into the following nine sections:

Section I examines satellite-based gravity measurements. In Chapter 1, Steffen et al. provide a comprehensive overview of recent advancements in satellite-based gravity measurements, their contribution to global gravity field models, and their diverse applications in geophysical research. Chapter 2, authored by Soltani, examines how the integration of Gravity Recovery and Climate Experiment (GRACE) data into hydrological models enhances our comprehension of water distribution throughout Earth's surface and subsurface regions. In Chapter 3, Gupta presents a comprehensive overview of satellite-based geodesy, detailing its fundamental principles, innovative techniques, and wide-ranging applications. Chapter 4 by Vishwakarma et al. focuses on the evolution of glacial isostatic adjustments (GIA) research using remote sensing.

Section II discusses satellite magnetic field measurements. In Chapter 5, Upadhyay and Dimri explore the fundamental concepts underlying magnetic signatures of solar-terrestrial interactions and Earth's interior, while also examining the characteristics of magnetometers. Chapter 6, authored by Rani, examines the fundamental principles of remote sensing applied to mineral exploration, along with an analysis of diverse satellite datasets and their processing methodologies. In Chapter 7, Kapil and Dimri explore a range of remote sensing platforms, sensors, and data processing techniques crucial for effective ionospheric monitoring.

Section III explores satellite-based methods for seismic studies. In Chapter 8, Mshiu and Kiswaka demonstrate the efficacy of integrating remote sensing with seismic data interpretation through a case study of the Coastal Tanzanian Basin. Chapter 9, authored by Marchetti and Bailo, highlights the vital role of remote sensing in examining the complex interplay between seismic activity and anomalies in the lithosphere, atmosphere, and ionosphere, potentially linked to earthquake precursors. In Chapter 10, Theilen-Willige demonstrates the effectiveness of integrating diverse remote sensing techniques with other geospatial data to identify, inventory, and document structural features and fault zones, with particular emphasis on those exhibiting recent and ongoing deformations associated with neotectonic activity.

Section IV investigates geoelectrical phenomena using remote sensing. In Chapter 11, Jothimani et al. implement integrated approaches to enhance the accuracy and efficiency of geoelectrical methods in identifying high-potential groundwater zones. Chapter 12, authored by Gupta, explores the synergistic application of remote sensing techniques and geoelectrical methods to enhance mineral mapping capabilities. In Chapter 13, Melgarejo-Morales and Martínez-Félix examine the core principles of ionospheric electric fields, elucidating their generation mechanisms, spatio-temporal variations, and responses to geomagnetic storm events.

Section V explores the application of remote sensing techniques and electromagnetic (EM) methods in near-surface geophysical investigations, highlighting their complementary roles and effectiveness. In Chapter 14, Jefflin et al. demonstrate the critical importance of remote sensing technologies in observing and analyzing glacier dynamics. Chapter 15, authored by Gupta, examines the expanding role of Remotely Piloted Aircraft Systems (RPAS) in geophysics, highlighting their advanced capabilities, diverse applications, and significant potential for enhancing our comprehension of Earth's subsurface structures. In Chapter 16, Gupta provides an in-depth analysis of EM methods, including ground-penetrating radar (GPR) and induced polarization, emphasizing their applications in the emerging field of biogeophysics. In Chapter 17, Abdoli explores the integration of remote sensing technologies with advanced agrogeophysical methods, including Electrical Conductivity (EC), EM Induction, and GPR, to provide comprehensive insights into soil properties and enhance agricultural management strategies. In Chapter 18, Torrecillas and Payo demonstrate, through detailed case studies, the pivotal role of remote sensing technologies in elucidating complex coastal dynamics.

Section VI discusses remote sensing technologies for radioactivity methods of geophysical exploration. Chapter 19, authored by Pour et al., provides a comprehensive analysis of alteration minerals containing radioactive elements, exploring advanced remote sensing sensors, data acquisition methods, image processing techniques, and their applications in ore exploration. In Chapter 20, Gupta examines the integration of remote sensing technologies and geophysical methodologies for the detection and continuous monitoring of radioactive substances in oceanic environments.

Section VII examines remote monitoring systems for well-logging data acquisition, transmission, and real-time analysis. Chapter 21, authored by Gupta, explores the synergistic use of integrated approaches, particularly remote sensing technologies, in conjunction with well-logging techniques for enhanced hydrocarbon exploration. In Chapter 22, Gupta elucidates the crucial role of remote sensing techniques in enhancing well-logging processes for more effective groundwater exploration.

Section VIII explores remote sensing techniques for geothermal resource exploration and monitoring. In Chapter 23, Muanza et al. offer a comprehensive analysis of remote sensing applications in geothermal studies of cold regions, emphasizing the detection and monitoring of geothermal sources, volcanic heat fluxes, and subsurface reservoirs beneath ice-covered terrains. In Chapter 24, Guimarães et al. present a novel perspective on the characteristics and spatial distribution of terrestrial heat flow in Antarctica, synthesizing data from diverse geophysical sources, including seismic surveys and remote sensing technologies. Chapter 25, authored by Gupta, explores recent advancements in satellite-based technologies for detecting and analyzing volcanic thermal signatures and associated anomalies. In Chapter 26, Abu-Mahfouz provides a comprehensive overview of remote sensing techniques integral to geothermal exploration, examining their diverse applications and integrated approaches for delineating geothermal reservoirs.

