ISSN: 1687-1006 p
ISSN: 2682-3640 e

The Egyptian International Journal of Engineering Sciences and Technology

Vol. 39 (2022) 49–59

https://eijest.journals.ekb.eg/

Investigating the Spatial Autocorrelation of Surface-Air Temperature for Different Ground Materials in Hot Desert Climate

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ARTICLE INFO

Keywords:

1st Surface-Air Temperature
2nd Spatial Interpolation
3rd Ground Surface Materials
4th Spatial Autocorrelation
5th Hot Desert Climate

ABSTRACT

Several studies have been conducted in recent decades to investigate how different pavements affect the microclimate conditions and thermal comfort for humans. However, few studies explore how different ground materials are associated with surface and air temperature spatially. This paper examines and quantifies the micro-scale influence of various ground surface materials on the microclimate conditions in a hot desert climate, like Aswan City. This study applied several methods and techniques such as; on-site measurements, a statistical analysis of variance (ANOVA), multivariate regression models, and advanced spatial statistics techniques that control for spatial autocorrelation. The key findings of this research reveal that the mean values differed significantly from one material to another. The mean air temperatures ranged from 25.47°C to 41.4°C at the grass and the asphalt respectively, while the highest mean value for surface temperature was recorded above the asphalt (50.27°C), and the lowest value was with a mean value of 22.31°C above the grass. Alternatively, based on the spatial analysis, the results of the IDW interpolation show that the lowest mean air temperature is above the grass (26.03°C), while the highest temperature can be observed over the asphalt (42.27°C). In terms of surface temperature, the lowest and highest temperatures were recorded above the grass and asphalt (19.52°C and 50.32°C). There were no substantial differences between the IDW interpolation results, and the results obtained from the measured data. Thus, using spatial interpolation of point data values can be an effective tool to generate detailed spatially continuous temperature maps. The research findings can be utilized to develop effective mitigation strategies to enhance urban microclimate in hot desert regions by using passive approaches of decreasing temperatures.

1. INTRODUCTION

Urban heat island (UHI) is a prominent phenomenon of urban areas being significantly warmer than its surroundings rural areas due to rapid urbanization and human activities [1, 2]. The most common methods for determining UHI are air temperature and surface temperature [3]. Most UHI research has focused on data sources, simulation modeling, unit selection, analytical methodologies, driving factors, and mitigation strategies. Early UHI research focused on the differences in air temperatures between urban and rural areas, which was based on data from a limited number of unevenly positioned weather stations over several regions [4, 5].

Due to variations in the intensity of the solar radiation during different seasons (summer/winter), the effects of UHI varies dramatically. Surface layer heat island varies based on the season, location, solar intensity, land cover, and weather.

In hot desert climate, summertime fluctuations in these conditions and the magnitude of surface temperatures are especially evident. When researching the phenomenon of UHI, the size and location of cities are key concerns. The UHI effects rise in direct proportion to the size of the metropolis [6, 7].

Essentially, a comprehensive understanding of the climatic factors is vital for efficient management of agriculture, natural resources, disaster resilience, urbanization, transportation, and a wide range of other activities. One of the significant climatic factors is the surface temperature because it not only regulates air temperature in the canopy layers in the urban environment, but also it assists in determining building internal temperatures and impacts energy exchanges that affect city residents' comfort [8]. In many urban areas, diverse types of

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pavements, such as streets, parking lots, walkways, plazas, and playgrounds, cover a substantial part of the land surface. Heat stress has increased in these urban areas because of the use of inefficient artificial materials and a lack of vegetations and mitigation solutions [9, 10].

Heat island effects are becoming more prevalent in urban environments because of increasing population densities and impervious surface areas. These effects can be mitigated by urban planning policies, mitigation strategies, and adaptation activities. However, there is no one-size-fits-all mitigation solution, and any mitigation must take into account the unique characteristics of the specific geographic location [11]. Several recent studies demonstrated that the urban thermal climate can be mitigated by creating green spaces and greening building roofs. Other studies focused on the techniques to improve surface and air temperatures by increasing the roof albedo and land coverings [12-15]. Various studies have indicated that vegetation and the protection of existing green spaces and forested areas had enormously influenced reducing the urban heat island effect [16, 17]. Indeed, vegetation offers cooling through a wide range of mechanisms, including the seasonal shade of infrastructure, evapotranspiration, and limiting solar radiation.

The influence of outdoor space characteristics on the outdoor microclimate, such as surface albedo, sky view factor, and other factors on the ambient air temperature has been studied extensively in the past decades [13, 18-21]. In one of these studies, the Computational Fluid Dynamics (CFD) simulation was performed to analyze the thermal and energy impacts of five samples of color thin layer asphalt in outdoor spaces by measuring and analyzing their spectrum solar characteristics and thermal performance compared to a conventional black asphalt sample. They used statistical analysis to examine surface temperatures [18]. In addition, it was discovered that all colored-thin layer asphalt samples have lower surface temperatures than conventional asphalt.

Another research developed a novel albedo measurement system with a dual pyranometer and an automated data collection system, which they utilized to undertake field albedo measurements for different paving materials and long-term albedo monitoring [13]. The researchers also used experimental measurements to analyze the seasonal impacts of albedo on the thermal performance of paving materials. Furthermore, they discovered a positive relationship between the cooling effect and the peak solar radiation intensity.

Spatial statistics using Geographic Information Systems [19] have been extensively utilized to assist in the assessment and monitoring of numerous climatic variables by using spatial interpolation techniques such as Inverse Distance Weighting (IDW). In this regard, Ozelkan et al [19] demonstrated a novel modified inverse distance weighting (M-IDW) spatial interpolation technique using Landsat surface temperature data combined with meteorological station data for air temperature, relative humidity, and total precipitation. The findings demonstrate that if the monthly average computation includes images and cloudless pixels, the proposed M-IDW approach has potential for spatial interpolation of climatic data.

