JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Python-Based Mapping of Urban Heat Island Expansion: A Machine Learning Approach for Time Series and Spatial Gradient Analysis in Aurangabad (Maharashtra, India)

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***Abstract*—** The Urban Heat Island (UHI) effect, intensified by rapid urbanization and unplanned growth, presents significant challenges for sustainability and climate resilience in Indian cities. This study, conducted as part of an M.Tech. student's final year project, focuses on a 30-year analysis of UHI expansion in Aurangabad, Maharashtra (India), leveraging machine learning and Python-based geospatial tools. Landsat satellite images spanning three decades provide the land surface temperature data essential for detecting urban heat patterns. By employing shapefiles, we delineate precise boundaries within Aurangabad, enabling targeted analysis of temperature distributions within specific areas. Satellite-specific conversion formulas transform digital values to Celsius, providing accurate temperature readings across the dataset.

A Tkinter-based graphical user interface (GUI) enables intuitive interaction with the tool, supporting data processing, visualization, and user navigation. Key features include options for loading data, selecting shapefiles, generating Excel temperature reports, and a weather display for historical and current climate information relevant to UHI analysis. Core functions allow users to initiate data processing, perform comparative temperature analysis between locations, and visualize temperature trends across multiple regions in Aurangabad. An image slideshow offers a temporal view of spatial temperature shifts, with a gradient color map to clearly depict heat patterns, where blues represent cooler areas and reds indicate warmer zones. Temperature data can also be exported to Excel, facilitating further analysis or information sharing.

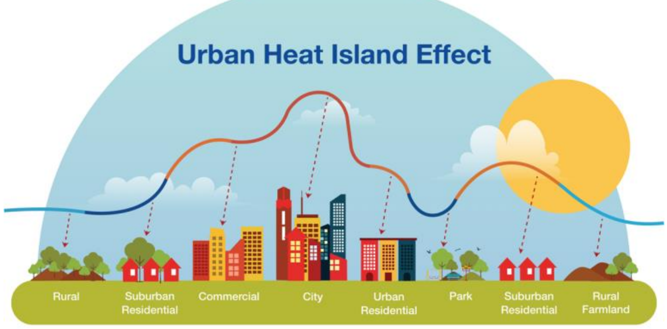
Looking forward, this project incorporates machine learning models to predict UHI trends, detect anomalies, and automate regional classifications based on temperature patterns. Potential predictive models could analyze time series data for forecasting, while convolutional neural networks (CNNs) may aid in identifying UHI expansion areas through spatial pattern recognition. This toolkit, combining a user-friendly GUI, robust data processing, & machine learning capabilities, provides a valuable resource for researchers & urban planners dedicated to addressing the pressing issue of urban heat.

I. Introduction

The conventional expansion of urban centers may inadvertently elevate temperatures due to human activities. In India, rapid urbanization faces challenges from climate change induced by sprawling cities and unplanned growth. This expansion diminishes green spaces, amplifying emissions and reducing cooling capacity, leading to Urban Heat Island (UHI) effects.

In addition to changing the local aerodynamics, radioactivity, thermal properties, and moisture, artificial building materials also affect the local radioactivity. The manner in which these alterations cause a change in the energy & water balance regimes is not fully understood [1], [2].

The urban heat island (UHI) effect describes the temperature difference between urban and rural areas. This is a direct consequence of the alterations in the surface energy balance (SEB) of the area [3]. Depending on the type of temperature and the observational methods, different types of UHIs are defined. In contrast to UHI, which is commonly used to describe differences in urban and rural temperatures, it is better to refer to near-surface air temperatures. It is more suitable to discuss the differences between rural and urban land surface temperature (LST) under the concept of "surface UHI", which was proposed by Voogt and Oke [4].



A country-based analysis underscores China as the most extensively studied country in SUHI (Surface Urban Heat Island) research, with 213 studies, followed by the United States (106) and India (38). Rapid urbanization has caused significant land use changes in metropolitan cities:

- In the last forty years, Delhi's urban area increased by 30.6%, while agriculture and dense forest areas decreased by 22.8% and 5.3%, respectively.

- Mumbai has undergone substantial paving and concretization in the span of 40 years.
- Kolkata witnessed a reduction in vegetation area from 33.6% to 7.4% between 1980 and 2010.
- Chennai's urban built-up area tripled between 1991 and 2016, accompanied by a 12% reduction in vegetation area.

