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ARTICLE

Simulated Solar Radiation Experiment to Detect and Model Temperature Rise in the Metropolitan City, Karachi

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Abstract: Karachi is the only metropolis in Pakistan, and in the last two to three decades, there has been a continuous increase in the daily average temperatures. Consequently, there has been an average increase of 4% to 6% in the annual temperature over this period. The main reasons for this rise could be an increase in cementation and a reduction in green areas due to abrupt and unplanned construction in the city. To verify this statement, we devised a simulated solar heat energy experiment tailored to the environmental conditions of Karachi. This experiment was carried out in both open and covered areas. The findings of the study outcome indicate that the heat energy retained in the environment has increased due to cementation, reduced green spaces, and the population increase. An average increase of 3.5 °C was recorded during the experimental procedure.

Keywords: Solar radiation, Temperature rise, Environment, Urban heat island.

1. Introduction

Solar radiation is the energy emitted by the Sun as a result of its nuclear fusion reactions. This energy is essential for the survival of human beings and has sustained the Earth's natural cycles for billions of years. In general, humans are dependent on solar radiation. Solar radiation provides a huge amount of energy that sustains the globe. The energy penetrating the Earth's atmosphere is nearly infinite, and it holds the potential to provide valuable energy for an almost continuous period. It depends on human interventions and development and how much utility can be catered to by capturing solar energy. However, solar energy remains a relatively unexplored field of science, and as such, it demands valuable data to empower engineers, architects, and professionals in the development of efficient solar systems. Data on solar radiation is of utmost importance due to the Sun's potential as an energy source and its significance in climatological studies. Over the past 50 years, the transformation of solar flux measurement has become a globally researched topic due to its diverse range of applications [1]. Its significance has grown manifold due to the ongoing energy shortage and the emergence of renewable energy storage techniques. Solar radiation is closely tied to geographical parameters and the number of days in a year [6].

The term "global warming" focuses attention on temperature growth. It is widely recognized that instrumental near-surface temperature records worldwide have documented the warming of the Earth's surface since the nineteenth century. Equally undeniable is the fact that the concentrations of greenhouse gases in the Earth's atmosphere have increased due to human consumption of fossil fuels [7]. In the Fourth Assessment Report in 2007, the IPCC declared that "most of the discovered increase in

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global average temperatures since the mid-20th century is very doubtless because of the determined increase in anthropogenic greenhouse emission concentrations" [10].

Given the widespread acknowledgment of global warming, there is a growing demand for accurate forecasts of its effects, coupled with a rising apprehension regarding its impact on biological diversity. In recent years, there has been a substantial increase in the dissemination of data to the general public about the causes and consequences of global warming and temperature changes [4].

World temperatures continue to rise with each passing year, likely as a result of global warming. However, regional temperature increases are often attributed to factors such as population growth and the expansion of infrastructure. This has led to the phenomenon known as the urban heat island (UHI), which is recognized as a significant issue in this century. The UHI effect impacts the three billion urban population worldwide, as it is a direct consequence of urbanization and the re-radiation of heat energy from buildings in the city areas. It is essential to plan the design and parameters of buildings with environmental considerations in mind [8].

In our study, we aimed to establish a relationship between solar radiation and its reflectance upon reaching the Earth's surface. To accomplish this, we gathered all pertinent data related to the city of Karachi and started working on our project.

2. Study Area

The subcontinent in general, and Pakistan in particular, lacks an effective environmental policy [3]. Our study area is the largest city in Pakistan. This city is among the top ten most populated cities, with over 25 million spread over 3,780 sq. km. At the same time, the urban built environment shares approximately 700 sq. km. of the city's land. It contributes 60% of the country's total tax collection and GDP. This city is also a gateway to Russia, Afghanistan, China, and Central Asian Muslim states. It also fulfills logistics needs through its two seaports to all across the landlocked countries mentioned above [5]. The issue of temperature rise is due to the amalgamation of different factors in recent years [9].

