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Urban Heat Island and Thermal Human Comfort in Tulkarm, West Bank, Palestine

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✓ West Bank.

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Abstract

The objective of this article is to examine the climate in the urban center of Tulkarm (West Bank) and compare it with the climate of other regions (Haifa, Ben-Gurion) in terms of local climate zones (LCZ). The outcome measures for the thermal comfort were the physiologically equivalent temperature (PET), the thermal discomfort index (DI), and the universal thermal climate index (UTCI). All the gathered data in this study derived from registrations of the weather stations located in these LCZs. The results showed that, the Tulkarm (LCZ 2_{4B}) was warmer than the Ben-Gurion (LCZ 6_{8E}) and Haifa (LCZ 8_{10A}) sites throughout the study period 2000-2014 (mean difference in monthly air temperatures between LCZ 2_{4B} and LCZ 6_{8E} was 1.5 °C with maximum of 2.4 °C in May and a minimum of 0.9 °C in February). Between LCZ 2_{4B} and LCZ8_{10A} as well as between LCZ 2_{4B} and LCZ6_{8E} the differences in minimum air temperatures are higher than in maximum air temperature. Wind speed was lower and dew point depression (DPD) was higher in the LCZ 2_{4B} region compared to the others. In the low-rise built up areas of Ben-Gurion and Haifa, the PET and UTCI were always lower than in the mid and high-rise urban region of Tulkarm. The DI indicated that, during summer months, more than 50% of the total population felt discomfort in regions characterized by urban or industrial structures (Tulkarm and Haifa). The study suggests that heat exposure in Tulkarm is a consequence of local land use.

1. Introduction

Urban climate change was suggested as an ‘analogue’ for global climate change [1]. Similar to global climate projections, the urban atmosphere is warmer (and richer in greenhouse gases) when compared to the background climate [2]. As the Mediterranean region is expected to experience substantial future climatic change [3] their urban zones will become “hot-spots” of climate change related risks. These risks comprise of coastal erosion and coastal flooding [4], droughts [5], water scarcity [6], air pollution [7], and heat. Recently, the heat related effects in cities, such as the urban heat island (UHI) and the thermal comfort, came to the focus of urban environmental research [8], especially in the region between Jordan and Mediterranean coast that is among the most vulnerable regions. The urban temperature effect is the result of a number of processes involving the radiation balance, evapotranspiration, heat storage, anthropogenic heat, and the effects of convective heat transport between the surface and the atmospheric boundary layer [9]. The atmospheric UHI tends to keep the night-time temperature of the city higher than those of the faster cooling rural areas under calm wind and clear sky conditions. This is associated with urban-rural contrasts in air humidity, wind speed, cloud amount as well as rainfall [10]. Recent UHI studies [11, 12] involved the type of urban land use more in detail and utilize the local climate zones (LCZ) suggested by [13] for urban temperature studies. This classification scheme is based on land use, vegetation cover, building density and height and geometry, and ground perviousness. The present study aims at assessing the current state of urban climatic conditions in Tulkarm, West Bank Palestine, in a 15-year-period (2000-2014), their contrasts to sub-urban and rural sites (as classified into local climate zones) and its impact on human thermal discomfort. For that purpose, temperatures registered at the immediate surroundings of the urban inhabitants are relevant (canopy layer temperatures). So far, no studies dealing with the urban effect on climatic elements have been conducted in the West Bank, Palestine. The study analysis of long-term observations as well as simulations addresses 1) the extreme thermal burdens and 2) possible impacts of the West Bank Separation Wall on local climate.

