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Parametric Investigation of the Urban Heat Island Using the Internet of Things (IoT) in Putrajaya, Malaysia

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Keywords

Urban heat island (uhi) urban heat island intensity (uhii), internet of things (iot), sustainable metropolis, parametric analysis, urban planning

Abstract

The urban heat island (UHI) phenomenon has become a critical issue for Putrajaya, the administrative capital of Malaysia. This research experimentally investigates the UHI phenomenon in Putrajaya using the Internet of Things (IoT) and assesses the urban heat island intensity (UHII). This study investigates the effect of wind speed and rainfall on UHII. This study has chosen two strategic locations for green zone reference and residential or commercial zone reference, respectively. The major equipment used here are 81000 ultrasonic anemometer by R.M. Young for temperature and an IoT system fabricated and maintained by Enomatrix. We have installed an IoT-enabled system embedded with different sensors and equipment to record, store and analyze the data from selected strategic locations. The results of this study indicate the presence of UHI in this city and reveal that the maximum UHII is approximately 3.6 °C. Furthermore, the parametric analysis reveals that wind speed has a significant influence on UHII. Moreover, this research shows that rainfall has great potential to reduce the UHII. The findings of this study provide valuable insights into the UHI effect in Putrajaya and can be used to equip urban planning and design decisions to mitigate the UHI effect. The use of IoT and parametric analysis in this study also demonstrates the potential of these technologies to improve our understanding of urban environments and inform sustainable urban development.

1. Introduction

Urban Heat Island (UHI) is a phenomenon in which urban areas experience higher temperatures than the surrounding rural areas [1]. The UHI effect is caused by the absorption and retention of heat by urban surfaces such as buildings, roads, and pavements, which increases the surface temperature of urban areas [2]. The primary reason for the UHI effect is the modification of land surfaces due to urbanization. The buildings and other infrastructure in cities are made of materials that absorb and retain heat, such as concrete, asphalt, and metal [3]. These materials have lower albedo, which means they absorb more sunlight and emit more heat than natural surfaces such as grass and trees [4]. The UHI effect has several negative impacts on human health, energy consumption, and the environment. Higher temperatures in urban areas can cause heat stress, dehydration, and other health problems [5]. Increased energy consumption for air conditioning and cooling systems during hot weather can lead to higher electricity bills and greenhouse gas emissions. The UHI effect can also disrupt ecosystems, affect water quality, and exacerbate climate change [6]. The UHI effect is a growing concern for urban planners and policymakers worldwide. To mitigate the UHI effect, urban planners and designers can incorporate green infrastructure such as green roofs, trees, and parks to increase vegetation and shade [7]. The use of reflective or cool roofing materials can also reduce the absorption of heat by buildings.

In the presence of technology, environmental parameters can be tracked quite efficiently. Data could be stored in clouds and advanced prediction tools could be utilised to predict weather patterns The Internet of Things (IoT) has emerged as a promising technology for monitoring and analyzing the UHI effect [8] IoT sensors can collect real-time data on temperature, humidity, air quality, and other environmental factors, providing a more precise and detailed understanding of the UHI effect [9]. One of the key advantages of IoT for UHI monitoring is its ability to provide continuous and real-time data. Traditional methods of UHI monitoring involve manual measurements at fixed locations, which can be time-consuming and limited in scope. IoT sensors, on the other hand, can be deployed across a city to collect data at multiple locations simultaneously [10]. This allows for a more comprehensive understanding of the UHI effect and its spatial variability. IoT sensors can also provide data on multiple environmental factors simultaneously, allowing for a more holistic understanding of the UHI effect [11]. This paper presents a parametric investigation of the UHI effect in Putrajaya, the federal administrative center of Malaysia by using a network of IoT sensors. This study investigates the UHI phenomenon and evaluates the urban heat island intensity (UHII). Furthermore, this study evaluates the effect of wind speed and rainfall on UHII. We collected data on temperature, humidity, wind speed and rainfall at multiple locations across the city. The data was then analyzed to investigate the UHI phenomenon and the effect of wind speed and rainfall on UHII in Putrajaya. The findings of this study have important implications for urban planning and design in Putrajaya and other cities facing similar UHI challenges. By leveraging the power of IoT and parametric modeling, we can gain a deeper understanding of the UHI effect and develop more effective strategies for mitigating its negative impacts.