The built environment of Karachi shows a vast heterogeneity among the ways buildings are constructed in the city, from an ancient practice of wood/bamboo or stone masonry building to the most modern steel structure technique. It is well understood that different types of building materials have different capabilities for insolation. As mentioned earlier, the construction material in Karachi is significantly heterogeneous; however, at a regional level, homogeneity among the building types can be observed. To examine the relationship between temperature and construction materials used in Karachi's built environment, refer to the map in Fig. 1, which illustrates the different construction types.

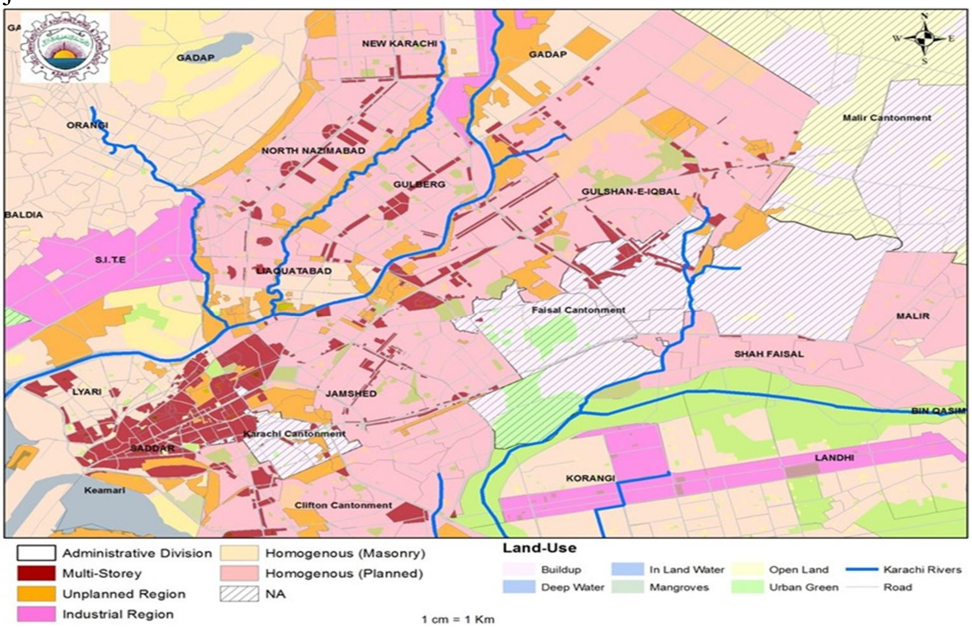

FIG. 1. Spatial distribution of different types of construction in Karachi.

3. Plan of Study

The primary focus of this study is the investigation of temperature increases attributed to various factors, including cementation, deforestation, unplanned urbanization infrastructure development, and population growth. This study aims to shed light on the underlying causes of the yearly rise in temperatures at a micro-level. Indirectly, we find a relation between solar radiation and rising temperatures associated with the aforementioned factors. In this research paper, we have used bricks, asphalt, water, soil, etc., to check the response of different materials to the reflectance or absorption of solar radiation.

4. Experiment Procedure:

4.1 Indoor Experiment

The first model for this research designed for indoor experiments comprised an apparatus assembled specially for this purpose. We determined the reflected lux of different surface layers like soil, grass, and cement, along with the heat-absorbing capability of each surface layer. The experiment simulates the Sun and its energy absorbed and reflected by the Earth. We used a 400-watt bulb to create simulated sunlight and heat; the incident and reflected light intensities were measured by a lux meter. The lux meter was installed at about two feet above a tray containing the aforementioned surface layers. The effect of reflected intensity is also measured by the rise in the temperature of 200 ml of hexane. A thermometer was submerged in hexane to note the temperature change.