Section IX addresses the synergistic use of multiple remote sensing techniques in solving complex geophysical problems. In Chapter 27, Abdalzaher and Saad highlight the significant advancements in seismic hazard assessment achieved through the synergistic integration of remote sensing technologies and AI methodologies. In Chapter 28, Nakhaei presents a comprehensive analysis of remote sensing technologies in archaeological applications, detailing the underlying geophysical methodologies and their practical implementations in the field. Chapter 29, authored by Castro-Melgar et al., examines the pivotal role of volcano monitoring in early warning systems, with particular emphasis on deformation analysis utilizing Synthetic Aperture Radar Interferometry (InSAR) techniques. In Chapter 30, Behera et al. provide exploration geophysicists with innovative knowledge and a comprehensive practical guide on integrating remote sensing data processing, Geographic Information Systems (GIS), and AI techniques for enhanced mineral exploration. In Chapter 31, Nguyen et al. examine integrated remote sensing approaches for analyzing urban soil thermal properties, providing a crucial foundation for urban planning strategies aimed at mitigating future heat island effects. Chapter 32, authored by Abdalzaher and Saad, explores innovative technologies, including

Unmanned Aerial Vehicles (UAVs), high-resolution satellite imagery, and GIS for enhancing earthquake disaster management through improved monitoring, analysis, and mitigation strategies.

The editor trusts that this preface has provided valuable insights into the diverse range of topics covered in this book. The book features 11 case studies from a global spectrum of locations, including Antarctica, the Czech Republic, Ethiopia, Germany, Great Britain, Greece, India, Iran, Ireland, Morocco, Spain, and Tanzania. Readers are encouraged to adapt the content to best suit their specific needs, enhancing their understanding of remote sensing technology's capabilities and potential applications in the field. The editor welcomes feedback, including error notifications, suggestions, or other comments, which can be directed to guptm@yahoo.com.

About the Editor

Mukesh Gupta is a geophysicist with expertise in remote sensing and a Professional Researcher in coastal engineering at the Department of Mathematics, Computer Science and Engineering, Université du Québec à Rimouski (UQAR), Rimouski (Québec), Canada. Before this, he held a post-doctoral fellowship and a contract at the Université Catholique de Louvain, Louvain-la-Neuve, Belgium (2019–2021) where he did Arctic climate modeling. He conducted his post-doctoral research in developing satellite data products at the Institut de Ciències del Mar (ICM), Spanish National Research Council (CSIC), Barcelona, Spain (2017–2018). He was the Visiting Fellow of the Natural Sciences and Engineering Research Council of Canada (NSERC) at the Environment and Climate Change Canada (ECCC), Dorval, Québec, Canada (2015–2016), where he assimilated satellite data in an ice prediction system. He was a Scientist/Engineer at the Space Applications Centre, Indian Space Research Organisation (SAC-ISRO), Ahmedabad, India (2002–2007) where he got expertise in ocean remote sensing applications. He earned his M.Tech. at the Indian Institute of Technology (IIT), Roorkee, India in 2000, and Ph.D. at the University of Manitoba, Winnipeg, Canada in 2014, specializing in applied geophysics (geophysical exploration) and Earth observation (EO) of Arctic sea ice, respectively.

Dr. Gupta's research focuses on exploiting EO data alone or synergistically with geophysical and climate models for computing key state variables of the Earth's cryosphere and geosphere, including Arctic Sea ice and crustal deformation. He is also researching the applications of remote sensing technology in coastal processes and its changes from either anthropogenic activities or geohazards (mainly cyclones, subsidence, and seismic). In this framework, he contributes to the development of algorithms in EO modeling and develops and implements all-inclusive benchmarking approaches to either satellite-based operational algorithms/products or global climate models, including machine learning.

Dr. Gupta serves as a life member of the Indian Society of Remote Sensing (ISRS); he is a Review Editor of more than 25 international peer-reviewed scientific journals in EO and earth sciences and has peer-reviewed more than 140 international journal papers. He is a government expert reviewer of the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports. He is the author of three book chapters, more than 25 peer-reviewed journal articles, and has attended more than 20 international conferences. He has developed fruitful collaborations with key scientists in his area of specialization globally, and his work has received international recognition through several noteworthy awards and fellowships that he has obtained.

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31 Soil Textures and Urban Heat
Cooling Planning Strategies

Can Trong Nguyen, Tomasz Noszczyk, and Sanwit Iabchoon

31.1 INTRODUCTION

Compared to the past few decades, global urbanization has occurred rapidly and agglomerated over 50% of the population in only a small proportion of urban areas. High population density, compact urban infrastructures, and numerous anthropogenic activities cause different environmental challenges in cities around the world, such as air pollution hotspots (Goyal, Gulia, and Goyal 2021), unplanned urban sprawl (Lityński 2021), light pollution zones (Karpińska and Kunz 2022), urban flooding (Kashyap and Mahanta 2018), and urban heat islands (UHI). The last phenomenon, urban heat islands, is a concerning issue, as it is closely linked to climate change and global warming, which is supposed to be exacerbated in the future (Nguyen et al. 2023). Higher temperatures pose many problems and risks to the environment and human well-being (Arifwidodo and Chandrasiri 2020; Nguyen and Chidthaisong 2023). The impacts on environmental degradation, health risks, and economic burdens for residential energy consumption and health care are widely acknowledged and convinced (Nguyen, Nguyen, and Sakti 2024; Li et al. 2018; Santamouris 2020; Nguyen, Diep, and Diem 2021).

UHI describes the differences in temperatures between urban areas compared to the surrounding rural regions. It is formed from the resonance impacts of local climate, natural topography, anthropogenic inputs, urban morphology, and the most important element of changing surface characteristics (Diem et al. 2024). More impermeable surfaces and materials that absorb and accumulate heat more readily in urban areas alter solar radiation interactions compared to usual surfaces (Diem et al. 2023). Also, CO_2 emissions in urban areas are much higher than those in rural areas, which, therefore, absorbs the heat and enhances urban temperature. Ultimately, it substantially exacerbates the UHI effects in urban areas.