The UHI effect has been studied extensively over the past few decades, and a large body of research has highlighted the negative impacts of this phenomenon on human health, energy consumption, and the environment [12]. Numerous studies have investigated the causes and extent of the UHI effect in various cities around the world, and a range of strategies have been proposed to mitigate this effect [13],[14]. One promising approach to UHI monitoring and analysis is the use of the IoT. IoT sensors can provide real-time and continuous data on temperature, humidity, and other environmental factors, allowing for a more precise and detailed understanding of the UHI effect. Several studies have explored the use of IoT for UHI monitoring and analysis, with promising results [15], [16].

Yao et al. [17] conducted a study to examine the influence of urban function and landscape structure on the Urban Heat Island (UHI) phenomenon in Beijing, China, by employing remote sensing techniques. The findings of the study revealed that the urban thermal environment demonstrated distinct spatial and temporal heterogeneity due to the varying degrees of urban function and landscape complexity. Selvy et al. [18] used IoT sensors to monitor the UHI effect in Melbourne, Australia. The study found that the UHI effect was most pronounced in the city center and that the use of green roofs and walls could significantly reduce surface temperature. The authors concluded that IoT sensors could provide a valuable tool for evaluating the effectiveness of UHI mitigation strategies. As the presence of the UHI phenomenon in the metropolitan area is prominent nowadays, Malaysian cities are not immune to the UHI phenomenon [19]. Malaysian cities are also experiencing the UHI phenomenon to a different degree. In Kuala Lumpur, Malaysia, the UHI phenomenon has been investigated, and 6 °C UHII has been reported at nighttime [20]. In Putrajaya, the UHI phenomenon has been studied, and 2-3 °C UHII has been reported [21]. Few researchers have performed numerical studies on the UHI phenomenon in Putrajaya [22].

The lack of experimental investigation about the UHI phenomenon in Putrajaya, as well as other Malaysian cities, is quite palpable in recent literature, even though the researchers have conducted few numerical kinds of research. The need for experimental investigation regarding the UHI phenomenon in Putrajaya, as well as other Malaysian cities, is paramount for developing in-depth knowledge and understanding for decision-making and advanced simulation to evaluate and assess the UHI phenomenon. The present study aims to fill the research gap by addressing the UHI phenomenon experimentally by using a network of IoT sensors to collect real-time data on weather parameters to evaluate and highlight the real-life phenomenon.

2. Methodology

The methodology for the present research encompasses study area selection, instrument and equipment, deployment of IoT network, and data acquisition and analysis.

2.1 Study Area Selection

The city of Putrajaya, Malaysia, has been selected as the study area for this research due to its unique urban design, which comprises several different land use types and vegetation covers.

