Influence of Surface Temperature on Urban Heat Island Effect in Two Sub-cities in Muscat, Oman

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Abstract*— Rapid urbanization and its associated land use and land cover change are well known. Urban Heat Island (UHI) effects are reported in many cities due to the increase in the built-up area for different purposes. This phenomenon may affect local climate as well as thermal comfort of inhabitants. UHI was quantified in two sub-cities namely Bosher and Muscat in Muscat governorate in winter and summer. The two sub-cities were selected based on the contrasting rate of change in population between the year 2010 to 2020, Bosher and Muscat with 98.5% and 15.1% respectively. The UHI quantification was carried out by measuring land surface temperature and air temperature in the accompanied changes in residential, commercial, residential/commercial and industrial land use types. Field measurement was compared with secondary data from meteorological and remotely sensed data. The strength of UHI was found to be higher in winter season compared to summer especially in Bosher. UHI showed a value of 3.67 °C and 4.10 °C in Bosher and Muscat measured as land surface temperature in summer during the day, while during the night it was higher in Bosher by 0.83 °C. In winter season, it showed a value of 2.89°C in Bosher and 1.94 °C in Muscat in the night. However, data from measured air temperature in summer indicated absence of UHI in summer during the day and night in Muscat, and occurrence in Bosher sub-city. Analyzing meteorological data indicated that formation of UHI during the day and night time in winter with values between 0.90-3.36°C. However, in summer, no UHI formation during the day and night in Muscat, while it occurred in Bosher with a value of 4.22°C during the day. Remote sensing data showed formation of this phenomenon in summer in Bosher, while not occurred in Muscat during the day. In general, results from the three different data sets indicated higher UHI in summer in populated Bosher sub-city during the day and night time. Measuring and evaluating the effect of this event using both primary and secondary data is important to come up with a clear understanding of changes happening in the city. Findings from this study will help city planners understand the microclimate variations associated with land use and land cover change happening in and around the city and most importantly use as input in future planning and decision-making.

***Keywords*—** Urbanization, Urban heat island, Field measurement, Meteorological data, Remotely sensed data.

I. Introduction

Studies showed that changing in land use and land cover is a major human contributor to climate change beside the increasing carbon dioxide and other gases in the atmosphere [1], [2]. By 2050 more than 70% of population in the world will reside in urban areas as a result of current growth rate of urbanization according to the United Nation [3]. Changing land use and land cover as a result of urbanization will accelerate formation of Urban Heat Island (UHI) effect. In addition to that, the increase of inhabitants in the city is accompanied with the development in urban structures, such as asphalt, pavements, buildings exacerbate this phenomenon [2]. UHI was documented in many literatures [1]–[4]. It means that surface temperature and air temperature are higher in urban areas compared to the surrounding rural or less urbanized places [5].

This phenomenon can be quantified through measuring land surface temperature (LST) or air temperature [6]. This quantification is usually conducted in different land use and land cover through different methods [6], [7], by using either direct measurement (surface temperature and air temperature) or indirect estimation through remotely sensed data [5], [8]. Most work relay on remotely sensed data due to the challenges and time consumed in the field [9].

UHI has been noticed in many cities across the world especially in developed countries and less studies were conducted in developing countries [10]. Inhabitant's size in the city has highly and positively correlation with the strength of Urban heat island effect, demonstrates the negative impacts of urban growth on this phenomenon [11].

This study attempt to quantify UHI in two sub-cities in Muscat governorate with different population densities. Three different data sets were used to come up with clear understanding of changes happening in the city.

II. Materials And Methods

A. Study site

Muscat is the capital of Oman. According to Köppen classification, it is classified as hot arid climate (BWh) [12]. The annual mean air temperature and rainfall in the last few years (2016-2019) in Muscat sub-city (23.563345N,58.601809E) are 28.8°C and 107 mm respectively. While in Bosher (23.48438N,58.25435E), the air temperature is 30.2°C and rainfall of 74.5 mm [13].

According to the latest E-census of population in 2020, population of Oman stood at 4,471,148. The population of Muscat governorate was 1,302,440 which represents 29.13 % of Oman population. About 29.3 % of them resides in Bosher, while in Muscat only 2.4 %, which are the sub-cities selected in this study [14].

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Different land use types including, Industrial, Built-up area (Residential, Residential/Commercial, Commercial) and greenery space with different land cover (Road, Pavement, Bare soil and vegetation) were selected for the study (Figure1).