In Turkey's Southeastern Anatolia Project (GAP), six spatial interpolation approaches have been assessed to determine the optimum spatial distribution of six unique climate characteristics [20]. Using observed data from 1971 to 1999, simple cokriging produced the best forecasting models for temperature, solar radiation, relative humidity, wind speed and completely regularized spline for daylight and precipitation. In a further research, a novel method for calibrating spatial interpolation with satellite-derived surface emissivity was introduced to forecast surface temperature [21]. In summer 2001, four spatial interpolation algorithms were investigated to interpolate surface temperature in southern New England using ground temperatures collected at national weather stations; IDW, Spline, Kriging, Cokriging. When surface emissivity data are unavailable, they discovered that Kriging is suggested for surface temperature interpolation.

According to earlier literature, many studies investigated the correlations between land cover materials, surface temperature, and ambient air temperature on a large-scale area using satellite images, with little attention to the possibility of having multiple flooring materials on one spatial scale [4, 21-24]. In a different approach, this study focuses on the relationship between ground materials and different microclimate factors in a restricted urban boundary area. Although much of prior research have attempted to address the UHI impacts and its determining variables over the last few decades, they have a few major limitations;

I) There is not much quantitative data regarding micro-scale thermal variation due to changes in ground surface materials within urban environments in hot desert climate [5, 7, 25].
II) In terms of the scale of the study region, various studies focused on thermal environments in large-scale, high densely urbanized areas and megacities which showed how the size and type of different land use and land cover affect thermal environment [4, 6, 26-28].
III) Much of the literature into the thermal impacts of surface materials and land cover relies on large-scale techniques that employ satellites images from remote sensing data to estimate land surface temperature [6, 7, 22-24, 29-32]. Field experiments were performed in conjunction with remote sensing data to investigate the influence of land cover changes on air temperature across a large region [3, 5, 22, 24, 25, 33].
IV) A few other research have employed temperature data from meteorological weather stations, measuring air temperature in micro-scale methods to investigate thermal impacts of surface materials and land cover [34],[1, 18, 21, 35-38]. However, these studies are often limited by small sample sizes.
V) Methodological advances in statistical analysis (ANOVA and other correlation tests) have been widely applied for analyzing surface temperature and UHI effects [27, 39]. However, most existing literature have employed simple linear regression models to examine the correlation between different microclimate variables [3, 5-7, 40]. This research employs advanced spatial statical techniques that control for spatial autocorrelation and spatial heterogeneity.

The research of how different pavements affect the microclimate conditions and thermal comfort for the humans has been widely conducted [1, 38, 40-46]. Additionally, others examined the relationship between the surface and air temperatures for different climate zones.

However, thermo-spatial analysis for the correlation between surface and air temperatures has rarely been investigated previously. This research attempts to filling the gap by investigating the micro-scale influence of various ground surface materials on the microclimate conditions in a hot desert area, like Aswan City, using several methods and techniques such as; experimental measurements, correlation analysis and spatial statistics techniques.

The main objective of this research is to examine and quantify the correlations between surface temperature, ambient air temperature and other microclimatic conditions associated with different ground surface materials. Moreover, this study presents a novel approach, utilizing the spatial autocorrelation techniques to determine if surface temperature differences exist for various ground materials and if they influence air temperature above the corresponding materials.

2. MATERIAL AND METHODS

This study investigated an area with hot desert climate, taking Aswan University campus as a case study, exhibiting open areas of different impermeable, pervious, and natural materials such as; asphalt, soil, cement tiles, cement chequered tiles, and grass. Field measurements were conducted above the mentioned ground surfaces materials in June 2020, which represents one of the hottest months of the year, given the fact that climate heat pressure occurs mostly during the summer season. In the same regard, this study evaluates the impacts of different ground materials on the microclimate variables such as; surface and air temperature, relative humidity, and wind velocity. Therefore, the collected data on certain microclimate characteristics were analyzed using statistical analysis of variance (ANOVA), multivariate regression models and advanced spatial statistics techniques using Global Moran's I and Inverse Distance Weighting (IDW) interpolation.

2.1. Site Measurements

This research was performed at the College of Engineering, Aswan University Campus which is two kilometers north of Aswan City, Egypt. The city has different climatic characteristics, with the average annual temperature at 26.6°C, while the average maximum temperature in June is 40.5°C and the average annual rainfall is 1 mm (Climate Data for Cities Worldwide—Climate-Data.Org. Available online: https://en.climate-data.org/ (accessed on February 2022).

The climatic conditions of Aswan City are steady during the summer season, which characterized by hot, sunny, and cloudless circumstances. Therefore, measuring campaigns were performed for three consecutive days in June 2020 (6th, 7th, and 8th) as an indicative of these circumstances. Air temperature and relative humidity were measured at 1.5 m height using "HOBO U12" data loggers mounted in hand-made shields for solar radiation [47], shown in Figure 1. While the RADTKE device was monitoring the surface temperature.

In the study area, six distinct types of ground surface materials have been investigated at seven measuring points, as shown in Figure 2. Those materials were; 1) concrete tiles, 2) white concrete tiles, 3) grass, 4) soil, 5) cement chequered tiles, and 6) asphalt. These points were chosen to encompass all the available ground surface materials in the study area (details for each measurement location presented in Figure 3. The measurements were collected throughout the day on a 24-hour basis, while the data analysis focuses only on the daytime hours, which are typically between 08:00 AM to 06:00 PM. According to the monitoring data of air velocity that has been taken by Protmex 6252A, the measurements were taken during the day when there were no severe winds. Table 1 encompasses the descriptive statistics for the measurement instruments.