31.1.1 Geological Characteristics and Urban Planning

Although urban areas are sealed by impervious surfaces, e.g., buildings, roads, pavements, and parking lots, geological characteristics can significantly affect urban planning in several ways. Geological hazards (e.g., earthquakes, landslides, sinkholes, and soil liquefaction) can be the most concerning problem that possibly damages urban estates and affects urban planners' determination of suitable locations for infrastructure development and emergency preparedness plans (Poyiadji, Kontogianni, and Nikolaou 2017). Current remote sensing technology with a variety of satellite missions has been providing effective support for urban environmental monitoring and urban planning (Table 31.1) (Wellmann et al. 2020).

Terrain and soil stability can affect the foundations of buildings and infrastructures that determine the load-bearing capacity and the longevity of construction. Beyond these direct relationships, geological characteristics of the ground under urban areas also influence urban thermal environments.

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TABLE 31.1
Typical satellite missions applied to urban planning

Satellite	Launched	Resolution	Applications
Landsat	TM: 1982 – 2013 ETM: 1999 – 2022 OLI/TIRS: 2013 OLI2/TIRS2: 2021	Optical: 30 m Thermal: 60/100 m	Optical: Land use classification, urban change detection, urban green space mapping. Thermal: land surface temperature, urban heat islands.
MODIS	Terra: 1999 Aqua: 2002	250/500/1000 m	Optical: urban land cover changes, air quality monitoring, Thermal: Urban heat, land surface temperature, drought.
Sentinel-2	S2A: 2015 S2B: 2017	10/20/60 m	Land use classification, urban and impervious surface mapping, green space management, urban local climate mapping.
Sentinel-1 (radar)	S1A: 2014 S1B: 2016 – 2021	5/10/20 m	Urban growth, land subsidence, earthquakes, flood, building height.

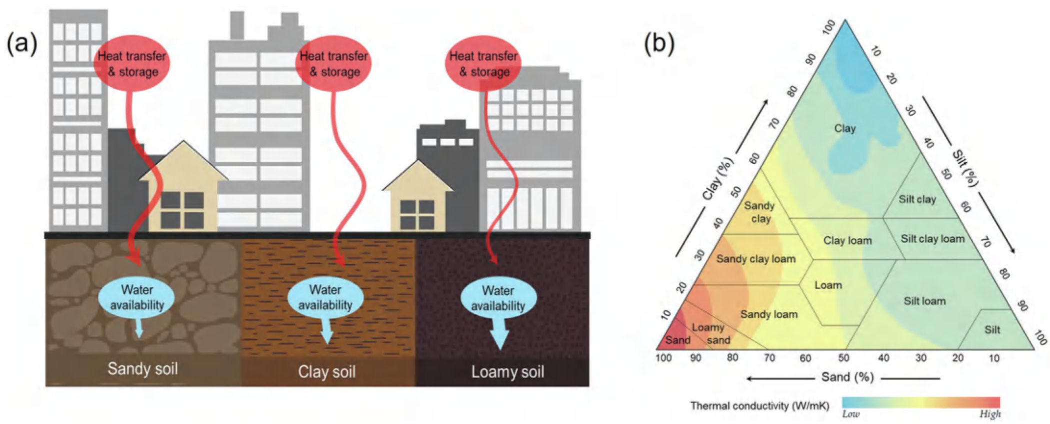

FIGURE 31.1 (a) The conceptual framework describes interactions between soil textures and heat in urban areas (authors' sketch), and (b) thermal conductivity of different soil textures.

It is relatively apparent in peri-urban and more rural areas for urban green spaces (Stumpe et al. 2023). Soil properties contribute to cooling effects through soil-to-plant processes. More specifically, the soil properties of water-holding capacity, hydraulic conductivity, capillary rise, and groundwater availability explain different land surface temperatures (LST) in urban green space types. The coarser grains have a lower water-holding capacity and higher thermal conductivity (Figure 31.1a), therefore, it has higher LST. In contrast, the water availability in the finer grain soils is higher, which supports the cooling effects through vegetation respiration and even evaporation through soil surfaces (Stumpe et al. 2023). According to the United States Department of Agriculture (USDA), soil textures can be defined using the triangle chart based on its composition of sand, clay, and silt (Figure 31.1b). They have distinct thermal characteristics depending on the grain size (Bertermann et al. 2018). Soil textures were included in climate models to investigate urban thermal environments. Their contributions, however, are in mesoscale (Saito et al. 2014; Göndöcs et al. 2017). The differences in soil texture beneath are expected to indirectly influence how heat is transferred through the ground and accumulates in urban structures, thus regulating urban thermal environments.

31.1.2 Eastern Economic Corridor (EEC)

The Eastern Economic Corridor is a special economic zone of Thailand located exactly adjacent to the east side of Bangkok's metropolis. It covers approximately 13,300 square kilometers and includes three key provinces: Chachoengsao, Chonburi, and Rayong (Figure 31.2). This region is characterized by a tropical monsoon climate with hot and dry summer months that last from October to April, yearly when the highest temperature can reach 40 °C (Aman et al. 2019; Promping and Tingsanchali 2021). The terrain is relatively flat in the northwest and higher in the east. It is especially divided in the northeast-southwest direction by a series of high mountains and hills interspersed with small coastal plains. These terrain characteristics limit the influences of the southwest monsoon and amplify the impacts of the northeast monsoon, which ultimately causes severe drought and water deficit in the hinterland areas.

The northwest plain is occupied by clay and clay loam soils, approximately 20.6% (Table 31.2). The fertile soil (silt loam and loam), beneficial to agriculture, only accounts for a small proportion of the total soil types (2.4%). Meanwhile, most of the area is sandy loam (49.8%) and loamy sand (7.6%) with disadvantages in water retention for cultivation (Figure 31.2). The remaining portion is mixed texture soil with gravel and other textures that are not revealed in the soil inventories of the Thailand Land Development Department (LDD) in cities and remote mountains.