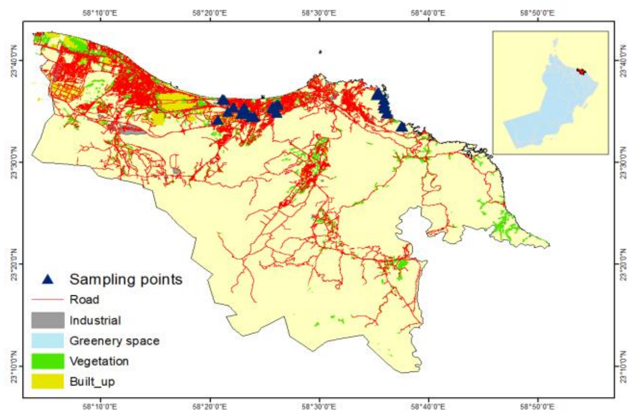

Fig. 1: Locations of field survey

B. Quantification of Urban heat island (UHI)

The survey was carried out in summer (June, July and August) 2019 and in winter season (December, January and February) 2019-2020. Temperature of each land surfaces were taken using non-contact infrared thermometer device (OS423-LS Ω OMEGA) with a probe to measure the air temperature. The locations of sampling were determined using a Global Positioning System (GPS-Germin-62s) with an accuracy of ~ 3 meters. Measurements were taken during the day (7-9) am and (12-2) afternoon to represent day time and 7-9 p.m. to represent night time.

Secondary data from meteorological station for the same months were analyzed. Hourly data of air temperature between 7-9 a.m.,12-2 noon and 7-9 p.m. were selected for comparative analysis with field measurement.

Landsat 8 OLI/TIRS images for these months (June-July-August) 2019 and (December-January-February)2019-2020 with spatial resolution of 30 m and path 158 and row 43 and 44 were acquired through the USGS Earth Explorer (earthexplorer.usgs.gov). Thermal infrared bands which are band 10 and 11 with spatial resolution of 100 m were utilized in order to extract values of land surface temperature of the corresponding locations in the field.

C. Analyzing satellite images and data

Acquired satellite imageries undergoes processing using ArcGIS 10.8 software in order to quantify land surface temperature of different land cover in study area. IBM SPSS Statistics 21 software was used to analyze the data.

III. RESULT AND DISCUSSION

A. Urban heat island (UHI)

Urban heat island (UHI) was calculated using (1), where T is the temperature (°C), u is the Urban, r is the Reference [15].

$$UHI = Tu - Tr \quad (1)$$

Land surfaces measurements show occurrence of UHI in both sub-cities in both seasons with a value of about 4.00°C during day time in Summer. But at night the intensity of UHI is higher in Bosher compared to Muscat. In winter the value of it exceeds 4.0°C during day time, while at night it is 2.89°C in Bosher and 1.94°C in Muscat. Table. 1

TABLE I: THE QUANTIFIED UHI FROM FIELD MEASUREMENT

Sub-cities / Reference	Day / Night	Season	Land surface temperature (°C) Mean ± SE	UHI (°C)
Bosher	Day	Summer	49.05 ± 0.17	3.67
	Night	Summer	36.90 ± 0.49	1.23
	Day	Winter	33.43 ± 0.41	4.73
	Night	Winter	24.25 ± 0.41	2.89
Muscat	Day	Summer	49.48 ± 0.76	4.10
	Night	Summer	36.08 ± 0.53	0.40
	Day	Winter	34.57 ± 0.47	5.87
	Night	Winter	23.29 ± 0.34	1.94
Reference	Day	Summer	45.39 ± 1.00	0.00
	Night	Summer	35.68 ± 0.68	0.00
	Day	Winter	28.70 ± 0.70	0.00
	Night	Winter	21.35 ± 0.52	0.00

Air temperature from field measurements indicates also formation of UHI and its strength is more in winter season. Bosher has highest intensity UHI in the day and night. It reaches about 4.65°C in the night and 2.33°C at day. During summer season Muscat exhibits no formation of UHI. In contrast it reaches a value of about 1.10°C and about 0.70°C in the day and night respectively in Bosher. Table. 2