2. Material and Methods

2.1. Methods

Meteorological data were obtained from three weather stations (Figure 1) in Tulkarm, Haifa Airport, and Ben-Gurion Airport. For the period 2000-2014 mean monthly data of air temperature (°C), minimum air temperature, relative humidity (%), wind speed (km/h), and dew point depression (DPD, °C) were gathered from Palestinian Meteorological Department and historical climate data records of Israel (Global climate data). Air temperatures were measured by dry bulb mercury thermometers sheltered from direct solar radiation 2m above ground level with an accuracy of 0.1°C. The mean monthly minimum temperatures were derived from an average of the daily minimum temperatures and the mean monthly diurnal temperature range (DTR) is defined as the difference between the mean monthly maximum and minimum temperatures ($DTR = T_{max} - T_{min}$). Wind speeds were recorded by anemometers (standard height 10m). Dew point depression (DPD) is the difference between air temperature and dew point temperature. Hygrometers registered relative humidity. Monthly and seasonal differences of the meteorological parameters were calculated between the urban, suburban, and rural stations. Thermal comfort was assessed by three indicators: Physiological Equivalent Temperature (PET) (based on the numerical radiation model RayMan [14]; calculations were made at 12 pm and in the mid of each month); Discomfort Index [15] calculated according to $DI = Ta - (0.55 - 0.0055*RH)*(Ta - 14.5)$ from the mean monthly temperature (Ta in °C) and the mean monthly relative air humidity (RH in %); Universal Thermal Climate Index (UTCI).

2.2. Study area

(a) Tulkarm is a town situated on the western part of the northern West Bank (weather station located at 32º19 N, 35º01 E, 83m a.s.l). It is about 40 km away from the south of Haifa, 25km north of Tel Aviv and 14 km from the Mediterranean Sea. Given the fact that it is influenced by the Mediterranean climate, Tulkarm has a yearly rainfall of 568mm limited to the winter. The relative humidity is on average 60% (Palestinian Meteorological Department)while the average temperatures, moderated by the sea breeze, range from 8 to 18 °C in winter, and from 23 to 31 °C in summer. Since the 1980s, several industries have been relocated to areas in the west part of the Tulkarm city resulting in increased air pollution. A high amount of pollution emitted from industrial areas reaches this district and further complicates the problem of air pollution. The Israeli government decided to construct the Separation Wall, which was built in 2002 along the west side of Tulkarm. This concrete wall of 8m height takes up large proportions of agricultural land and thus it has affected the urban development [16,17]. About 62,300 fruit trees consisted of the most common type of irrigated trees, namely Olive trees and Citrus trees, which have reached 370 hectares approximately, have been uprooted (Tulkarm Department of Agriculture, 2003/2004). The Separation Wall passes 17 villages and as a consequence it has destroyed 604 hectares of the land sand isolated 2,836 hectares located behind it in the Seam Zone. In the west part of Tulkarm a huge portion of land, which was used for agriculture, was confiscated for the construction of the wall and therefore the city expansion is limited along the west side. As the wall has considerably limited the urban green land and densified the urban area, we classified the Tulkarm as urban site in this study.

(b)

Figure 1: Geographic location of the study area and the three selected meteorological stations.

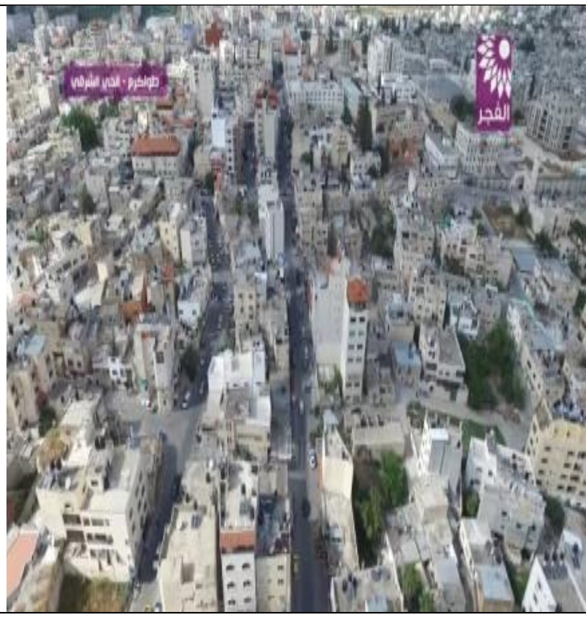
(c) Tel Aviv International Airport Ben-Gurion (32°0'1.16''N and 34°52'13.63''E) is located nearly 18km away from the Mediterranean Sea. The Ben-Gurion International Airport (Tel Aviv, Israel) weather station has a Mediterranean climate with dry hot summers and mild winters (Köppen climate classification Csa). The summers are dry and hot due to the predominance of subtropical high pressure systems while during the winters there is an experience of moderate and changeable temperatures (Israel Meteorological Service). The temperatures typically vary from 8°C to 32°C. The average summer temperature in Tel Aviv is 25°C, and the average winter temperature is 14°C. Precipitation during the summer is rare, winters are mild and wet. The relative air humidity ranges from 37% to 94% over the year, the driest months are April and May when relative humidity is dropping below 16%, while the most humid month is February exceeding 89% (Israel Meteorological Service). Tel Aviv Ben-Gurion International Airport is 19 km away from Tel Aviv city. There is a very vast open area around the Airport runway. There are no building activities around the Airport and the shortest distance between the nearest buildings and the Airport place is not shorter than 11 km. This area is covered by artificial surfaces (asphalt roads,29% and cropland,26%). The Ben-Gurion weather station is 19 km away from Tel Aviv city and it is considered as the rural site in the study.