The main strategy involves connecting the EEC to the Greater Bangkok region, which will serve as satellite city chains to support the capital in terms of agricultural production, industry, and tourism (Can, Diep, and Iabchoon 2021). This is an ambitious strategy to stimulate the country's economy through high-value-added industries, e.g., automotive industries, electronics, robotics, aviation and logistics, biofuels and biochemicals, digital technologies, and medical hubs (Bhrammanachote 2019; Niyomsilp, Worapongpat, and Bunchapattanasakda 2020). Although the EEC was just

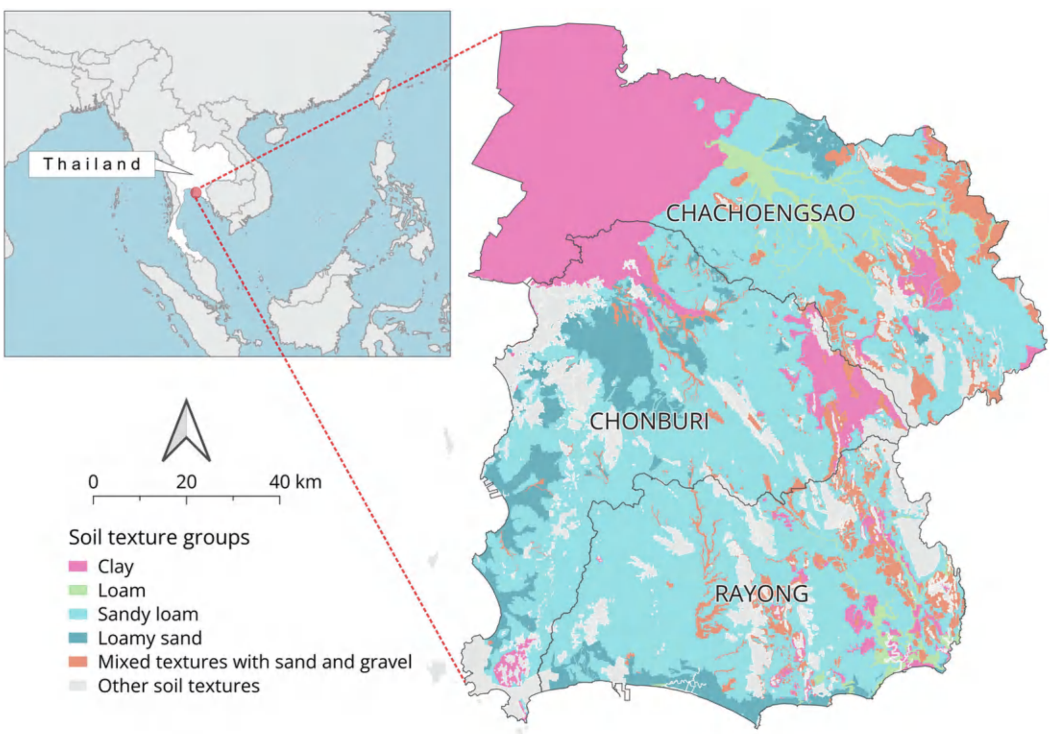

FIGURE 31.2 Three eastern provinces of Thailand and soil texture group distribution map.

TABLE 31.2
Distribution of major soil texture groups in the EEC and corresponding proportion

Soil texture	Area (km^2)	Proportion (%)
Clay	2,743	20.6
Loam	326	2.4
Sandy loam	6,636	49.8
Mixed textures	1,036	7.8
Others	1,577	11.8
Loamy sand	1,006	7.6

announced in 2016 and officially launched in 2017 under the 12th National Economic and Social Development Plan (2017–2021), this regional development has a long development foundation from the 1980s well-known as the Eastern Seaboard Development Program (ESB) (Tontisirin and Anantsuksomsri 2021). EEC is to revitalize the ESB, which was not extended after the first phase. EEC has attracted international and private investments in export-oriented products and heavy industry (Ngampramuan and Piboonsate 2021). Therefore, it significantly improves regional development in the general economy and reduces poverty (Hutasavi and Chen 2022). For example, the regional gross domestic product (GDP) and income have increased drastically since the 20th century and exceeded Bangkok's GDP in 2006 (Ngampramuan and Piboonsate 2021).

Rapid development in the EEC is closely related to dynamic changes in land use/land cover and urban expansion for massive transportation and infrastructure systems, industrial estates, and coastal cities (Boonyanam and Bejranonda 2021; Boonyanam and Somskaow Bejranonda 2022). This urban agglomeration, along with the natural characteristics of the terrain and climate, aggravates environmental and pollution problems, especially in the already harsh thermal environments in the area (Nguyen et al. 2023; Soytong et al. 2017).

This chapter was driven by the goal of finding possible relationships between soil textures and the urban thermal environment. How is this effect significant when the ground is almost sealed by impervious surfaces? It also simulated the inclusion of soil textures in future urban planning to explore its final impacts on urban temperatures. Taking the Eastern Economic Corridor region as a case study with rapid urban development and diverse soil textures, this chapter is expected to provide more evidence of the impacts of soil texture characteristics on urban thermal environments, considering limited research in this field.

31.2 DATA AND METHODOLOGY

This chapter engaged an integrated framework, which takes advantage of diverse satellite images, geospatial datasets, and methods to investigate the disparities in LST of urban features on different soil textures (Figure 31.3). Landsat surface reflectance was the primary dataset for acquiring LULC maps, urban impervious surfaces, and LST data at 30-meter resolution. A single Landsat-8 scene (27/02/2023) was acquired based on its minimum cloud cover ratio to explore the attributes of LST in different soil textures and limit inconsistencies caused by different image paths covering the study area. Two composite images covering the entire study area were also acquired from Google Earth Engine using median composite in 2010 (Landsat-5) and 2020 (Landsat-8) for the second objective of examining the effectiveness of soil texture in urban planning.