Clearly, urban heat island (UHI) is present in India cities, requiring research to understand its causes and the formulation of the mitigation policies.If urban heat island (UHI) effects continue to rise, several consequences may occur, impacting both the environment and human populations:

a. Health Risks: Increased heat leads to heat-related illnesses, especially among vulnerable groups.
b. Energy Demand: Higher temperatures raise the need for air conditioning, increasing energy consumption and emissions.
c. Air Quality: UHI exacerbates air pollution, impacting respiratory health.
d. Water Management: Altered precipitation patterns and increased evaporation complicate water management.
e. Ecological Impacts: UHI disrupts local ecosystems and biodiversity.
f. Social and Economic Disparities: Vulnerable communities suffer disproportionately from UHI effects.
g. Infrastructure Stress: Higher temperatures accelerate infrastructure deterioration.

Overall, rising UHI effects pose significant challenges for urban resilience, public health, environmental sustainability, and social equity. Addressing UHI mitigation and adaptation strategies is crucial for building more resilient and liveable cities in the face of climate change.

II. Literature Review:

With rapid urbanization,Urban Heat Islands (UHIs) have become a critical concern, necessitating comprehensive studies to understand their spatiotemporal dynamics. [5] This research delves into the extensive analysis of UHI changes across 369 cities in China from 2005 to 2020. The focus extends to 48 representative cities, providing nuanced insights into the development patterns of both new and pre-existing UHIs in response to urban expansion.

The significance of this study lies in its ability to discern contrasting UHI development trajectories. While long-urbanized regions exhibit relatively minor changes, areas undergoing urbanization represent hotspots for rapid UHI growth. The research emphasizes the pivotal role of urban planning in mitigating UHI effects, urging policymakers to consider potential UHI impacts during the planning of new urban construction land.

Review: Following examinations observed in the method: [5]

- A majority of the datasets were created using Google Earth Engine (GEE) and land use data was sourced from the European Space Agency (ESA), both requiring licenses.
- The extracted land surface temperature (LST) data from the moderate resolution imaging spectroradiometer (MODIS) which available on demand.
- For the raster calculator tool and spatial gradients of UHII uses licensed ArcGIS (Aeronautical Reconnaissance Coverage Geographic Information System) platform

***Scope for implementation**:*

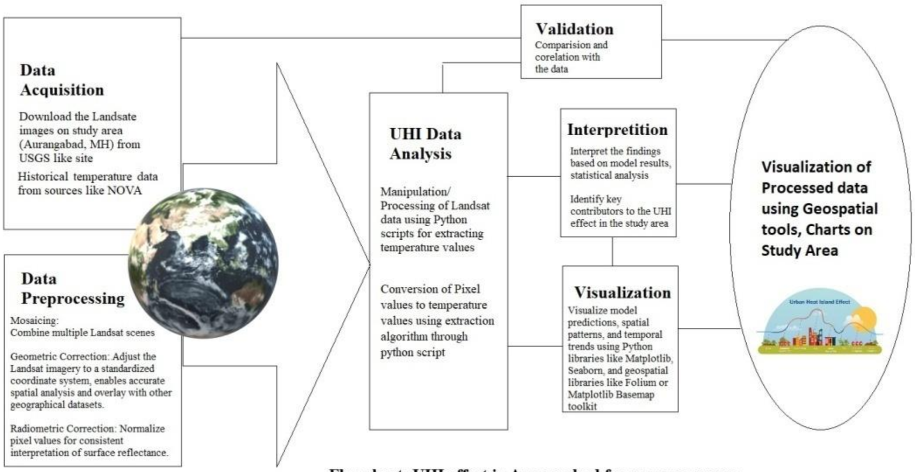
*T*he urgency of addressing UHI's adverse impacts in Aurangabad (MH India) , utilizing a Python module for analysis involving spatial gradient, time series, machine learning, and remote sensing images. A Python language can be used very efficiently for processing big data sets since it is fast, automated, and can utilize machine learning concepts.For acquisition of LST and satellite imagery of Earth, Landsat is used because it is free, oldest among them, easily accessible on USGS (United States Geological Survey) and has global coverage.

III. Study Area

Aurangabad [8], renowned for its rich tapestry of history and industrial prowess, occupies a unique geographical niche characterized by three distinct seasons: winter, summer, and rainy. Its ancient monuments, including the UNESCO World Heritage Sites of the Ajanta and Ellora Caves, draw visitors from far and wide, particularly during the balmy summer months when the city's cultural vibrancy is at its peak. However, Aurangabad's ascent as an industrial hub, coupled with the specter of climate change, has cast a shadow over its picturesque landscape.