TABLE II: THE QUANTIFIED UHI FROM FIELD MEASUREMENT

Sub-cities / Reference	Day / Night	Season	Air temperature (°C) Mean ± SE	UHI (°C)
Bosher	Day	Summer	36.19 ± 0.19	1.08
	Night	Summer	33.78 ± 0.19	0.65
	Day	Winter	26.17 ± 0.18	2.33
	Night	Winter	25.94 ± 0.23	4.65
Muscat	Day	Summer	34.82 ± 0.18	-0.28
	Night	Summer	32.33 ± 0.14	-0.80
	Day	Winter	25.16 ± 0.11	0.79
	Night	Winter	23.66 ± 0.14	2.37
Reference	Day	Summer	35.10 ± 0.15	0.00
	Night	Summer	33.13 ± 0.30	0.00
	Day	Winter	24.37 ± 0.30	0.00
	Night	Winter	21.29 ± 0.33	0.00

Analyzing hourly air temperature data from meteorological station corresponding to the field measurements illustrates formation of this phenomenon in winter season in both sub-cities. However, it occurs only in Bosher in summer during day time with a maximum value of about 4.22°C. Table 3.

TABLE III: THE QUANTIFIED UHI FROM METEROLOGICAL DATA

Sub-cities / Reference	Day / Night	Season	Air temperature (°C) Mean ± SE	UHI (°C)
Bosher	Day	Summer	37.33 ± 0.15	4.22
	Night	Summer	36.86 ± 0.14	-0.96
	Day	Winter	22.61 ± 0.16	2.90
	Night	Winter	21.95 ± 0.14	0.90
Muscat	Day	Summer	32.93 ± 0.14	-0.18
	Night	Summer	32.12 ± 0.18	-5.70
	Day	Winter	23.07 ± 0.10	3.36
	Night	Winter	22.33 ± 0.09	1.28
Reference	Day	Summer	33.11 ± 0.23	0.00
	Night	Summer	37.82 ± 0.18	0.00
	Day	Winter	19.71 ± 0.20	0.00
	Night	Winter	21.05 ± 0.18	0.00

Moving on to analyzing satellite imagery. Remotely sensed data shows formation of UHI in winter season in day time. Meanwhile, it is absent in Muscat and present in Bosher in summer season. It reaches a value of 0.13°C. Table 4.

TABLE IV: THE QUANTIFIED UHI FROM REMOTELY SENSED DATA

Sub-cities / Reference	Season	Land surface temperature (°C) Mean ± SE	UHI (°C)
Bosher	Summer	35.50 ± 0.17	0.13
	Winter	25.46 ± 0.20	1.27
Muscat	Summer	31.06 ± 0.09	-4.31
	Winter	27.04 ± 0.15	2.85
Reference	Summer	35.37 ± 0.70	0.00
	Winter	24.19 ± 0.39	0.00

Studies elsewhere have shown formation of this phenomenon with different intensity [4], [6]. According to [16], Urban area may be about 2.5°C higher than rural area. Santos et al [17], documented those urban areas at least 2.30 to 7.20°C higher than undeveloped places. While, Wang and Murayama [18], mentioned that the temperature in rural area is 3.5-4.5°C lower than in urban area.

B. Land use (LU)

In summer during day time and night time, mean air temperature in industrial area is higher compared to other land use and it reaches 35.31°C, 33.57°C respectively. While in day time greenery space is lowest by about 0.30°C. During night it is lowest in greenery space and residential area by about 0.40 °C. Measuring land surface temperature shows high temperature in residential / commercial in both day and night with value of 48.13°C and 35.98°C respectively (Figure 2a), (Figure 2b).

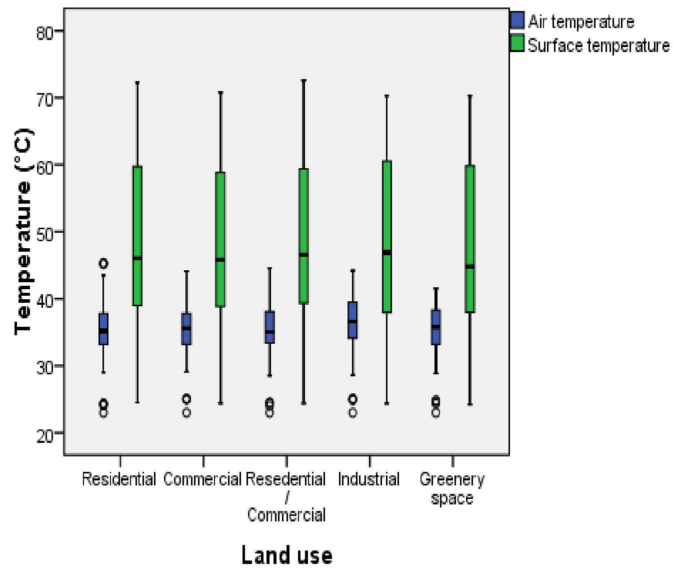

Fig. 2a: Boxplots of mean air (P-value > 0.05) and surface temperature (P-value > 0.05) by land use in day-summer