The satellite images were delineated by deep learning classification, which applies the Convolutional Neural Networks (CNN1D) model to classify LULC maps in 2023 (a specific year

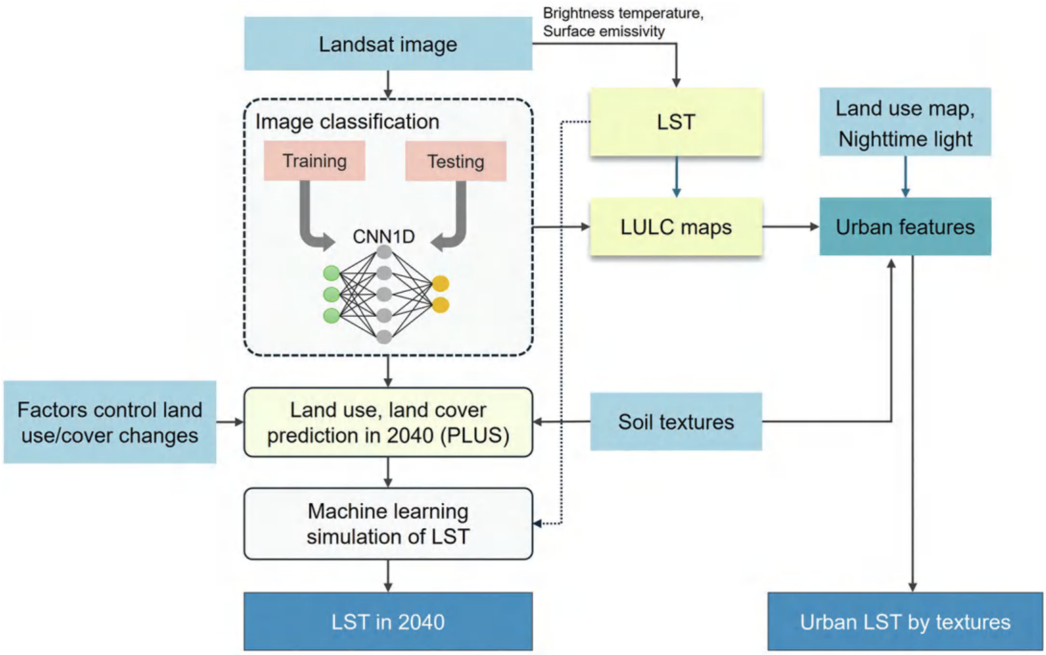

FIGURE 31.3 Datasets and overall methodology used in the research.

for LST comparison), 2010, and 2020 (Iqbal, Nurda, and Bryan 2024). To analyze the LST in soil textures, the urban features of the LULC map were combined with nighttime light data and the land use map to extract only consistent and representative urban features.

The LST data was retrieved from the thermal band of Landsat images using a conventional method, which calibrated the brightness temperature by vegetation index-based emissivity (Nguyen et al. 2022; Ermida et al. 2020).

To further study the significant effect of applying soil textures in urban planning to alleviate the urban thermal environment, this chapter also compared the future LST (2040) under the “business as usual” (BAU) and the alleviation scenario, which applies soil texture as a constraint element to limit urban development in areas supposed to aggravate the urban thermal environment. A set of potential elements (14 variables) expected to dominate the LULC change in the EEC was considered along with the LULC maps in 2010 and 2020 by the Patch-Generating Land Use Simulation (PLUS) model (Liang et al. 2021). These variables comprise various aspects of the development from nature to socioeconomic perspectives, i.e., elevation (DEM), slope, maximum and minimum temperature, precipitation, population density, gross domestic product (GDP), distance to urban areas, industrial estates, roads, towns, water bodies/lakes, coastline, and travel time (Nguyen et al. 2023).

The simulated LULC maps in 2040 were subsequently adopted to predict the corresponding LST maps for different scenarios by applying a machine learning-based model of random forest regression, which was trained by the LST data in 2020 on air temperature and the proportion of LULC categories. The LST maps were then compared together to verify the effectiveness of soil textures in urban heat alleviation.

31.3 EXTRACTION OF URBAN FEATURES

To examine the thermal characteristics of urban features on different soil textures, this study used an integrated approach to extract consistent and representative urban features. Indeed, urban land

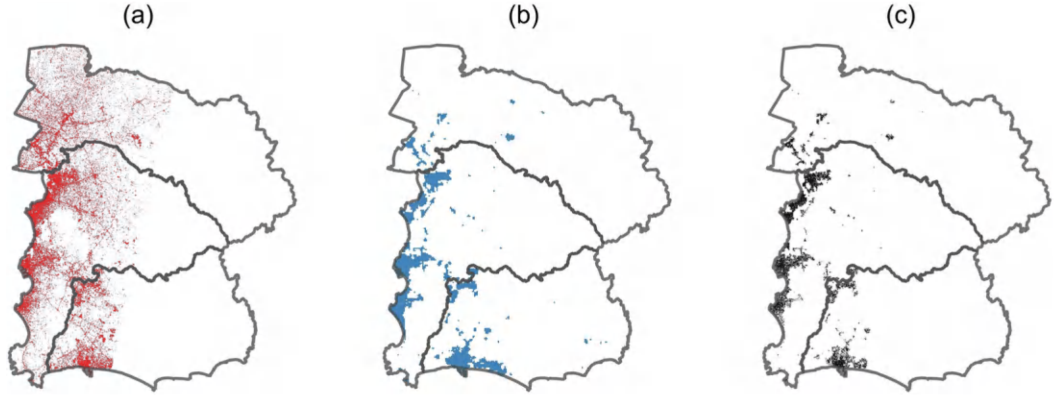

FIGURE 31.4 Urban feature extraction using a combination of geospatial datasets, (a) urban features from deep learning classification from Landsat-8 image, (b) high-development area with NTL>15, (c) consistent urban features after combining with NTL and land use maps.

use or land cover can be extracted from current land use maps and satellite images. Land use maps emphasize land use purposes with surfaces that may not be impervious (e.g., household gardens and playgrounds). Similarly, satellite images reflect only impervious surfaces, which can include a broad category, such as buildings, roads, and factories. Roads significantly absorb solar radiation, while factories release a huge amount of anthropogenic heat through energy combustion. Including these urban features can lead to an overestimation of the impact of soil textures on the urban thermal environment.