In recent years, Aurangabad has found itself grappling with a formidable adversary: rising temperatures exacerbated by urbanization and industrialization. The city's industrial corridors, which once symbolized progress and prosperity, now contribute to the urban heat island effect, where vast expanses of concrete and asphalt absorb and radiate heat, resulting in localized temperature spikes. As temperatures soar, residents face a slew of challenges, from increased energy demands and compromised air quality to heightened health risks.As Aurangabad strides towards modernity, propelled by industrial growth and urbanization, its once idyllic landscape is undergoing a metamorphosis. Urban areas experience significantly higher temperatures than rural areas, a phenomenon known as the urban heat island effect. Modern cities are pulsating with vitality, but this vitality also fuels the urban heat island effect. With concrete jungles replacing verdant landscapes and heat-absorbing surfaces dominating the urban fabric, Aurangabad finds itself ensnared in a cycle of rising temperatures and escalating challenges.

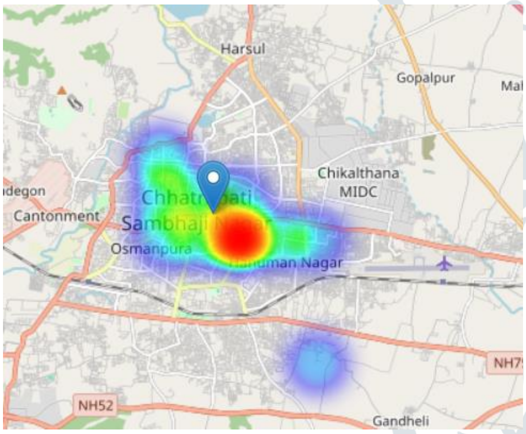
In India, while the focus of environmentalists and researchers often gravitates towards major metropolitan cities in the study of urban heat islands, Aurangabad emerges as a beacon of opportunity.Providing a unique insight into the UHI phenomenon in a city of historical and industrial significance, this study fills a critical knowledge gap regarding urban heat islands. Through the development of basic methodologies to accurately calculate and visualize UHI expansion, this study aims to lay the groundwork for informed decision-making and effective mitigation planning. In doing so, it aspires to not only address the immediate challenges faced by Aurangabad but also to contribute valuable insights to the broader discourse on urban sustainability and climate resilience.



Flowchart: UHI effect in Aurangabad for summer season

IV. Methodology

Initially will download the Landsat satellite images of the study area covering multiple time periods from reliable sources such as the USGS Earth Explorer or NASA Earth data. These images capture various spectral bands, including thermal infrared (TIR), which is crucial for detecting surface temperatures. The historical temperature data gathered from reputable meteorological datasets like NOAA or NASA's Modern-Era Retrospective Analysis for Research and Applications (MERRA).Once we have the Landsat images, we'll use geospatial libraries like GeoPandas and Rasterio in Python to preprocess the data. GeoPandas will help us handle geospatial datasets, while Rasterio will assist in reading and manipulating raster data, such as the Landsat images.



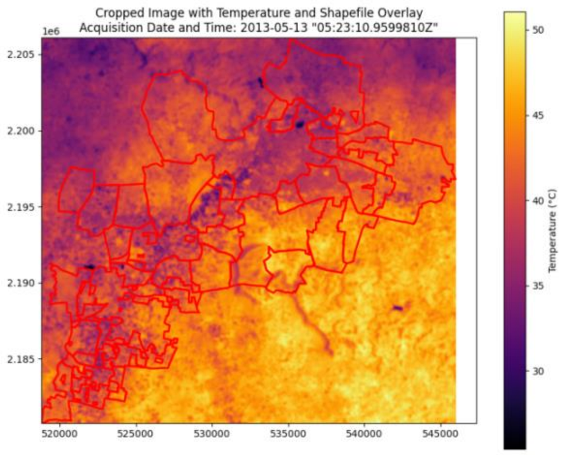
Next, we'll delve into the Python algorithm. This algorithm will work its magic on the Landsat images, converting them into numerical temperature values. These values represent temperature variations across different areas of the landscape.

Now, why is this step crucial? It is necessary to analyze temperature differences over time in order to understand the Urban Heat Island (UHI) effect. By leveraging machine learning algorithms and statistical methods, we can identify patterns and changes in temperature distribution.