The apparatus was adjusted adjusted to maximize the reflected intensity at the absorbing medium. Cardboard sheets were used to create borders around the instrument and to separate the bulb from the hexane, ensuring that unwanted scattered light did not interfere with the measurements. The distance between the thermometer and the bulb was maintained at the calibrated length of 1 foot. To prevent the highly volatile hexane from evaporating, the hexane, fixed on a retort stand, was sealed with sealing tape. Temperature readings were taken at regular intervals during the experiment. Initially, the thermometer was observed every 3 minutes. As the temperature rise began to stabilize, readings were taken at 5-minute intervals. Throughout the experiment, both the source and reflected lux values were systematically recorded. A total of two sets of data were collected, with each group consisting of at least 20 readings. The experiment was conducted in a low-light environment to minimize the influence of surrounding light. After completing a set of readings for a surface layer, the hexane was allowed to cool by placing it in a suitable location until it returned to its normal temperature.

4.2 Outdoor Experiment

The outdoor experiment was also performed to monitor the reflected lux of the three selected surface layers. Further simulated experiments were performed outdoors on three different surfaces, namely water, steel, and bricks. Due to various factors, including airflow, the results are not appreciable in the case of reflection from water and reflection from brick. The results are remarkable for the steel surface due to its high reflectance, as shown in Figs. 5-7.

5. Result and discussion

The purpose of this study was to investigate the response of different surface types to insolation in Karachi. This investigation aimed to better understand the factors contributing to the observed temperature increase of 4 to 6 °C over the past 20 years in the region [9].

We developed a simulation of solar radiation reflection and the persistence of heat due to reflected sunlight in the atmosphere. Figure 2 shows the experimental setup used to calculate the reflectance from various surfaces, and the desired material has filled the tray beneath the bulb. We performed the experiments with different surfaces, such as concrete, grass, water, mud, etc., but we presented the results of only two surfaces, grass and concrete. The reason is that over the last ten years, from 2005 to 2015, a significant change in the corresponding areas has been observed.

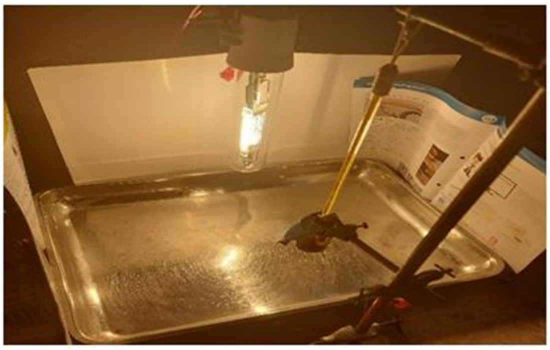

FIG. 2. Simulated solar radiation model.

In the experiment with grass and cemented surfaces, we observed the incident and reflected intensities as a function of the zenith angle. The following equation shows the dependence of reflectance R on the zenith angle φ.

$$R = R_0 \varphi^{\propto} \# \quad (1)$$

where R_o is the reflection coefficient and $\propto$ is a constant whose value depends on the nature of the surface [2].

Graphs in Figs. 3 and 4 show the variation of reflectance concerning the zenith angle when the reflection occurs from concrete and grass. The reflectance from grass is much lower than that of the concrete road and metallic surfaces. Steel was also examined in an outdoor experiment with two other surfaces, water and brick. Reflectance from steel is very high due to its nature results can be verified from the Figs. 5-7. The regions with grassier surfaces would have lower temperatures than non-grassy areas. To verify this statement, temperatures are recorded simultaneously at five different locations in Karachi city. In Fig. 8, the bar charts compare the change in areas of concrete and grassy surfaces over the last ten years, i.e., from 2005 to 2015 (see also Fig. 9). The other bars show the reflected intensity of these areas. We assume the rise in temperature by two surfaces is proportional to the reflected intensities. The ratio of reflected intensities from concrete and grassy surfaces is 3.5. This number is in accordance with the rise in temperature in Karachi over the last ten years.