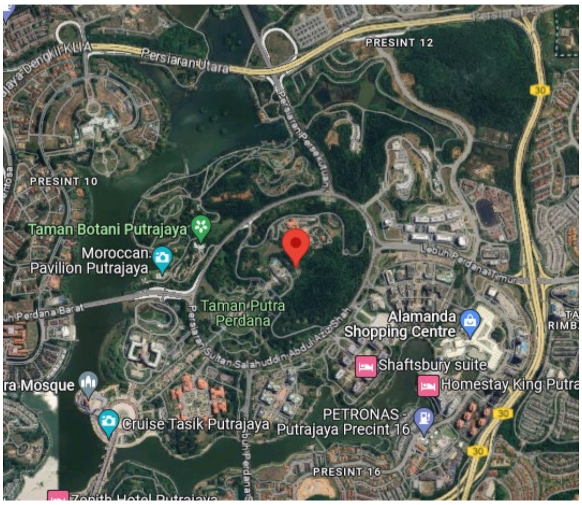

Fig. 1 *Green zone reference area, Taman Putra Perdana*

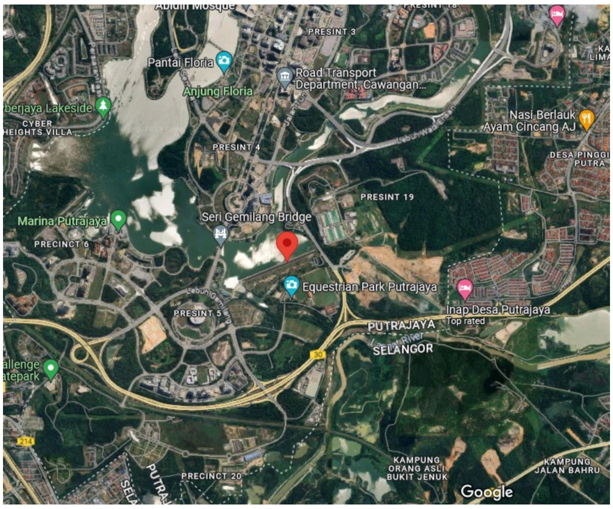

Fig. 2 *Residential or commercial zone reference area, Presint 5*

This study has chosen two strategic locations for green zone reference and residential or commercial zone reference in Putrajaya, respectively. Fig. 1 and Fig. 2 show the selected locations for this study in Putrajaya. Choosing the appropriate locations in Putrajaya was difficult, because of the security issues as Putrajaya is the administrative capital of Malaysia. However, we were allowed to install the instruments and equipment at strategic locations for the studies. We installed the same set of calibrating instruments and equipment at both locations, green zone reference and residential or commercial zone reference in Putrajaya.

2.2 Instrument and Equipment

The air temperature, wind speed, and rainfall are the principal parameters for this study. The details of instruments and sensors used in this experimental study are shown in Table 1. The instruments were calibrated in a wind tunnel laboratory [21]. Temperature calibration has to be performed on-site for all stations.

Table 1 *Specification of instruments*

Device	Measured parameters	Accuracy
81000 ultrasonic anemometer, R.M. Young	Wind speed	± 0.05 m/s
CS215-L, Campbell Scientific	Air temperature	± 0.4 °C
Bucket type rain gauge, NiuBol	Rainfall	± 4%

2.3 Deployment of IoT Network

The deployment of IoT sensors for measuring temperature, rainfall, humidity, and wind speed was a significant stage of this research. The sensors equipped with sophisticated technology that allows for real-time data collection and transmission, making it possible to monitor environmental conditions in remote or inaccessible areas, were deployed in several locations within Putrajaya, including urban and rural areas. The sensors are designed to be robust and withstand harsh weather conditions, ensuring accurate data collection. The sensors were connected to a wireless network to transmit the data in real-time. This system is capable of recording multiple parameters at a time. This system works remotely and eliminates human interactions. This system is embedded with high-precision and resolution sensors. The temperature sensors were calibrated using LINI-T

UT363 while the wind speed sensors were compared using the Pangkor Low-Speed Wind Tunnel (PLSWT) located in the Beach and Water Resouces Engineering [23]. All other sensors were calibrated before the installation at the sites.

2.4 Data Acquisition and Analysis

The deployed IoT system stores the collected data on a cloud database center. The data can be downloaded from the cloud. Data on temperature, humidity, wind speed, and rainfall were collected over several months. Other relevant data, wind direction, solar radiation, atmospheric pressure, were also collected for the study area. The collected data was analyzed to investigate the UHI phenomenon and assess the UHII, and to investigate the effects of wind speed and rainfall on UHII. Data was analyzed in MATLAB. UHII has commonly been defined as the temperature difference between urban and rural places (or areas), $\Delta T_{u-r} = T_u - T_r$, T_u is urban temperature and T_r rural temperature. Fig. 3 demonstrates the schematic diagram of the system.