2.2. Statistical Approach

Both descriptive and predictive analysis were used to analyze the differences in surface and ambient air temperatures. Meanwhile, statistical analysis was utilized to examine the correlation and variations associated with each ground surface materials, existed in the study area.

The statistical analysis has been performed using statistical software IBM SPSS 25. The analysis of variance (ANOVA) test has been applied to examine variances in mean surface temperatures among all ground materials and to detect material differences using the Tukey-Kramer test [46]. Similarly, ANOVA test was conducted to determine if mean air temperatures differed across different ground materials. For a predictive analysis, the correlation between surface and air temperatures was assessed using multivariate regression models. Using OLS regression analysis, stepwise regression models have been used to find the best fitted model.

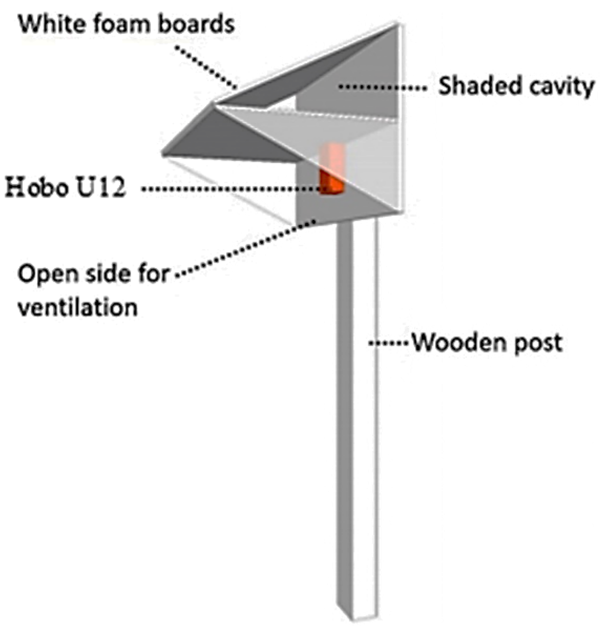


Figure 1. A diagram showing the installation of the HOBO U12 device to protect it from direct solar radiation [48] (Edited by Authors).

Table 1. Summarized descriptive data for the measurement instruments.

Variable	Accuracy	Range	Output resolution	sample
Ta	± 0.35 °C from 0°C to 50 °C	−20° to 70 °C	0.03 °C at 25 °C	1 hour
RH	± 2.5 % from 10% to 90 %	5 % to 95 % RH	0.03 % RH	