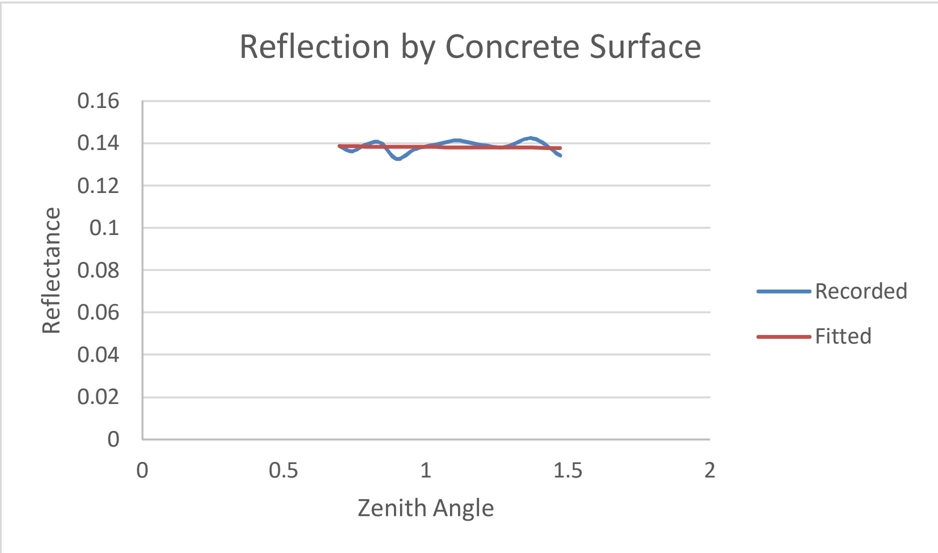

FIG. 3. Reflection by concrete surface.

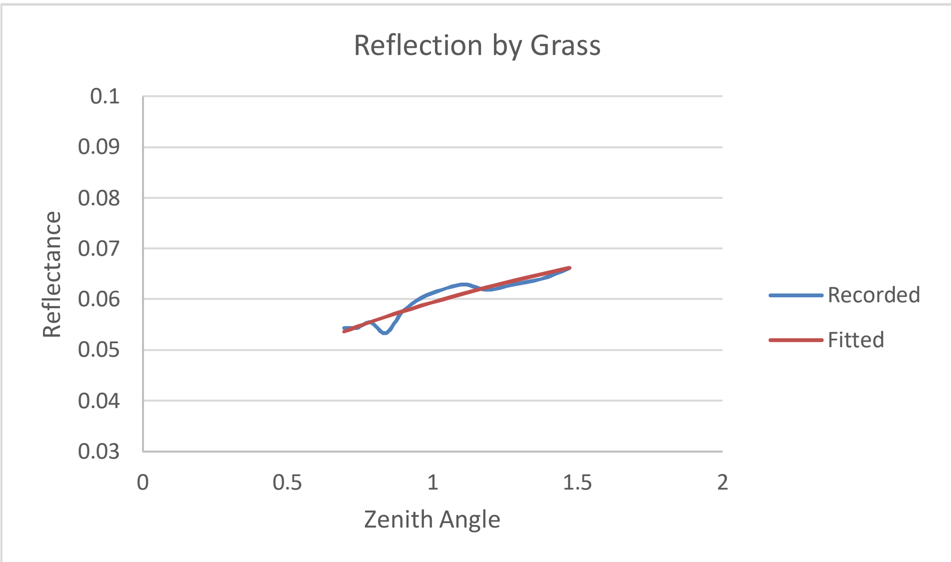

FIG. 4. Reflection by grass.