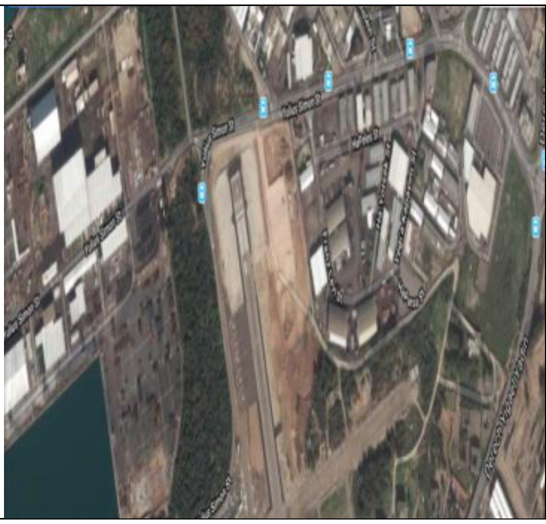
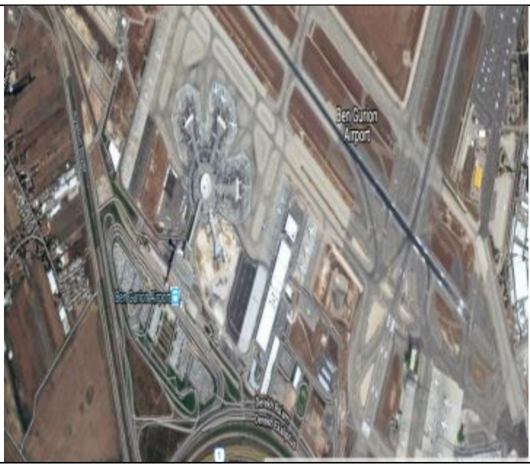
(d) Haifa International Airport (32° 47' 38.5584" N, 34° 59' 22.4556" E, 9m a.s.l) is situated on the Mediterranean coastline. Haifa has a Mediterranean climate with dry hot summers and mild winters (Köppen climate classification Csa). Over the course of a year, the temperature typically varies from 11°C to 32°C and is rarely below 8°C or above 33°C. The hottest month of the year is the July, with average maxima of 32°C and minima 26°C. The coldest month of the year is the January, with average minima of 11°C and maxima 18°C (Israeli Meteorological Service). The relative humidity typically ranges from 35% to 85% over the course of the year, rarely dropping below 20%. The air is the most driest around the November (relative humidity drops below 43% on three days out of four) and the most humidest around the April (exceeding 78% on three days out of four). Haifa International Airport is located nearly 10 km away from the east Haifa city and its role in the air pollution of the area is considered major. This becomes more apparent when the high incidence of cancers exceeding the national average rates in 1984-1999 [18] are taken into account. In this study, we consider Haifa International Airport as a suburban site.

2.3. Local climate zone classification of the study area

The classification of the studied sites was based on land use characteristics around the meteorological stations and follows the scheme of [13]. Surfaces and physical properties of land cover are classified into 17 standard LCZs; deviations from this standard set of classes can be made using subclasses that result in combinations of built types, land cover types, and land cover properties. The three studied sites were characterized according to surface cover, building height and terrain as LCZ2_{4B} (Tulkarm), LCZ 8_{10A} (Haifa; the station at the SW side of the airport runway was surrounded by forest to prevent from wind), and LCZ 6_{8E} (Ben-Gurion) (Table 1).