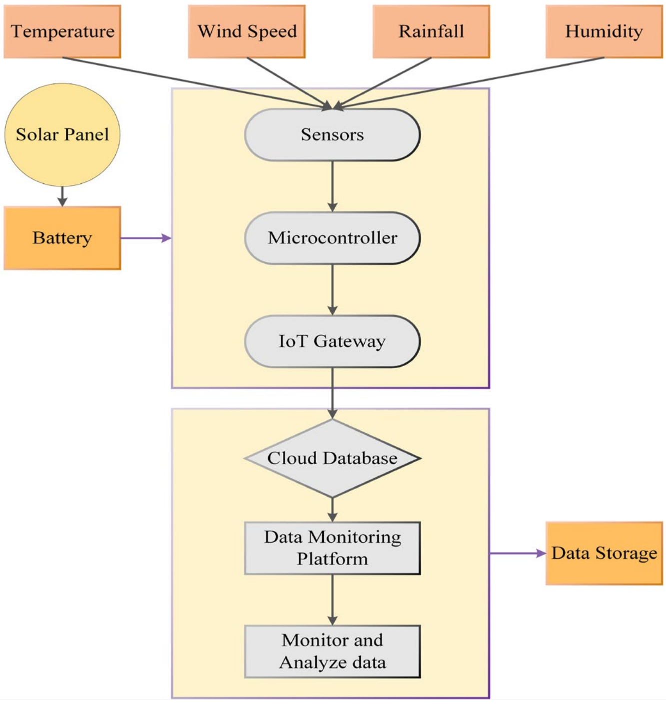

Fig. 3 *Schematic diagram of the IoT-enabled system*

3. Results and Discussion

A limited period of the end of 2022 was chosen as the period of study. The start of the year, such as February and March is usually marked by very a stable temperature pattern. There shall be a lot of rain and thunderstorms in May due to changes in monsoons. This is between when the North East monsoon has just ended in March and before the southwest monsoon begins in early June. The South West monsoon brings warm weather and is usually dry. If there is haze usually blamed on the peat fire and agriculture activities in Kalimantan and Sumatera Indonesia in September, these effects would abruptly disappear in October because of the changes of wind from the North East. The North East monsoon brings heavy rain and the weather is cool [24]. We chose this period because we want to avoid the temperature effect due to the monsoon.

3.1 Experimental Investigation of UHI

Fig. 4 demonstrates UHII with green zone temperature and residential zone temperature on December 8-9, 2022. This figure reveals the presence of UHI to a significant degree; the maximum UHII in this period is 2.3°C. This figure also depicts that UHII is more prominent at nighttime than in the daytime. It is mainly due to the heat released from concrete, buildings, and pavements. Throughout this period, the residential zone temperature was always substantially higher than the temperature in the green zone.

Fig. 5 illustrates the green and residential zone temperatures, along with the measured UHII on November 12-13, 2022. This illustration clearly demonstrates the strong presence of UHI, with the highest value of 2.9°C in this period. Likewise, Fig. 4 and Fig. 5 also display that UHII is more evident at nighttime than in the daytime. The similar patterns in Fig. 4 and Fig. 5 emphasize that the absorbed heat by concrete, building, and pavements during the daytime releases during the nighttime, which causes significant temperature differences with nearby rural areas or green zones. Fig. 6 depicts the UHI phenomenon on October 23-24, 2022. This figure reveals UHII along with the temperatures of the residential zone and green zone temperature, with the highest UHII value of 3.6°C. As Fig. 4 to Fig. 6 demonstrate the same pattern for UHII, the UHII is more apparent at nighttime than in the daytime, and the temperature of the green zone is always significantly higher than the temperature of the residential area regardless of the time.