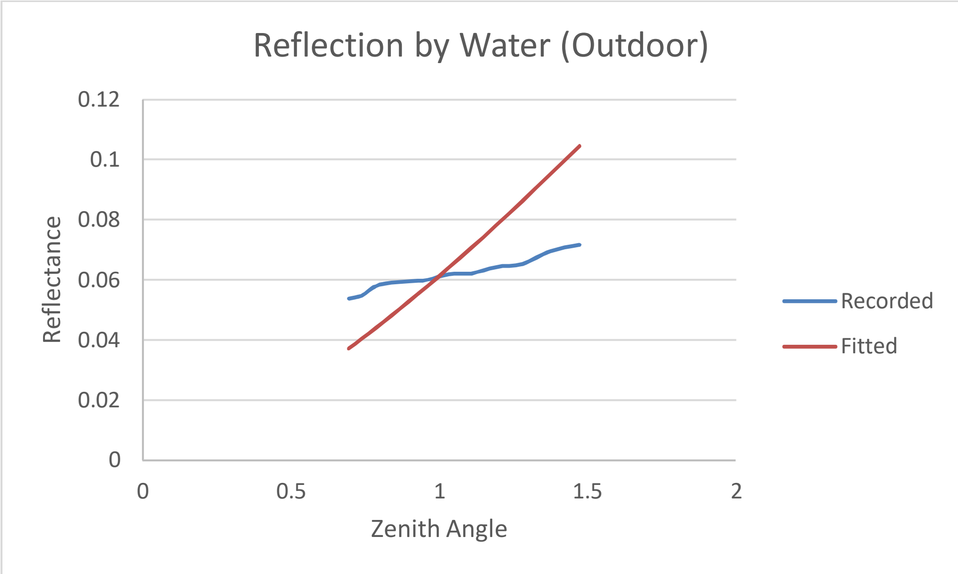

FIG. 5. Reflection by water (outdoor experiment).

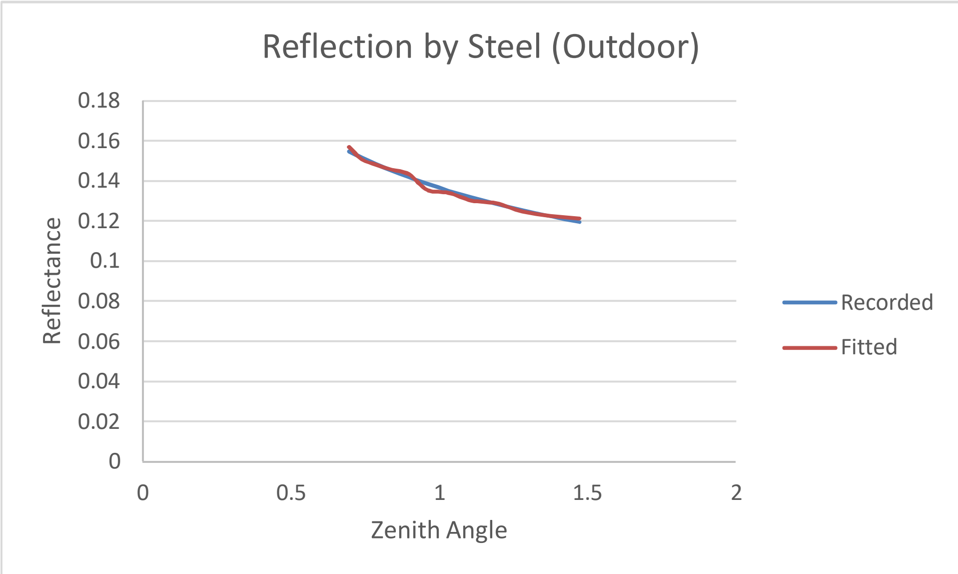

FIG. 6. Reflection by steel (outdoor experiment).