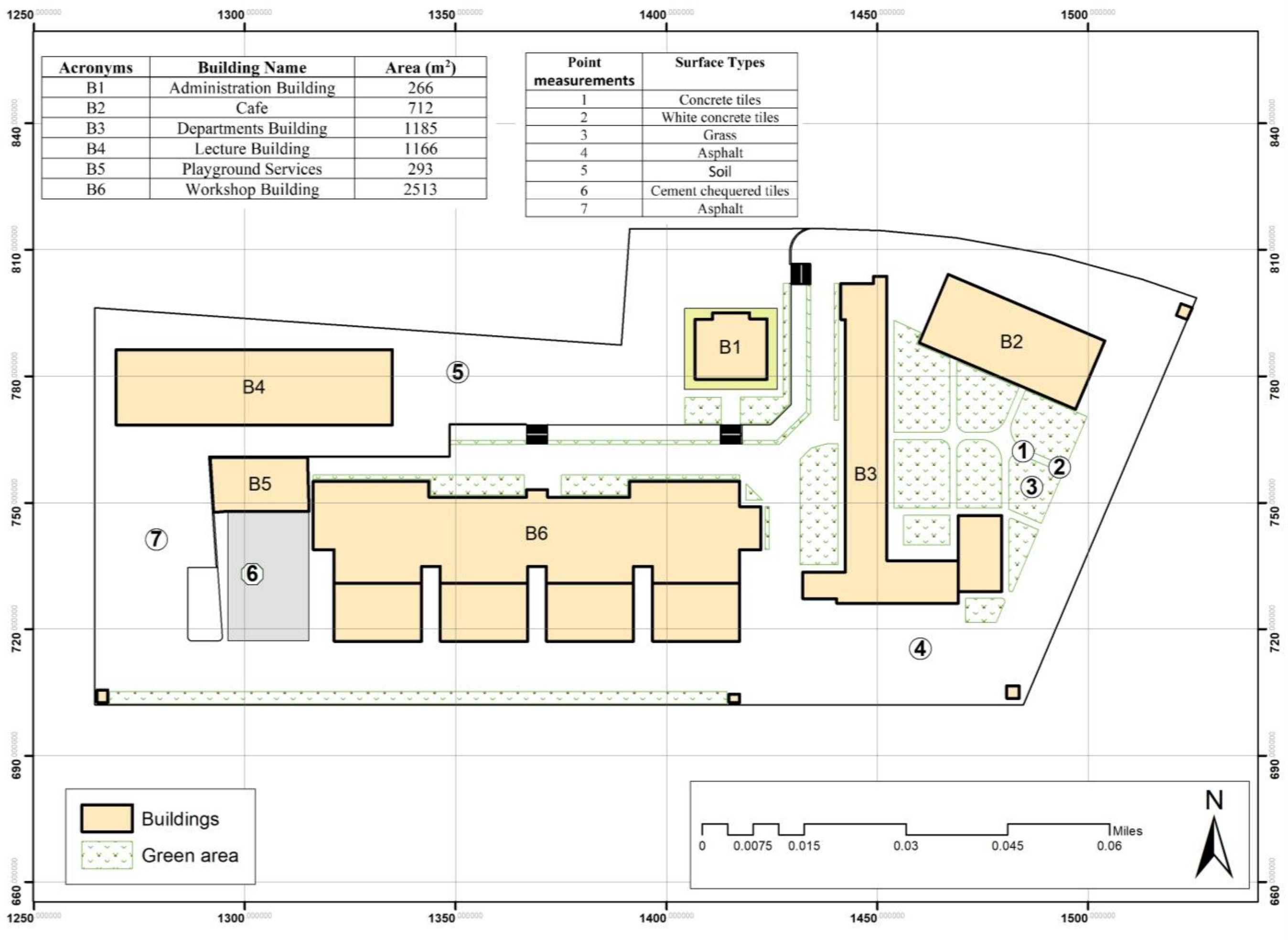


Figure 2. The map for the College of Engineering at Aswan University and the measurement points (Source: Aswan University, Engineering Administration, 2020).

1) 2) 3) 4) 5) 6)

Figure 3. Locations for data point measurements with ground materials; 1) Concrete tiles, 2) White concrete tiles, 3) Grass, 4) Asphalt, 5) Soil and 6) Cement chequered tiles

2.3. Spatial Interpolation Approach

Spatial interpolation is a technique for predicting the value of attributes at unobserved locations within a study region using existing measurements [49]. One of the most frequent interpolation methods is Inverse Distance Weighted (IDW) interpolator. This study proposed using the inverse distance weighted (IDW) interpolator rather than other interpolation techniques such as the kriging method due to the limited accuracy of kriging interpolation when the number of sampled observations is small, as in the current study. Therefore, IDW was used as an accurate interpolation method where the estimated value of a point is impacted more by nearby known observations than by those further away. It is used to estimate the values for any unmeasured place by measuring the values in the vicinity of the anticipated location. It is fundamentally dependent on two assumptions: First, the influence of an unknown point value is instantly increased to the close control point rather than the far points. Second, the impact degree point is inversely proportional to the distance between the two places. This can lead to the following equation:

$$Z^{*} = \sum_{i=1}^{n} \omega_i \, Z_i$$

Where Z_i is the value of the data to be interpolated by a number of n points and weights (ω_i) formulated as:

$$\omega_i = \frac{h_i^{-p}}{\sum_{j=0}^{n} h_j^{-p}}$$

P is a positive value that can be changed is called the power parameter and h_j is the distance to the point of interpolation which is described as:

$$h_i = \sqrt{(x - x_i)^2 + (y - y_i)^2}$$

Where (x, y) is the coordinate of the interpolation point and (x_i, y_i) is the coordinate of the default data point.

Using known climatic data readings from adjacent dataloggers, we could predict many environmental variables such as air temperature, surface temperature, relative humidity, and air velocity at a place with no recorded data using spatial interpolation. This phase of the research passed by several steps as follow:

- All climatic measurement locations were signed as point features on the college site map.
- The mean temperature values during the daytime (08.00 a.m. and 06:00 p.m.) were calculated and entered in the attributes table of the point features.
- IDW interpolator was utilized for each variable to predict all unobserved locations.
- The output results were obtained as a raster map for the college site showing the climatic results for each point in the study area.

3. RESULTS& DISCUSSIONS

Each data collecting location has a distinct landscaping ground material, according to the field survey. All climatic measurements were collected above seven points that represents 6 (six) diverse types of ground surface materials. Table 2 lists the urban ground materials utilized at each measuring site.

3.1. Analysis of Surface-Air Temperature Associated with Ground Surface Materials

A comparative means statistical test was used to examine the association between the mean values of surface temperature at each measurement location. The one-way analysis of variance (ANOVA) is the appropriate method to use when comparing the means of more than two groups. Before the tests, the data were checked for normality using the Kolmogorov-Smirnov test. The results of the normality test show that the data were normally distributed ($p > 0.05$), hence, one-way ANOVA test has been conducted comparing the mean surface temperature values between the measuring locations for the six ground surface materials.

The findings indicate that the mean surface temperatures differed from one ground surface material to another. The warmest materials were; asphalt (50.27°C), soil (46.06°C) and cement chequered tiles (45.74°C) respectively, while the coolest material was the grass (22.31°C) (Table 2). Further analysis has been conducted to compare means between each materials using a Tukey-Kramer test (Figure 4). Based on the findings from ANOVA analysis, $F = 7.443$ with $P = 0.000$, this implies that the surface temperature at each measuring location differs significantly (Table 3).

In addition, the results show that the highest mean value for surface temperature was recorded above the asphalt at points 4 and 7 (50.27°C), with maximum and minimum values of 61.80°C and 33.20°C respectively. While the lowest value was at point 3 with a mean value of 22.31°C above the grass, with maximum and minimum values of 24.95°C and 18.50°C respectively. Other findings indicate that there were no substantial differences comparing the means of asphalt vs. soil, asphalt vs. concrete tiles, and concrete tiles vs. soil. However, when comparing the means of all artificial materials and grass, they show significant difference between them.

Table 2. Mean values of surface temperature, air temperature, relative humidity, and air velocity across all the ground surface materials.

Measuring Point	Surface Material	Surface Area (m^2)	Surface Temperature (◦C)	Air Temperature (◦C)	Relative Humidity (%)	Air Velocity (m/Sc)
1	Concrete Tiles	2045.45	43.65	37.36	17.64	0.37
2	White Concrete Tiles	16.65	40.95	37.63	22.57	0.28
3	Grass	2589.98	20.34	26.91	31.34	0.39
4 , 7	Asphalt	6334.8	49.19	41.4	18.19	0.48
5	Soil	3418	47.72	40.03	18.03	0.41
6	Cement Chequered Tiles	590.45	42.36	36.57	16.40	0.43

Table 3. One-Way ANOVA test results of surface temperature between the measuring points.