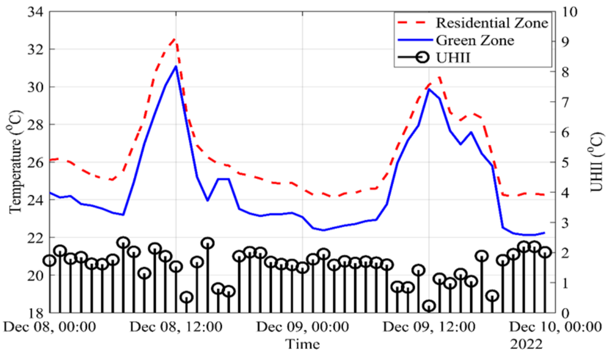

Fig. 4 *UHII on December 8-9, 2022*

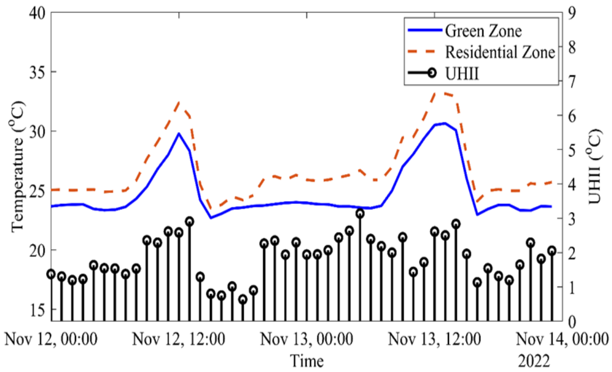

Fig. 5 *UHII on November 12-13, 2022*

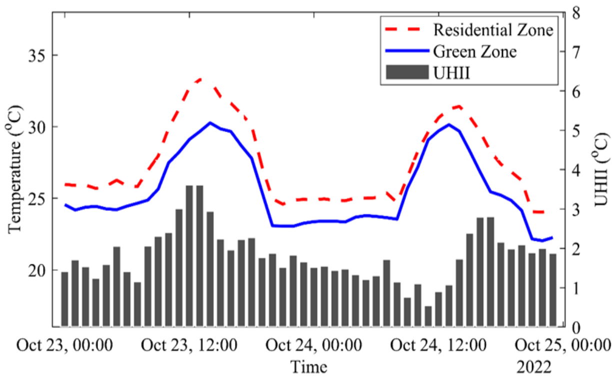

Fig. 6 *The effect of UHII on October 23-24, 2022*

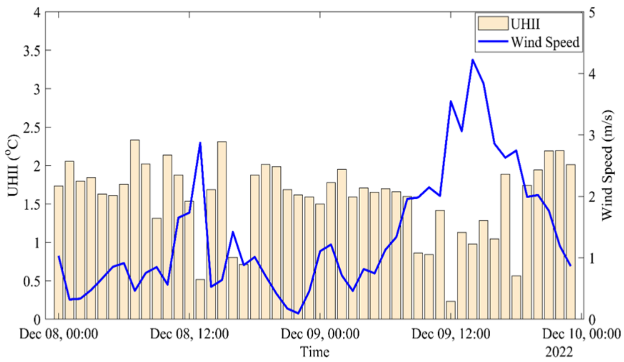

Fig. 7 *The effect of wind speed on UHII on December 8-9, 2022*

The results of the experimental investigation of UHI in Putrajaya show significant spatio-temporal variations in temperature and humidity levels across the study area. The data collected from the IoT sensors reveals that the urban areas of Putrajaya were significantly hotter than the surrounding rural areas, particularly during the night, which is caused by the thermal properties of urban materials, such as concrete and asphalt, that absorb and store heat. The study also finds that the intensity of the UHI effect is influenced by land cover and urban morphology. Areas with higher percentages of impervious surfaces and lower vegetation cover exhibited higher urban heat island intensity. This finding suggests that urban planning decisions, such as increasing green spaces and implementing cool roof technologies, could help mitigate the UHI effect in Putrajaya.

3.2 The Effect of Wind Speed on UHII

Fig. 7 demonstrates the effect of wind speed on UHII on December 8-9, 2022. This figure reveals that wind speed profoundly influences UHII; consequently, when the wind speed is significantly higher, the UHII reasonably lowers. Hence the inverse relation exists between wind speed and the UHII. Wind is the medium for removing heat from urban areas, and higher wind speed can remove a greater amount of heat from the metropolitan area, which can reduce the UHII.

Fig. 8 illustrates the effect of wind speed on UHII on November 12-13, 2022. This illustration clearly demonstrates that strong wind reduces the degree of UHII. Likewise, Fig. 7, Fig. 8 also display that UHII is more evident while wind speed is lower. Fig. 9 depicts the effect of wind speed on UHII on October 23-24, 2022. This figure reveals UHII is lower while wind speed is higher. As figs. 7, 8, and 9 demonstrate the same pattern for the effect of wind speed on UHII, the UHII is more apparent at lower wind speeds; on the other hand, while wind speed is higher, UHII is comparatively lower.

The results of investigating the effect of wind speed on urban heat island intensity in Putrajaya reveal interesting findings. Firstly, the study finds that wind speed has a significant negative correlation with urban heat island intensity, indicating that an increase in wind speed was associated with a decrease in UHI intensity.