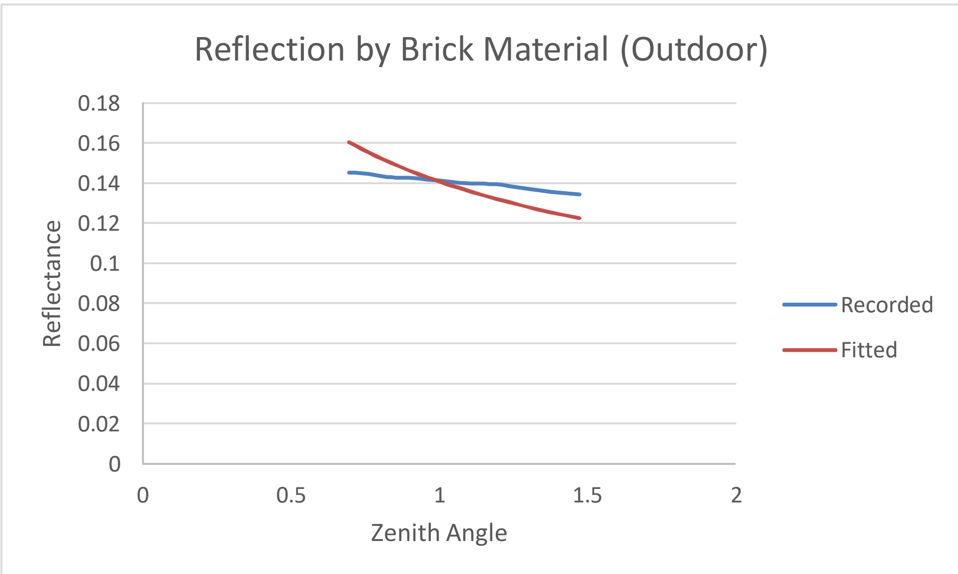

FIG. 7. Reflection by brick material (outdoor experiment).

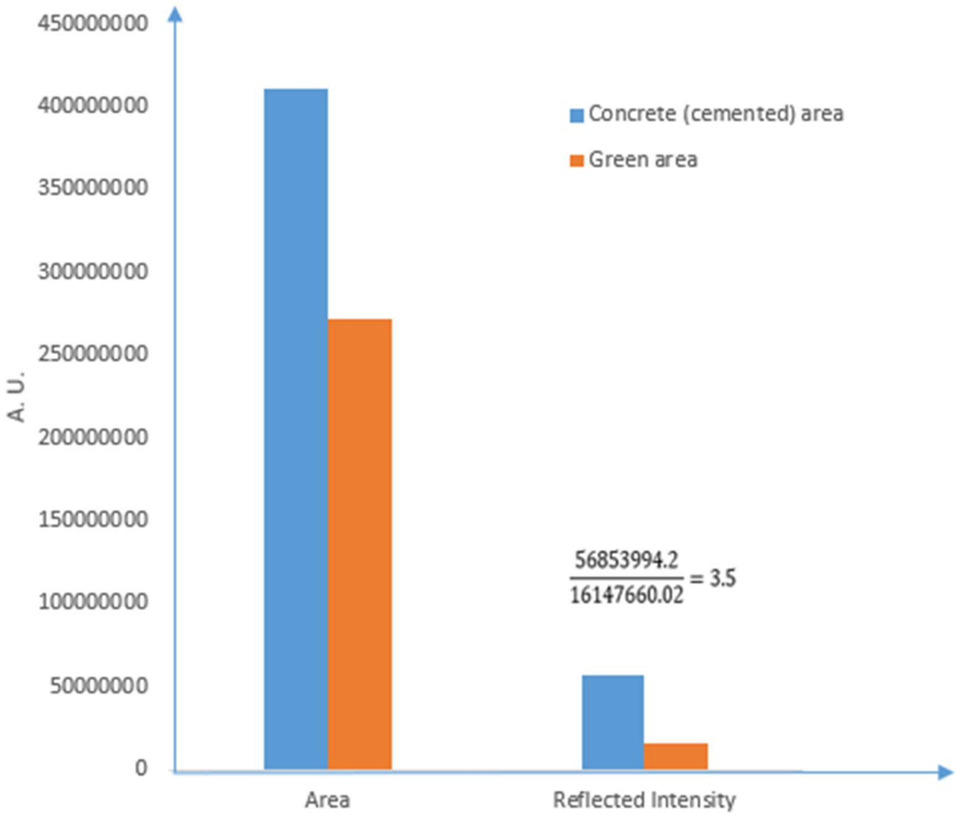

FIG. 8. Comparison of areas and reflected intensities by concrete and grassy surfaces.