Table 1: LCZ classification of the three study sites [13].

<table>
<tr><th>Site</th><th>Landscape (Google Earth)</th><th>Photo</th></tr>
<tr><td rowspan="2">Tulkarm
LCZ 2_{4B}
(urban)</td><td></td><td>
</td></tr>
<tr><td colspan="2">• Dense mix of mid-rise and high-rise buildings; mostly paved; few or no trees.
• Land cover types: scattered trees; lightly wooded (low plants).
• 83 m a.s.l.
• 14 km distance from Mediterranean coast.</td></tr>
</table>

<table>
<tr><td rowspan="2">Haifa
LCZ 8_{10A}
(sub-urban)</td><td></td><td></td></tr>
<tr><td colspan="2">• Open arrangement of large low-rise buildings, mid-rise industrial structures (Haifa Bay) oil refinery, chemical and petrochemical industries.
• Land cover: mostly paved. Wooded landscape of evergreen trees (at west and south side).
• 9 m a.s.l.
• 2 km distance from Mediterranean coast.</td></tr>
<tr><td rowspan="2">Ben-Gurion
LCZ 6_{8E}
(rural)</td><td></td><td></td></tr>
<tr><td colspan="2">• Open arrangement of large low-rise buildings. Land mostly paved; abundance of pervious land cover (low plants, scattered trees).
• Land cover: Featureless landscape of paved cover.
• 40 m a.s.l.
• 18 km distance from Mediterranean coast.</td></tr>
</table>

3. Results and discussion

3.1 Climatic Differences between the studied LCZs

The mean difference in monthly air temperature averages is 1.5 ºC between urban (LCZ 2_{4B}) and rural (LCZ 6_{8E}) areas. It peaks in May with 2.4 ºC and has a minimum in February (0.9 ºC). The urban-suburban difference (LCZ 2_{4B} - LCZ 8_{10A}) is on average 0.7 °C (maximum 2.1 °C in May, minimum 0.0 °C in August). The temperature in the urban area is always higher than in the rural and suburban areas throughout the whole year. A formula of [19] suggests an urban-rural temperature difference of $\Delta T = 2.01 \log_{10} P - 4.06 = 6.5$ °C to the Tulkarm's population of $P = 182.000$ inhabitants (in 2015) . This level of urban heat island is exceeded by the maximum of 8.5 °C observed in April. In spring, the warmth increases more at the urban site compared to the rural region. Box plots of the climatic data over the summer months are shown in Figure 2.

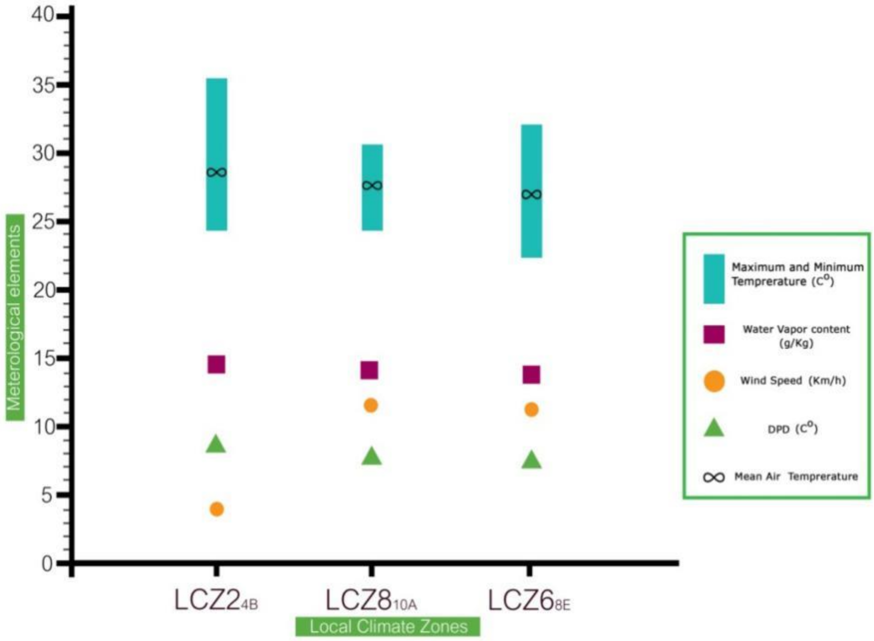


Figure 2: Local Climate Zone analysis during summer months for three selected stations from 2000 to 2014.