		Sum of Squares	df	Mean Square	F	Sig.
Surface Temperature	Between Groups	3941.77	5	788.355	7.443	.000
	Within Groups	41627.74	393	105.923		
	Total	45569.52	398			

One of the objectives of this study is to investigate the variations of surface and air temperatures associated with different ground materials. According to the findings, the mean values of the surface temperature imply significant differences for each ground surface materials (Figure 4). There are many reasons for these variations such as; pavement composition, thermal characteristics, color, and texture. The heat storage capacity for each ground surface material is affected by solar absorption, the reflectivity and the emissivity of the surface, depending on the material composition [42]. The albedo of a substance is affected by the color of a surface, which impacts surface temperatures. Lighter surfaces have a higher albedo and more light, whereas darker surfaces absorb a higher solar level and are less albedo [50].

Asphalt is typically dark and absorbs large amount of heat [44]. These findings can reveal the impacts of color on surface temperatures. For instance, the highest mean value for surface temperature was recorded above the asphalt at (50.27°C), while lighter surfaces such as white concrete tiles recorded a mean value of 32.93°C. Furthermore, the roughness of a surface also influences the direct absorption of solar radiation. Since the surface area is exposed throughout the day to direct sunlight, smoother surfaces were cooler and rougher surfaces were warmer [46]. These trends can also be observed in the findings, smoother surfaces such as concrete tiles and white concrete tiles have lower surface temperatures (45.04°C and 32.93°C), comparing with rougher surface such as asphalt and soil (50.27°C and 46.06 °C). Due to the fact that all materials absorb daytime solar radiation, they radiate nighttime heat, rising ambient air temperatures [51].

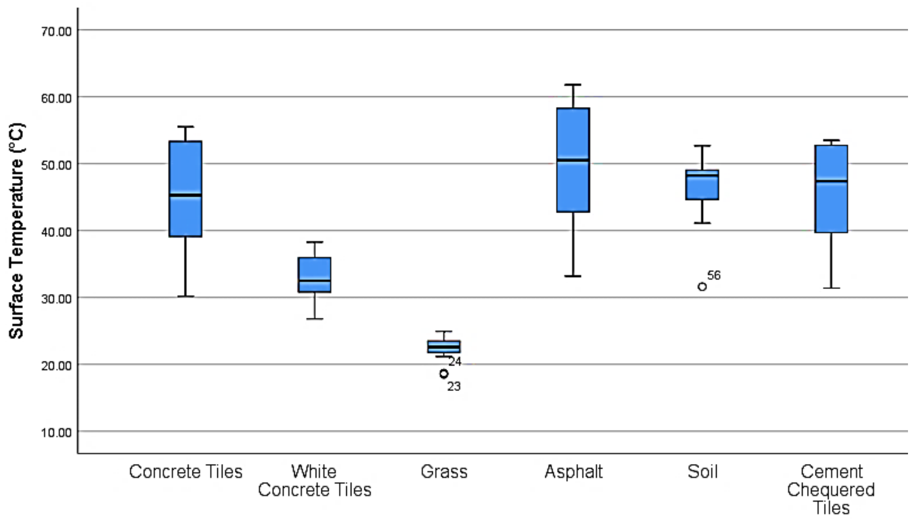


Figure 4. Mean values of surface temperature. The highest value was recorded above the asphalt, while the lowest value was above the grass.

Ambient air temperatures contribute to human thermal comfort. Temperature variations may be uncomfortable; therefore, a variety of ways can control the ambient air temperature in the built environment to maintain the temperature steady. In addition to the variations in the surface temperature existed at each measurement location, the differences between ambient air temperatures at each location have been analyzed as well. There is a substantial variation in the ambient air temperature for each measuring location. The findings imply that the mean values of air temperature significantly differed from one material to another. The results show that the mean air temperatures ranged from 25.47°C to 41.4°C at the grass and the asphalt respectively (Table 2).

Comparative means statistical tests were used to examine the ambient air temperature at each measurement location. First, the data was examined by the Kormolov-Smirnov test resulting in a normal distribution and the data distribution should be assessed by a parametric test. For the data to be analyzed comparing the means among measuring points, One-Way ANOVA test and Tukey's Post Hoc test was further conducted. Based on the findings, presented in Table 4, the ANOVA results (F = 4.074 with P = 0.000) implies that the mean values of air temperature at the seven measuring points are significantly differentiated. It indicates that the air temperature at every measuring point differs significantly. For instance, at points 4 and 7, the average ambient air temperature was 41.4°C above the asphalt (the highest value compared to other means), while point 3 exhibited the lowest temperature with a mean value of 25.47°C above the grass.

Table 4. One-Way ANOVA test results of air temperature between the measuring points.

		Sum of Squares	df	Mean Square	F	Sig.
Air Temperature	Between Groups	759.18	5	151.838	4.074	.001
	Within Groups	14647.20	393	37.270		
	Total	15406.46	398			

Similarly, the air temperature above the various ground surface materials imitates the trend found in the surface temperature. Mean values of air temperature above each ground material is presented in Figure 5. The boxplot illustrates the air temperature distribution using bold lines that represent the mean value of each ground surface material. Excluding the grass material, the mean values of air temperature seem slightly comparable above other artificial materials. This might be attributed to higher summer temperatures in the study area.