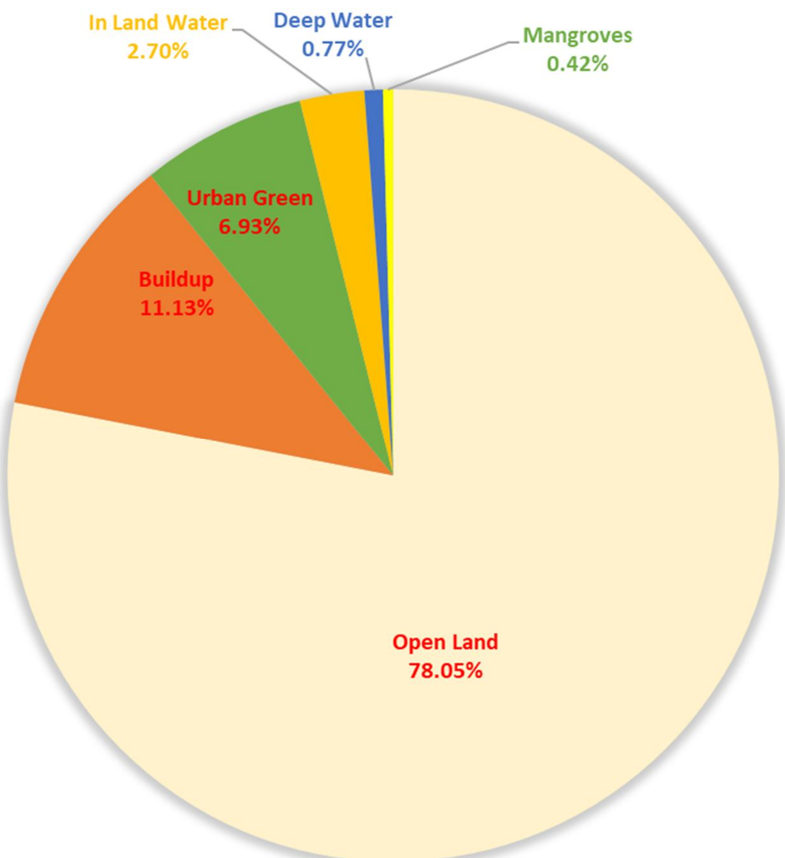

FIG. 9. Proportion of land utilization in Karachi.

6. Conclusion

Following are the conclusive findings from the simulated experiment conducted in Karachi, a city that ranks among the most densely populated in the world, as mentioned earlier.

1. The indoor experiment was conducted in the International Center for Chemical Biological Sciences and Centralized Science Laboratories, University of Karachi. Experimental observations suggested that cement and soil have a greater rate of reflectance calculated through a lux meter than grass. Further simulated experiments were performed outdoors on three different surfaces, namely water, steel, and bricks. Due to various factors, including airflow, the results in the case of reflection from water and reflection from brick are not significant. However, the results for the steel surface are noteworthy due to its high reflectance, as shown in Figs. 5–7.
2. During the second phase, we gathered data from the Karachi region and made a contour model of 3740 km^2, as presented in the Study Area section of this paper. We found that between 2005 and 2015, there was a substantial increase in the cemented area. The city's infrastructure has expanded rapidly, following a poorly planned pattern. The figures in the Study Area section show a scarcity of green areas in the city.
3. During the third phase, we established a correlation between the simulated reflectance of different objects and the city's landscape, highlighting the cementation process and unplanned urbanization as the main factors contributing to the rise in temperature over the past 10 to 15 years. As a matter of fact, the city has experienced a temperature rise of 3 to 4 °C in recent years [9].
4. As a remedial measure, one approach could involve planting vegetation and grass on rooftops exposed to direct sunlight. Additionally, efforts may be made to reduce the use of steel materials or apply insulating coatings to them.
5. Furthermore, it is essential to establish green belts within the densely cemented zones, such as around high-rise buildings and roads. The implementation of such measures, if undertaken, could help halt any additional temperature increase. Failure to do so would result in the temperatures continuing to rise.

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Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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