In this study, the differences in minimum air temperatures are bigger compared to average temperatures. The urban heat island (UHI) effect manifests mainly in nighttime warming and therefore urban-suburban and urban-rural differences in minimum temperatures (T_{min}) are larger than in maximum temperatures (T_{max}). This finding has been confirmed by previous studies [20,21] analyzing annual mean minimum and maximum temperature anomalies from rural and urban stations in China. These studies observed a significant increase of the mean minimum temperature and the annual mean temperatures at all stations. However, the warming was being significantly larger at the urban stations. In another study [22] found from northern hemisphere land datasets that warming over the past five decades is primarily due to an increase in the daily minimum (night-time) temperatures with little contribution from daily maximum (daytime) temperatures. Furthermore, [23] detected a trend of 0.090 and 0.444 °C in annual maximum and minimum temperatures, respectively, in records of 19 weather stations in arid and semi-arid regions of Iran due to urbanization and greenhouse gas emissions from human activities. Likewise, [24] found that for 1966-1999 annual trends of warming temperatures near surface exist at all stations in Nairobi city with higher rates of change in annual minimum temperature compared to the annual maximum temperature. Humidity data recorded at the urban (LCZ 2_{4B}), sub-urban (LCZ 8_{10A}) and rural (LCZ 6_{8E}) stations of the study indicate that the air in the urban area is drier than the rural area throughout the whole year. The maximum urban-rural difference in relative humidity took place on January with 5.3 %, while the minimum difference occurred in March with 0.9 %. Also the mean difference in relative humidity between suburban and urban was 3.2%, and in June 4.3%, while the urban air was humidor from November to March, reaching a maximum in February with 4.3%. Humidity changes seasonally, being lower in the winter and higher in the summer when the air was much warmer. During clear and calm summer nights with weak wind speeds, higher urban humidity levels are temporarily observed [25]. In summer Tulkarm is influenced by the sea breeze coming from west in the morning. Towards noon, winds change to southeast and later in the evening they turn to south and southwest. Wind speeds in rural and suburban areas are higher than in urban areas throughout the year. A maximum urban-rural difference was observed in March (9.8 km/h), while it was a minimum in November (5.4 km/h). In this study, wind plays an essential role as it affects the temperature and the relative humidity. Westerly and south-westerly winds are loaded with moisture gathered from the Mediterranean. They modify summer heat by means of the sea breeze and bring rain from November to February. Easterly and south-easterly winds prevailing from February to May convey heat and dust from the Arabian Peninsula. A particular strong wind phenomenon is the Khamsin condition. The dew point depression (DPD= $T-T_d$, T_d= dew point temperature) was higher in urban than in rural area throughout the whole study years. Minimum temperature and DPD are strongly associated. The mean difference of monthly value of dew point depression between urban and rural areas was 0.7ºC and peaked in January at 1.2ºC. As the temperature is decreased, the relative humidity is increased, thus DPD in urban area is higher than that of the rural area. Ideal conditions for the formation of urban heat island are clear sky and weak wind during night [19], which also favor the formation of temperature inversion layers.

3.2 Thermal human comfort in Local Climate Zones

Different grades of cold stress (PET < 18 °C) occurred mostly from December to February in LCZ 6_{8E}(rural) and LCZ 8_{10A}(sub-urban), while in LCZ 2_{4B}(urban) these months were thermally comfortable (Figure 3). PET values over 30 °C, indicating at least moderate heat stress, can be found from June to September in rural and suburban stations. In contrast, there was extreme heat stress at the urban station during the same months.