This finding is consistent with previous studies, which have shown that natural ventilation can help reduce the UHI effect by enhancing convective heat exchange. Furthermore, the study found that the negative correlation between wind speed and UHI intensity is stronger during the daytime compared to nighttime. This finding suggests that daytime wind speed is a more important factor in reducing the UHI effect compared to nighttime wind speed. This is likely due to the fact that during the daytime, solar radiation heats the urban surfaces, causing a more significant temperature differential between urban and rural areas, which can be mitigated by increased wind speed. Overall, the results of this study provide important insights into the role of wind speed in reducing the UHI effect in tropical cities like Putrajaya. The findings suggest that urban planning and design decisions that prioritize natural ventilation through the incorporation of green spaces and wind corridors can help mitigate the UHI effect and enhance urban livability.

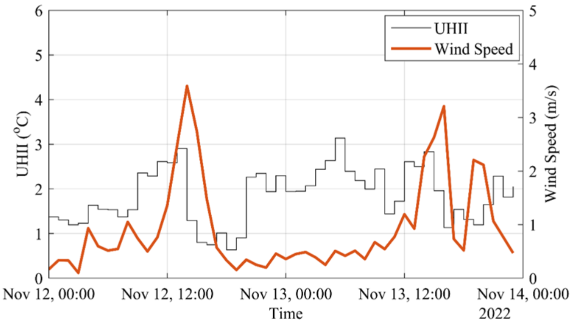

Fig. 8 *The effect of wind speed on UHII on November 12-13, 2022*

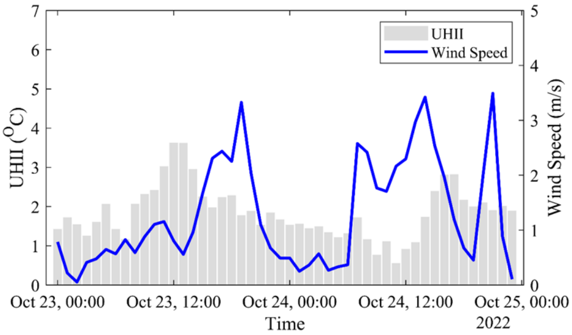

Fig. 9 *The effect of wind speed on UHII on October 23-24, 2022*

3.3 The Effect of Rainfall on UHII

Fig. 10 demonstrates the effect of rainfall on UHII on December 8-9, 2022. This figure lucidly reveals that rainfall profoundly influences UHII. The inverse relation exists between rains and UHII. Fig. 11 illustrates the effect of rainfall on UHII on November 12-13, 2022. Likewise, Fig. 10, this illustration clearly demonstrates that rain reduces the degree of UHII. Fig. 12 depicts the effect of rainfall on UHII on October 23-24, 2022. Rain can potentially reduce the UHII by removing a massive amount of heat from the environment.