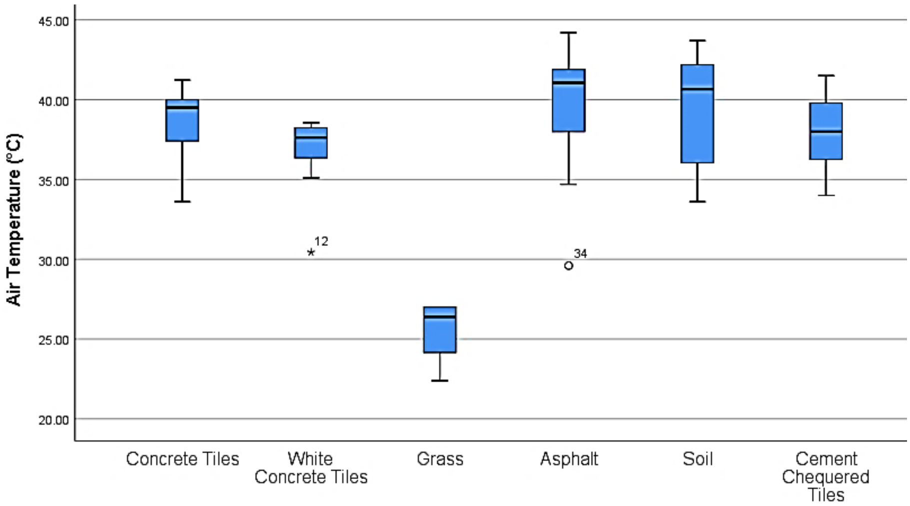


Figure 5. Mean values of air temperatures. The highest ambient air temperature compared to other locations was above the asphalt, the lowest temperature was above the grass.

3.2. Analysis of the Correlations between Surface and Air Temperature

Based on the earlier findings, there were significant variations in both surface and air temperatures associated with different ground surface materials. Using OLS regression analysis, air temperature was the dependent variable and considering the other microclimate variables as independent variables such as; surface temperature, relative humidity, and wind speed. Stepwise regression model has been used to find the best fitted model. The correlation analysis between surface and air temperatures reveals relatively strong positive correlation between them, considering different ground materials (as presented in Figure 6). The results of the multivariate regression models, presented in Table 5, show a strong positive correlation between surface and air temperature with overall R^2 value of 0.710 as a model fit.

Air temperatures are impacted by seasonal, climatic influences and pavement characteristics. This occurs when ground surface materials expose to direct solar radiation and absorb more heat during the summer months. Thus, surface temperatures rise, causing increase of ambient air temperatures due to convection current from the materials. This phenomenon occurred with the artificial pavements such as asphalt, concrete tiles, and soil. However, the air temperature is significantly lower over natural covers like grass because of evapotranspiration.

Table 5. OLS Regression Model Summary& Coefficients.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.842[a]	0.710	0.708	3.36029

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	32.116	1.439		22.315	.000
Relative Humidity	-.356	.030	-.464	-11.803	.000
Surface Temp	.257	.023	.443	11.254	.000

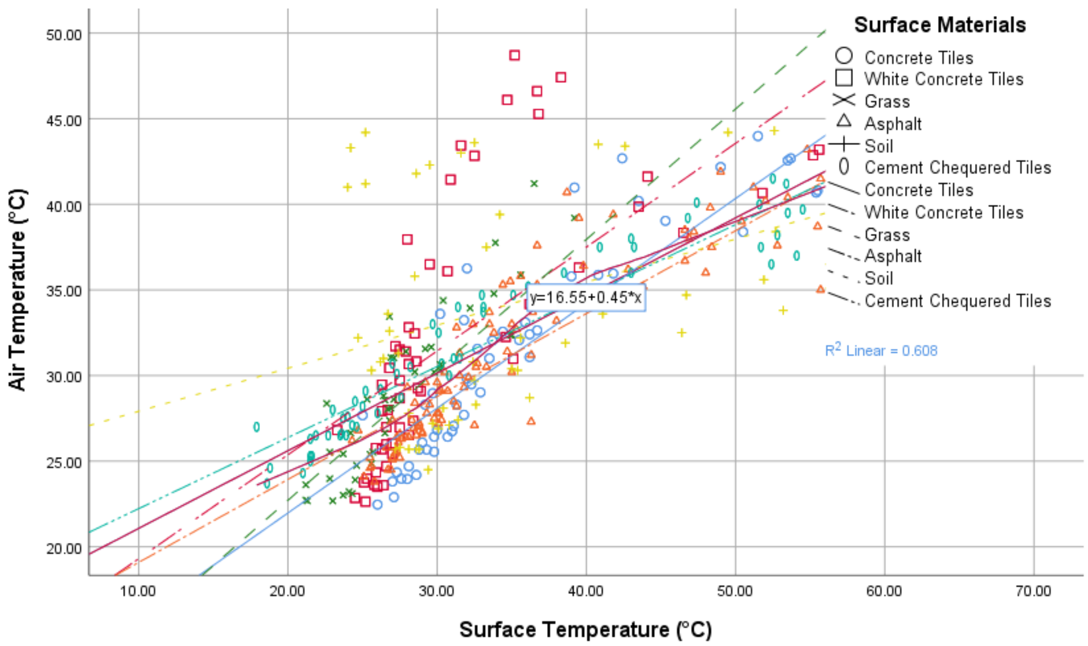


Figure 6. Correlation analysis between surface and air temperatures for different ground materials.

3.3. Spatial Autocorrelation and Interpolation Results

Spatial statistics like the spatial autocorrelation (Moran's I) is a valuable tool for determining the spatial pattern of the collected data. They are more effective when the spatial pattern is consistent across the study area. In general, spatial patterns can be described as three types either; clustered, dispersed, or random. Spatial autocorrelation is positive and clustered when similar values are located near each other, while negative and dispersed correlation is common where the adjacent area has many different values. Between the two patterns, there is a random pattern showing no spatial autocorrelation.