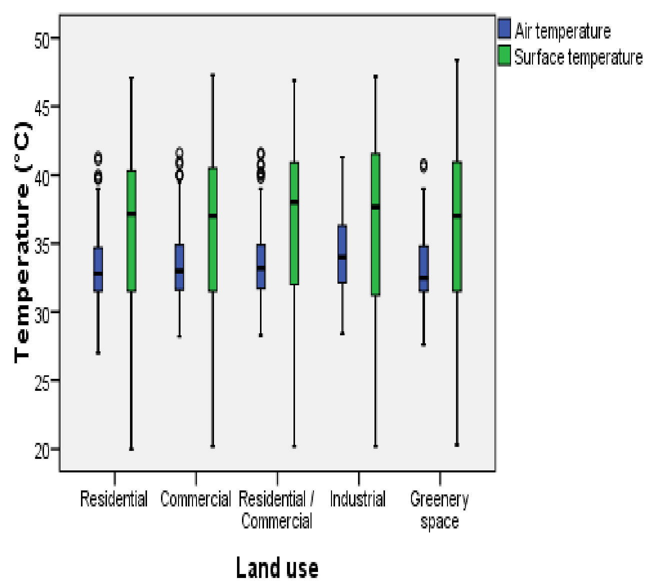

Fig. 2b: Boxplots of mean air (P-value > 0.05) and surface temperature (P-value > 0.05) by land use in night-summer

In winter, mean air temperature measured is higher in residential/ commercial and industrial areas with 25.44°C and 25.27°C respectively. While it is lowest by about 1.47°C in greenery space. At night it is highest in residential/commercial area compared to other land use. Day time measurements show higher mean land surface temperature in residential/commercial area and it reaches 33.34°C, while it reaches 23.33°C at night (Figure 3a), (Figure 3b).

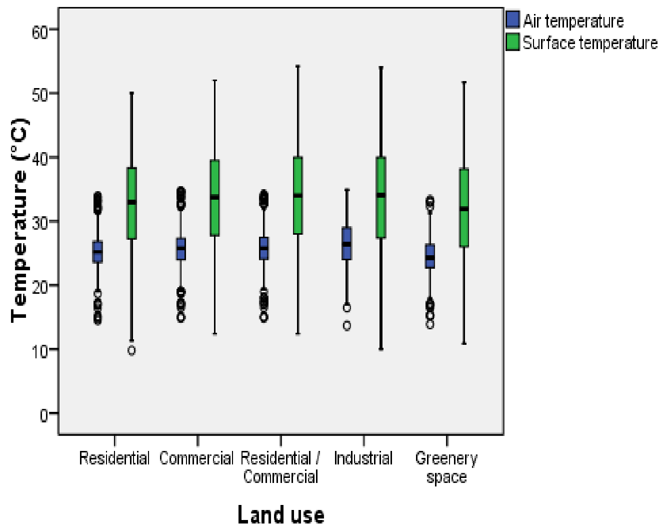

Fig. 3a: Boxplots of mean air (P-value > 0.05) and surface temperature (P-value < 0.05) by land use in day-winter

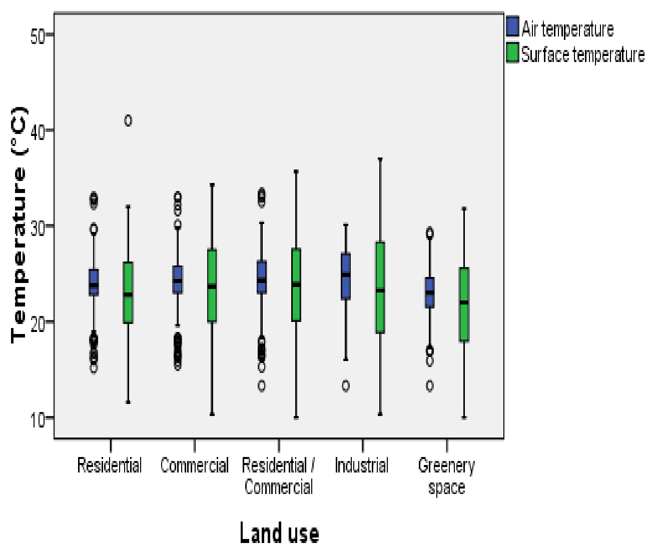

Fig. 3b: Boxplots of mean air (P-value > 0.05) and surface temperature (P-value < 0.05) by land use in night-winter