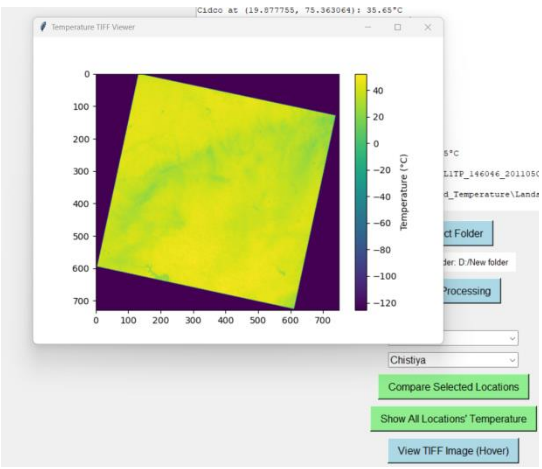
For visualization, we'll employ Python libraries like Matplotlib, Seaborn, and Folium. Matplotlib and Seaborn are excellent for creating static visualizations, while Folium is perfect for interactive maps. These tools will help us present our findings in a clear and visually appealing manner.

V. Results and Discussion

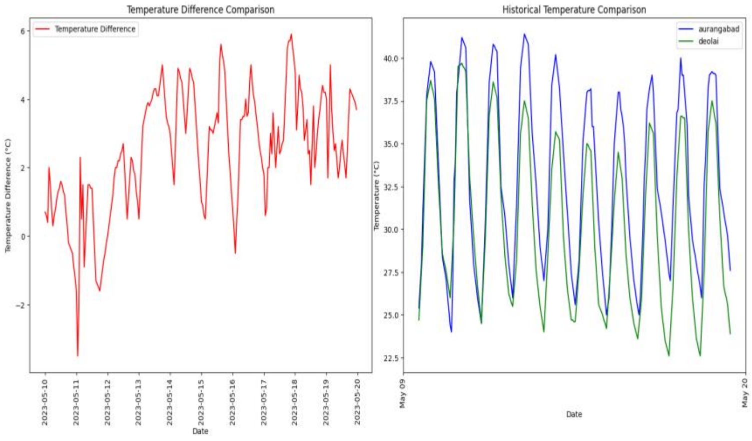
This methodology provides a comprehensive approach to UHI analysis, from preprocessing Landsat images to visualizing results and exploring advanced predictive analytics options. The combination of a user-friendly GUI, efficient data processing, and potentially machine learning makes this tool valuable for researchers and city planners tackling urban heat challenges.



- The GUI includes an image slideshow feature for visualizing spatial temperature variations over time, showing the progression of heat across the city. This visualization enhances the understanding of UHI growth in specific areas.



- Gradient Effects and Color Mapping: Each time slice is represented using a gradient color map, with cooler temperatures shown in blues and warmer temperatures in reds, making it easy to interpret heat distribution.
- Excel Export: For each location and year, the tool saves temperature data in Excel, allowing users to review historical trends, conduct additional analysis, or share data.
- The project could incorporate machine learning models to predict future UHI trends, detect anomalies, or automate region classification based on temperature patterns.



Discussion

The introduction illuminated the escalating challenges posed by rapid urbanization and climate change, emphasizing the need for research to comprehend the causes and implications of UHI effects. Furthermore, the study area description provided valuable insights into Aurangabad's unique geographical and climatic characteristics, highlighting its susceptibility to UHI phenomena amid industrial growth and urban development. Our methodology involves downloading Landsat images from the USGS Earth Explorer, preprocessing the data using GeoPandas and Rasterio, applying a Python algorithm to convert images into numerical temperature values, analyzing temperature patterns using machine learning algorithms, and visualizing the results using Python libraries like Matplotlib, Seaborn, and Folium. This comprehensive approach allows us to gain insights into the Urban Heat Island effect and its implications for urban planning.

VI. ACKNOWLEDGMENT

It is indeed with a great sense of pleasure and immense sense of gratitude that I acknowledge the help of these individuals which led to the successful completion of this paper "Visualizing Time Series and Spatial Gradient effect of Urban Heat Island Expansion in Aurangabad (MH) with Machine Learning and Python". I would like to thank our Guide Prof. Suvarna D. Pingle and Prof. Dr. M. M. Dhobe, HoD, M Tech(CSE) PES college of Engineering, Aurangabad, Maharashtra, India for their support and advices while completing this paper.

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