This study uses data of the mean values of air temperature measured at the study area of Aswan University campus. The autocorrelation test result using Global Moran's I is presented in Figure 7. The results show, with 95% confidence level, that the mean air temperature data has a positive spatial autocorrelation, which means that the formed spatial pattern for the study data is clustered. The results of Moran’s index test report that Z-score has a value of 974.689 and Moran’s index of 0.737. Based on the test criteria with 99% confidence level, because Z (I)> Z ($\alpha 2/$) then null hypothesis is rejected, and it can be concluded that air temperature data has clustered and positive spatial autocorrelation.

Since the results from the Moran’s Index test reveal that the data has a positive and cluster spatial autocorrelation, the spatial interpretation method should be valid for the measured data predicting the other unobserved locations in the entire study area. In this regard, the interpolation technique IDW was applied, and the results were extracted as raster maps for the mean values of different microclimate variables during the daytime. Figure 8 depicts a statistically significant relationship between the ground surface materials and the microclimate variables such as; a) air temperature, b) surface temperature, c) relative humidity, and d) air velocity.

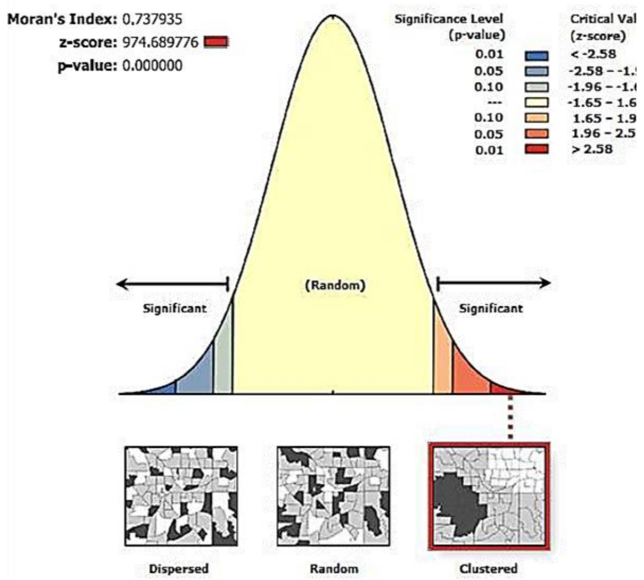
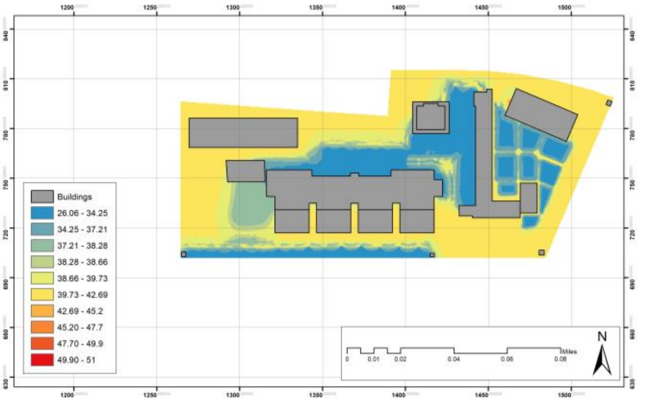
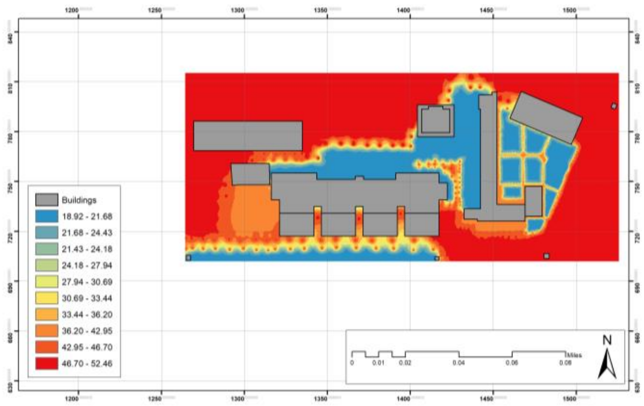


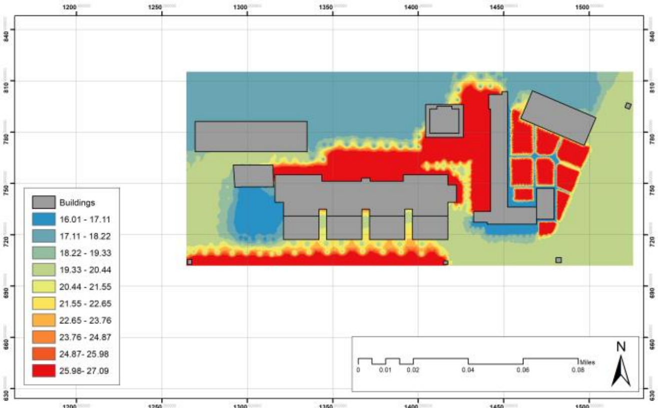
Figure 7. Global Moran's I result for surface-air temperature in Aswan University Campus.