Remotely sensed data shows a maximum value of the mean surface temperature in Industrial area compared to other land use in summer. Mean surface temperature difference between industrial and greenery space is 2.7°C. In contrast, in winter the difference reaches 1.21°C (Figure 4).

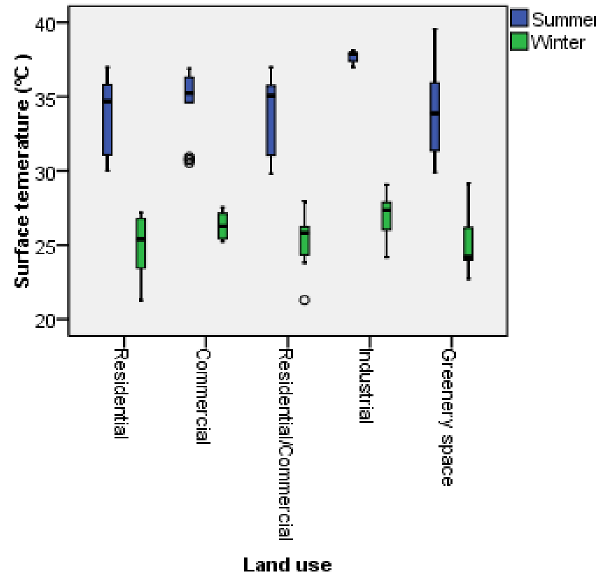

Fig. 4: Boxplots of surface temperature in day-winter (P-value > 0.05) and in summer (P-value < 0.05) by land use

C. Land cover (LC)

Land cover in these different land use plays major role in rising the temperature of both the air and the surface temperature. Field measurements in summer and winter in road, pavement and bare soil has the highest temperature compared to vegetation. In summer at day and night, mean air temperature of road is the highest and reaches about 35.58°C, 34.12°C respectively, while in vegetation it is lower by 1.99 °C at day and 2.47°C at night. Road surface temperature at day has a maximum mean value of 52.00°C, while vegetation has a minimum value of 35.00°C. At night the order is as follows: Road >Pavement>Bare soil>Vegetation (Figure 5a), (Figure 5b).

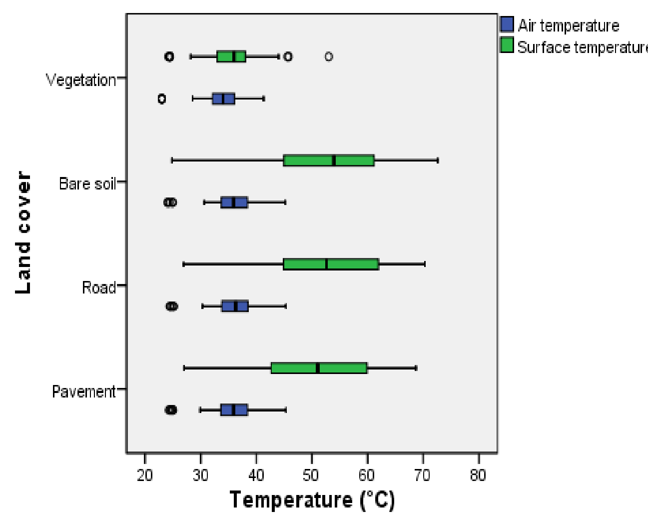

Fig. 5a: Boxplots of mean air (P-value < 0.05) and surface temperature (P-value < 0.05) by land cover in day-summer