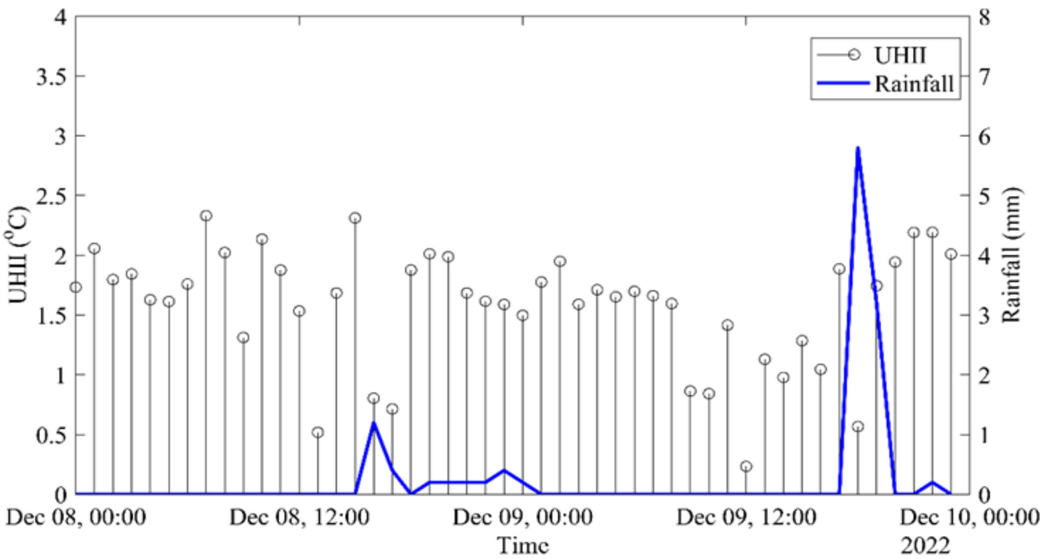

Fig. 10 *The effect of rainfall on UHII on December 8-9, 2022*

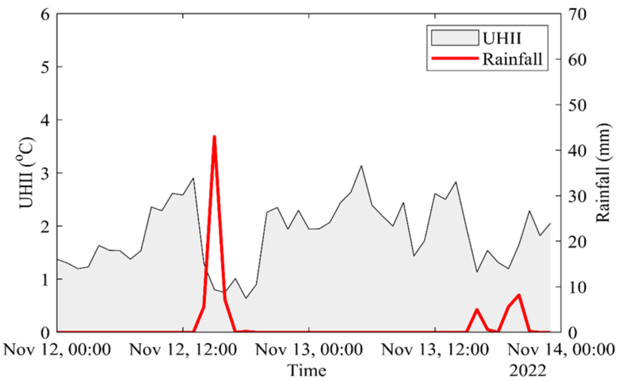

Fig. 11 *The effect of rainfall on UHII on November 12-13, 2022*

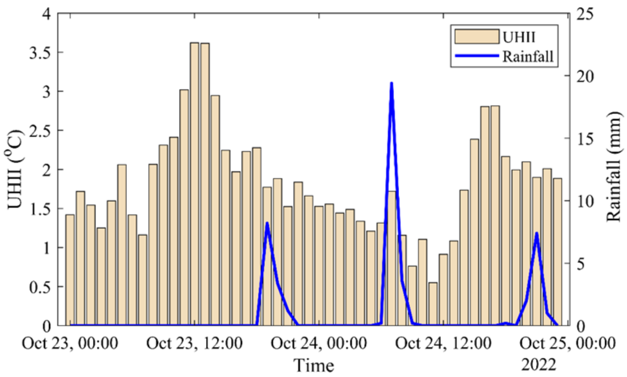

Fig. 12 *The effect of rainfall on UHII on October 23-24, 2022*

This investigation into the effect of rainfall on UHII reveals some interesting results. The analysis shows that there is a significant negative correlation between rainfall and UHII in Putrajaya. This means that as rainfall increases, the intensity of the UHI effect decreases. This finding can be explained by the fact that rainfall helps to cool down the urban environment by reducing surface temperatures, increasing humidity, and promoting evaporation. This, in turn, leads to a reduction in the temperature differential between urban and rural areas, resulting in a decrease in the intensity of the UHI effect. Furthermore, the results suggest that rainfall can play a vital role in mitigating the UHI effect in tropical regions such as Putrajaya, where high temperatures and humidity are prevalent. Therefore, urban planners and policymakers should consider incorporating measures to increase the permeability of urban surfaces to allow for more infiltration and absorption of rainfall, as well as the creation of green infrastructure to encourage more evapotranspiration and reduce surface temperatures. Overall, these findings are significant and offer valuable insights into the potential of rainfall as a natural means of mitigating the UHI effect.

4. Conclusions

This study has investigated the UHI phenomenon at Putrajaya. The findings show that Putrajaya is not immune from the UHI phenomenon, and it is experiencing UHI phenomenon to a significant degree. This study has observed that the highest value of UHII is 3.6 °C. This study has also investigated the effect of wind speed on UHII. This research has found that wind speed is inversely proportional to the UHII, suggesting that natural ventilation may help reduce the UHI effect. Furthermore, this investigation has also observed the effect of rainfall on UHII, and it shows that rain has excellent potential to reduce the UHII, suggesting that rainfall can help mitigate the UHI effect. This experimental investigation may assist in advanced modeling and simulation for developing in-depth knowledge and decision-making to achieve a sustainable metropolis.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper as follows: ***study conception and design:*** *Z. Harun,* ***data collection:*** *A. H. Molla;* ***analysis and interpretation of results:*** *E. Reda, M. Z. Mat Saman;* ***draft manuscript preparation:*** *E. Reda****; Financial arrangement****: H. Hashim; All authors reviewed the results and approved the final version of the manuscript.*

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