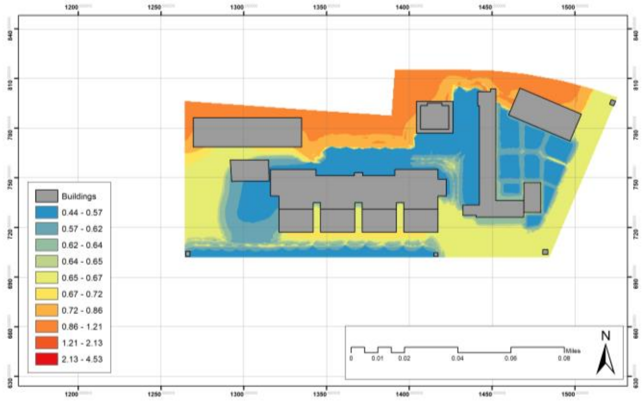
(a) Air temperature (◦C)



(b) Surface temperature (◦C)



(c) Relative humidity (%)



(d) Air velocity (m/Sc)

Figure 8. The results of IDW interpolation technique in terms of average of (a) air temperature (◦C); (b) surface temperature (◦C); (c) relative humidity (%); (d) air velocity (m/Sc).

The results of the IDW interpolation method (Figure 8) report that the lowest mean air temperature is above the grass (26.03°C) followed by cement chequered tiles (37.22°C), while the highest temperature can be observed over the asphalt (42.27°C). In terms of surface temperature, the lowest and highest temperatures were recorded above the grass and asphalt (19.52°C and 50.32°C, respectively). The findings also report that the highest level of relative humidity was measured above the grass (32.25 %), while the minimum value was recorded above the cement chequered tiles (16.84 %).

According to the statistical analysis of the measured data, each ground surface materials has different surface and air temperatures. The findings also show that the surface temperature influences the temperature of the air above. Pavement composition, thermal characteristics, color, and texture all play a significant role in these variations. According to Tan and Fwa [42], heat storage capacity for each type of the ground surface materials used in the analysis is influenced by solar absorption, reflectivity, and emissivity of the surface.

The interesting result was that the IDW interpolation results are slightly comparable with the measured data. The justification for that is the interpolation results represent the mean value for the entire study area which might be different from the observed data recorded at specific measurement location. There is no substantial difference in air velocity values above any ground surface materials, indicating that ground surface materials and air velocity have a weak correlation. These findings are consistent with earlier research [39], which found that grass had the lowest or coldest surface temperature, whereas asphalt has the greatest or warmest surface temperature.

4. LIMITATIONS

The relationship between surface and ambient air temperature associated with different ground surface materials has been investigated in this research using a variety of methods, including experimental measurements, ANOVA statistical test, regression analysis, spatial interpolation using (IDW), and Global Moran’s I. It is worth mentioning that this study has some limitations such as; A spatial limitation due to the study's application in Aswan city, which characterized with a hot desert climate. Measurement campaigns were conducted only in June, the hottest month of the year in the study region, without considering the other months. Additionally, the sky view factor at each measured point is not considered in this study because it has roughly the same value across all studied locations.

This study found no correlation between albedo and other climatic variables such as surface and ambient air temperature, so it is considered a technical limitation. This finding was more in line with prior studies [51-53], which found that materials with a low albedo may provide the best thermal conditions, and that increasing the albedo of materials does not have a significant impact on enhancing thermal performance.

5. CONCLUSION

Generally, this study employs several adopted approaches for extracting spatially thermal variables above the indicated ground materials, such as; on-site measurements, statistical analysis of variance (ANOVA), inverse distance weighting interpolation (IDW), and spatial autocorrelation using Moran's I. The results of this research have revealed significant surface temperature variations among different ground surface materials and comparable results revealed that the heat absorbed influenced the above ambient air temperature. For instance, the mean air temperatures ranged from 25.47°C to 41.4°C at the grass and the asphalt respectively, while the highest mean value for surface temperature was recorded above the asphalt (50.27°C), and the lowest value was with a mean value of 22.31°C above the grass. The microclimate properties of all other types of ground materials above the surface are all different of the selected areas at Aswan University Campus.

Considering the high spatial autocorrelation of surface air temperature, inverse distance weighting (IDW) interpolation method has been employed to generate spatially continuous temperature maps from point measurements. Based on the results obtained from the spatial analysis (Moran’s I and IDW interpolation), maximum surface and air temperature values were recorded above the asphalt material (50.32°C and 42.27°C, respectively), while the lowest surface and air temperature values were recorded above the grass (19.52°C and 26.03°C, respectively). There is a positive correlation between the tested ground surface materials and the obtained values for different microclimate variables (surface temperature, air temperature, and relative humidity).

The results of this research have broader implications, denoting those comparable hot desert regions may benefit from similar studies to cool down their urban regions throughout the summer season. This research provides quantitative thermal data that can be utilized to develop effective solutions to enhance urban micro-scale thermal conditions in hot desert climate. The research findings offer a range of temperature differences that can be used to examine the impacts of different ground surface materials on the surface and air temperatures, from a microclimate standpoint. Using this passive approach of decreasing temperatures would improve air temperature and save energy by reducing the need for air conditioning and other artificial cooling methods. This research also highlighted critical data about how different urban ground materials varied in terms of surface and air temperatures, assisting urban planners and architectural designers in selecting suitable ground surface materials in terms of climatic considerations in the preliminary stages of landscape design.

As a recommendation for future research, we propose conducting further research in a wide range of conditions, such as more neutral and cooler temperatures. Furthermore, more research is required to improve and modify ground materials characteristics, such as albedo and reflectance, by considering the relative contributions of various radiation components. Additionally, pavement attributes such as emissivity and reflection can be evaluated in association with pavement factors such as surface roughness. Lastly, the influence of the height above the pavement on the thermal environment is also vital to further investigate, our measurement was done only on the pedestrian level at a height of 1.5 m.

6. ACKNOWLEDGMENTS

This research is based upon work under the grant "German-Egyptian Research Fund" (GERF4), ID: 23022 and funded by the Science, Technology, and Innovation Funding Authority (STDF).

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