It first applied deep learning classification of the CNN1D model to discriminate the Landsat-8 surface reflectance scene into land use subclasses including cropland, forest, plantation, urban features, and water bodies (Iqbal, Nurda, and Bryan 2024). The overall accuracy of the classification is approximately 95%, and the urban classes reach 97% agreement. Less developed areas with lower urban density and urban agglomeration were eliminated using nighttime light (NTL) data. A proxy of high-development areas (NTL>15) focused only on regions of higher development. Subsequently, urban features on land use maps (i.e., city, town, village, and other buildings) were used to mask transportation systems and industrial estates out of residential urban surfaces.

The image classification within the scene recorded approximately 12,555 hectares of urban features (Figure 31.4a), which are mostly distributed along the coastal areas in the west and south of the region. After combining NTL data and land use maps, the consistent urban area is approximately 4,022 hectares (Figure 31.4c), comprising three categories according to land use purposes. Cities and towns are characterized by dense urban fabric with extensive infrastructures. Village refers to settlements typically found in suburban and rural areas that are frequently smaller and low in agglomeration. Other built-up features are other impervious surfaces that do not fit the typical definitions of cities and villages, e.g., mixed-use developments and commercial areas.

31.4 ASSOCIATION BETWEEN SOIL TEXTURES AND LST INTENSITY

The extracted urban areas (Figure 31.4c) are distributed on four primary soil textures: loam, clay, sandy soils, and mixed texture. Sandy soils include sandy loam and loamy sand, with a high proportion of coarse sandy grains in their textures. The mixed texture comprises more than three soil textures (e.g., sandy-clay-loam) and gravels in different proportions.

The average land surface temperature (LST) of different urban features by four soil textures proved the control of subsurface urban characteristics on urban surface temperature (Table 31.3).

TABLE 31.3
Mean and standard deviation of LST grouped by soil textures and urban categories (unit: °C)

Textures	City, town	Village	Others	Urban features
Clay	36.8 ± 1.17	36.2 ± 1.55	36.9 ± 1.37	36.5 ± 1.42
Loam	35.5 ± 0.947	36.4 ± 0.544	-	35.5 ± 0.951
Sandy	39.5 ± 1.86	39.2 ± 1.79	38.4 ± 1.78	39.3 ± 1.84
Mixed textures	39.4 ± 1.32	39.0 ± 1.20	38.3 ± 1.35	39.2 ± 1.29

More explicitly, urban features in loamy soil have the lowest LST with a relatively high uniformity (35.5 ± 0.951 °C). The disparity between urban features on loamy soil remains below 1°C, while it is highest for sandy soil, always higher than 1.7 °C. It is followed by urban features on clay soil, which have an average LST of about 36.5 °C. The most torrid urban thermal environment was found in sandy soil. These areas experience an average of 39.3 °C, and the highest temperature reaches 49.1 °C compared to only 37.5 °C on loamy soil. The mixed textures have high average temperatures (39.2 °C) and are insignificantly different from sandy soils because their main composition is also sandy soils mixed with gravel.

The general mechanism of soil texture on LST of urban features is relatively similar compared to the overall impacts, being higher for mixed and sandy textures and lower for clay and loamy soils. Specifically, dense cities and towns always have a higher LST than villages and other built-up areas except for loamy soil, which holds its higher value for villages (36.4 °C). Meanwhile, other built-up areas also have comparable LST against cities and towns regardless of soil textures.

Control of soil textures on surface temperatures was revealed over general consideration and specific urban categories, which can eliminate potential resonance impacts from urban compactness and agglomeration. Although urban surfaces are typically sealed by constructions and impervious surfaces, they are greatly influenced by the beneath characteristics of soil layers. Soil properties (e.g., air-filled porosity, water content, bulk density, and texture) regulate the way solar radiation is transferred and accumulated inside urban surfaces. Sandy soil has coarse grains with the lowest water content and high thermal conductivity, which therefore stimulates the urban surface temperature (Bertermann et al. 2018). On the contrary, the finer grain of clay soil constitutes a higher water content and a lower thermal conductivity. It leads to the lower surface temperature of urban features in these soil textures. Loamy soil has lower water content due to its coarse grain, leading to water loss. However, its surrounding environment is humid due to high water availability in the soil. This amount of water can prevent a thermal transfer by decreasing the surrounding thermal conductivity. Therefore, the surface temperature of urban features is lower than clay soils, although their thermal conductivity is typically high.

31.5 MAINSTREAMING SOIL TEXTURE INTO URBAN PLANNING

The application of surface temperature similarities across different soil textures in urban planning is expected to diminish urban torridness because of synergistic effects. A case study was conducted to mainstream soil textures for urban planning and to investigate the impact of this effort on urban thermal reduction. Land use and land cover maps in 2010 and 2020 were acquired using a similar method to extract urban features using CNN1D deep learning, which achieved approximately 96% overall accuracy. The LULC subclasses were grouped into five primary categories: cropland, forest, plantation, urban features, and water bodies (Figure 31.5). The region had approximately 98,098 hectares of urban areas in 2010 (7.38%), which subsequently expanded to 131,440 hectares in 2020