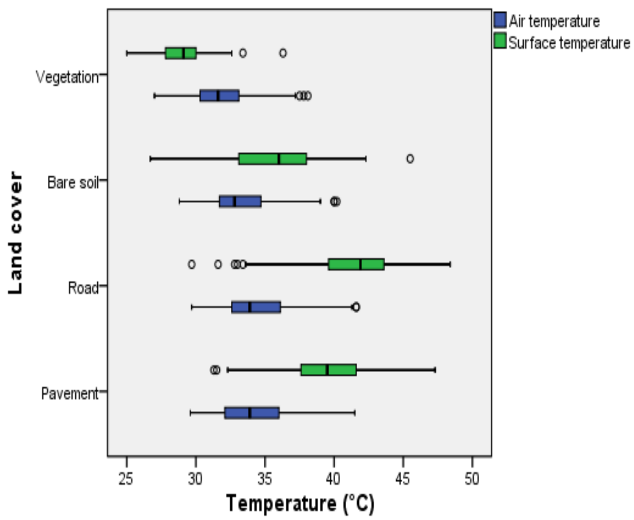

Fig. 5b: Boxplots of mean air (P-value < 0.05) and surface temperature (P-value < 0.05) by land cover in night-summer

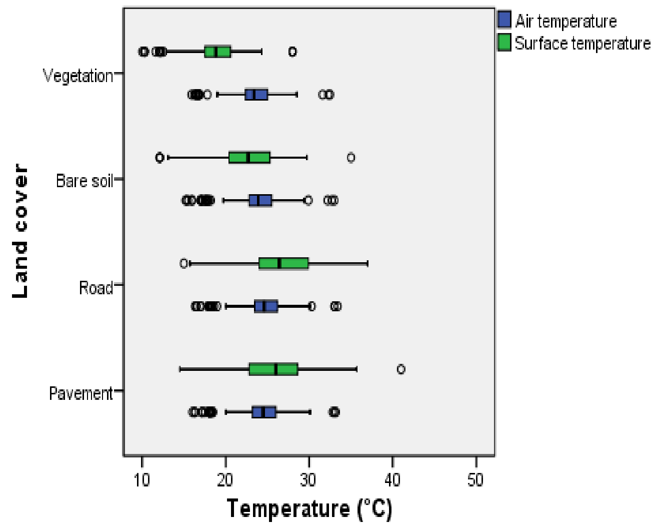

Fig. 6b: Boxplots of mean air (P-value > 0.05) and surface temperature (P-value < 0.05) by land cover in night-winter

In winter season mean day air temperature difference between vegetation and other land covers is in the range of 0.63°C and 0.81°C. While, in the night time it is between 0.66°C and 1.33°C. Road and pavement surface temperature at day have a maximum mean value of 35.25°C and 34.21°C respectively, while vegetation and bare soil have the lowest. Also, at night road and pavement have the highest value of temperature in comparison to bare soil and vegetation (Figure 6a), (Figure 6b).

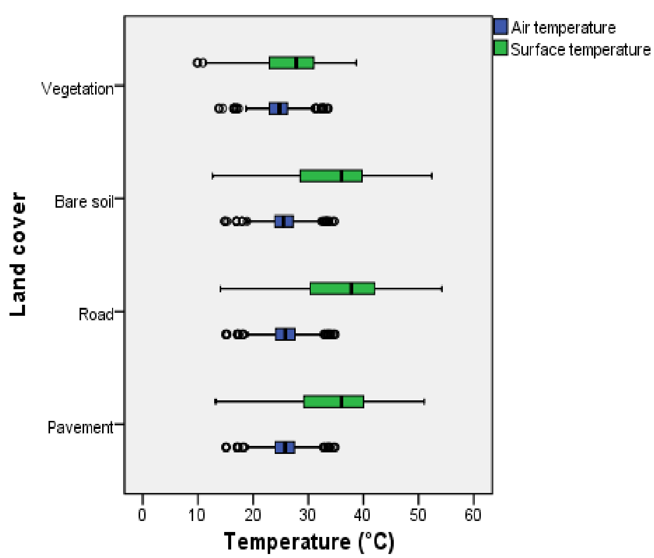

Fig. 6a: Boxplots of mean air (P-value > 0.05) and surface temperature (P-value < 0.05) by land cover in day-winter

IV. Conclusion

This study aimed to quantify UHI in two sub-cities in two seasons using primary and secondary data. In general, air and surface temperature results showed formation of UHI especially in winter season with different values. Urban heat island occurred in the two sub-cities studied, ranged between 0.40-5.87°C. However, it was high during the night with the strength of 2.37°C in Muscat and reached to 4.65°C in Bosher. Analysis of remotely sensed and meteorological data confirmed the formation of this phenomenon. Greenery space recorded the lowest air temperature with the reduction of 0.30-1.47°C, emphasizing the importance of vegetation in the city. Findings from this study may be helpful for decision makers as well as city planner.

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