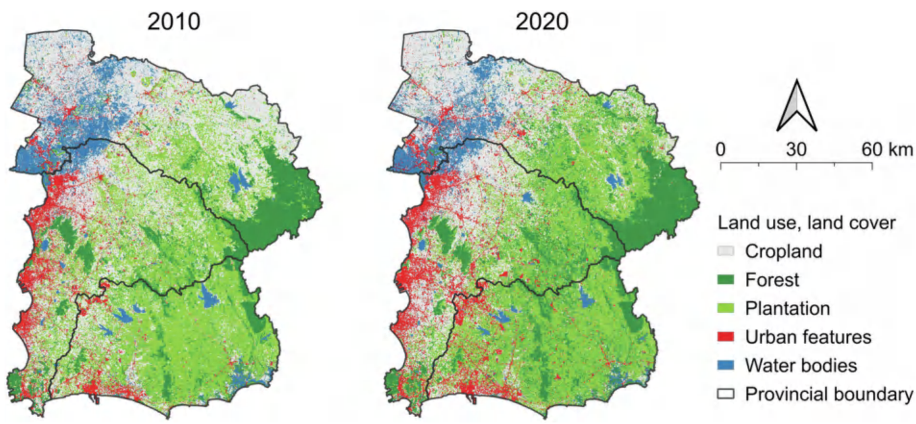

FIGURE 31.5 Land use, land cover maps in 2010 and 2020 interpretation from Landsat images and CNN1D deep learning.

in the western coastal plains. More specifically, urban areas increased by 33.56% compared to urban areas in 2010 to represent 9.88% of total area in 2020.

The 2010 map and a set of potential factors (14 factors) were used to simulate the 2020 map of LULC using a combined approach of Markov chain and Cellular Automata (CA) in the PLUS model (Liang et al. 2021). The maps of land cover change between two periods were combined with controlling factors to generate the potential maps for each land cover class. The CA model allocates each land use class at the target time based on land demand and potential maps. The simulated map in 2020 was compared to the original map, which has a relatively high agreement level, at a Kappa coefficient of 0.827 and an accuracy of 87.16%. Similarly, this model was applied to predict the changes in land use over a relatively long-term period in 2040 to emphasize urban changes. It is estimated that cropland will be narrowed down to 364 thousand hectares, losing 58 thousand hectares. Meanwhile, there will be an additional 17,479 hectares of urban land under the "business as usual" context, which will increase by 13.3% and raise the overall proportion of urban land to 11.2%.

Besides 14 controlling variables in the usual model, soil texture characteristics were included to constrain urban expansion, with the overarching goal of minimizing urban surface temperatures by considering soil textures in urban planning. The soil textures were quantified by nominal scores, implying the priority of urban development to alleviate surface temperatures. In particular, the priority gradually decreases from silt loam to clay loam, clay, mixed textures, sandy loam, and loamy sand.

It revealed that including soil textures in urban planning extensively affects urban land allocation in 2040 (Figure 31.6). More explicitly, urban expansion in coastal areas near the cities and towns that already exist in 2020 will be constrained compared to the BAU scenario. It will be reduced by 731 hectares in the coastal districts. Meanwhile, urban expansion will be strongly encouraged in the hinterland and northwest areas.

The effectiveness of this alleviation scenario in urban development with the contribution of soil textures was evaluated by an urban surface temperature comparison. A conventional random forest regression model was developed to simulate the LST of air temperature and the proportion of the five types of LULC. The model can simulate LST with a high level of acceptance, which is about 82.25% (Figure 31.7a). It was then adopted to predict LST in 2040 under two scenarios and differences in land use proportion. It revealed that the alleviation scenario including soil texture would significantly release the torridness of the urban thermal environment, especially in the coastal city chain (Figure 31.7b). For example, applying this strategy can reduce the surface temperature by

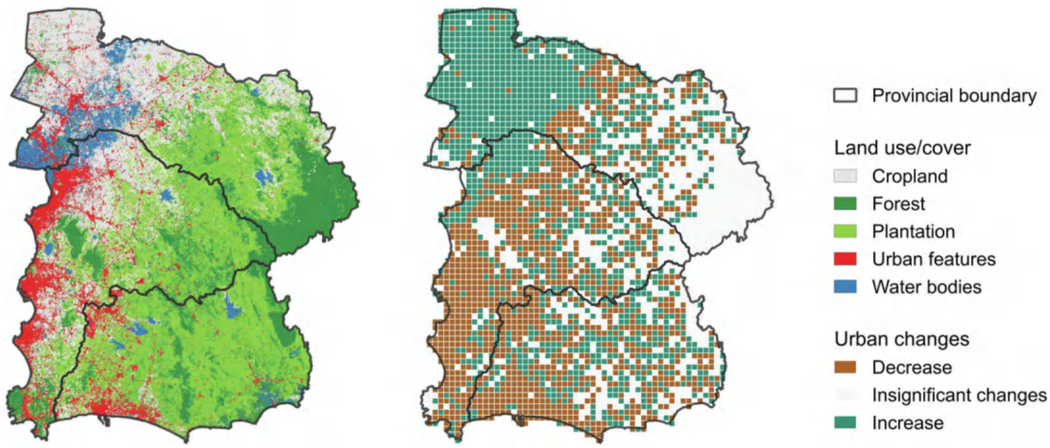

FIGURE 31.6 Predicted LULC map in 2040 under the LST alleviation scenario by considering soil textures in urban planning (left panel) and urban area changes compared to the BAU scenario (right panel).

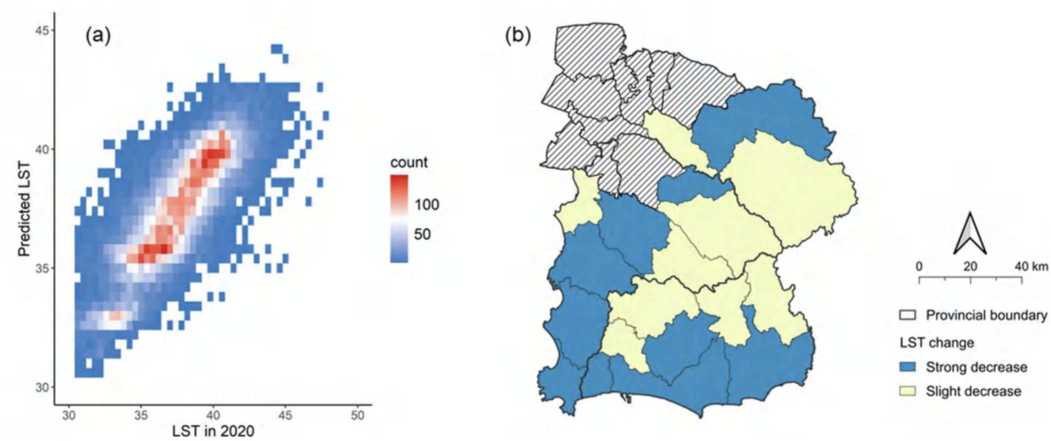

FIGURE 31.7 Surface temperature simulation, (a) density plot shows the relationship between LST and simulated LST (unit: °C), and (b) differences between simulated LST in 2040 under the alleviation and BAU scenarios.

0.5 to 0.75 °C on average, with a maximum temperature reduction of 2.5 to 3.7 °C compared to the usual development.

31.6 SOIL TEXTURES CONTROLLING URBAN SURFACE TEMPERATURE AND PLANNING IMPLICATIONS

Soil properties and textures are supposed to influence the surface cooling effect directly or indirectly through evaporation and water availability. It better explains the cooling mechanisms for green spaces on different soil properties (Stumpe et al. 2023). These characteristics dominate the cooling effects through surface processes and vegetation living activities. These processes are minimal in urban areas with mainly sealed surfaces, where the water cycle is typically limited by impervious surfaces. However, the dominance of disparate soil textures in urban surface temperatures was consistent with those indicated by Domroese (2017). It may be closely associated with the availability of water and the thermal conductivity that regulates thermal transmission and accumulation on urban surfaces. It supports Domroese (2017) that sandy soils and mixed soils (mostly sandy with clay and gravel) have the highest surface temperature because they have a high thermal conductivity (Abu-Hamdeh 2003). The thermal conduction and heat accumulation of the surfaces above them will also be maximized. In addition, the low water availability in sandy soils helps to increase the temperatures of urban features in these textures. Clay soils have a higher water content, about 40–50% due to finer grains, along with a low thermal conductivity that reduces the surface temperatures of urban features above this soil (Weil and Brady 2017). Although the water content of loamy soil is lower than clay soil, it should be noted that this chapter considered sealed urban areas with limited evaporation through the surface. Therefore, the water availability in loamy soil may be higher than in clay soil because the finer grains hold water in their pores instead of the form. Temperature is more related to the water in the soil, which constrains the thermal conductivity. Another coincidence of soil textures and terrain may also facilitate a high and near-surface level of underground water in loam and clay soils. Clay and loamy soils are frequently distributed in low plains with shallow groundwater depth (<5 m), while the water table of sandy soil is deeper than 5 meters (Stumpe et al. 2023). However, loamy soil is highly fertile and is prioritized for agriculture rather than for urban development. Its proportion is also low compared to other textures (see Table 31.1). Therefore, the temperature magnitude of loamy soil may be less uncertain because these urban points are insignificantly representative of this soil type against others. Surface temperatures in loamy soil need to be studied more specifically to reach a more confident conclusion. The impact of soil textures is supposed to be indirect; however, the accumulative effect may be significant and higher than the daily individual. The temperature differences between textures during the drought period after a long series of hot days and nocturnal comparisons could be interesting targets to further explore.

In more than half of the study area, sandy soil predominates, presenting a challenge to convincingly incorporate soil texture into future urban simulations. However, it revealed that applying texture in urban development constraints could reduce the surface temperature by 0.5–0.75 °C on average. It is useful for urban heat mitigation, especially in coastal areas that are already populous and compact. Simultaneously, consideration of soil texture takes the textures into account to avoid potential torridness and encourages leapfrog urban sprawl, which is suitable for urban heat mitigation strategies (Nguyen et al. 2022; Nguyen et al. 2023). Urban development in clay and loamy soils not only reduces surface temperatures but also facilitates the development of urban green spaces compared to sandy soils. More fertile soil with high water availability is advantageous for vegetation growth and increased cooling efficiency at low costs for watering and management. However, it may confront possible trade-offs when deciding to construct a residential area on loamy and clay soils instead of sandy soils. For instance, construction in clay and loamy soils can be pricey because of the high cost of foundation construction.

31.7 CONCLUSION

This chapter investigated the surface temperature of urban features in different soil textures. It found that surface temperature gradually decreases from sandy and mixed soils to clay and loamy soils. Urban surfaces are often sealed, and cooling effects through surfaces (e.g., evaporation and soil-to-plant interaction) are limited. The beneath characteristics of the urban surfaces can indirectly control the way and proportion in which heat is conducted through the surfaces. The overall mechanism is primarily dominated by thermal conductivity and water availability. The coarser grains have a higher thermal conductivity and lower water availability, which facilitates heat transfer and accumulation.

Applying soil texture in urban planning to constrain urban development in sandy soils showed differences in urban allocation compared to the usual scenario. Urban expansion in the coastal city chain was restricted and shifted toward the northwest areas. Therefore, the surface temperature in this region will decrease significantly by 0.5–0.75 °C on average. It revealed the critical basis of urban temperatures in disparate soil textures that are useful for urban planning to mitigate urban heat islands. An integrated strategy that combines soil textures with urban allocation and green infrastructures may have a more significant cooling effect than individual interventions.

The interconnectedness of urban thermal environments and geophysics poses both opportunities and challenges for urban planners and geophysicists to work closely together to effectively study urban problems. More explicitly, the integrated approaches using remote sensing can promote a better understanding of geological and geophysical characteristics in urban areas, such as soil investigation by ground-penetrating radars, 3D LiDAR for building reconstruction and urban morphology, groundwater tables, and urban subsidence using Synthetic Aperture Radar Interferometry (InSAR) technique. These promote sustainable development and resilience of cities in the face of increasingly diverse problems.

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