Highest PET values were observed at the urban station especially during summer months (42.3°C), while lowest PET we found at rural station during winter (13.7 °C). When comparing the seasonal values of PET, rural and suburban areas fell under moderate heat stress while urban area showed extreme heat stress during summer months (Tables 2 & 3). In spring months, rural and suburban areas were thermally comfortable while the urban area experienced moderate heat. [26] investigated human thermal perception of coastal Mediterranean climate and found PET between 20 and 25°C, higher than temperate climates and lower than that of hot and humid climate.

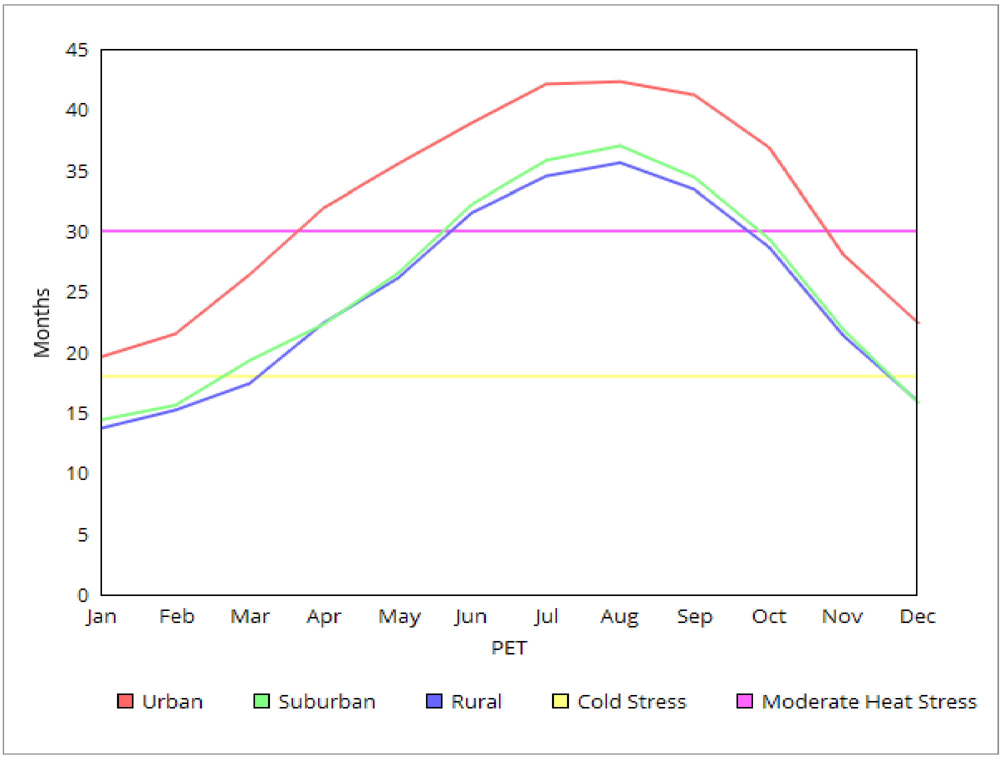


Figure 3: Mean monthly Physiologically Equivalent Temperature (PET) (30°C> PET > 18°C which is comfortable region) at three selected stations for the years 2000-2014.

Table 2: Seasonal values of PET (in °C) at selected stations from 2000 to 2014.

Season	*PET(urban)* *LCZ* 2_{4B}	*PET(sub-urban)* *LCZ* 8_{10A}	*PET(rural)* *LCZ* 6_{8E}
Winter	21.2	15.3	14.9
Spring	31.2	22.7	21.9
Summer	41.1	35.0	33.8
Autumn	35.4	28.5	27.8

Table 3: The number of months with PET exceeding 27 ºC at three sites during 2000-2014.

Area	*Frequency of monthly PET values over 30 °C*
Urban	8
Suburban	5
Rural	5

Highest air temperature together with highest relative humidity produces high thermal discomfort, and vice versa. Involving both parameters, [15] categorized a discomfort index DI (degrees Celsius) in different classes: moderate cold discomfort feeling (DI=10-15°C), relatively cold (DI=15-18°C), comfortable feeling (DI=18-21°C), warm discomfort for up to 50% of the population (DI=21-24°C), and warm discomfort for more than 50% of population (DI=25-27°C). The DI value in the months December and March indicated thermal comfort at all three stations as well as during November and April (Figure 4).

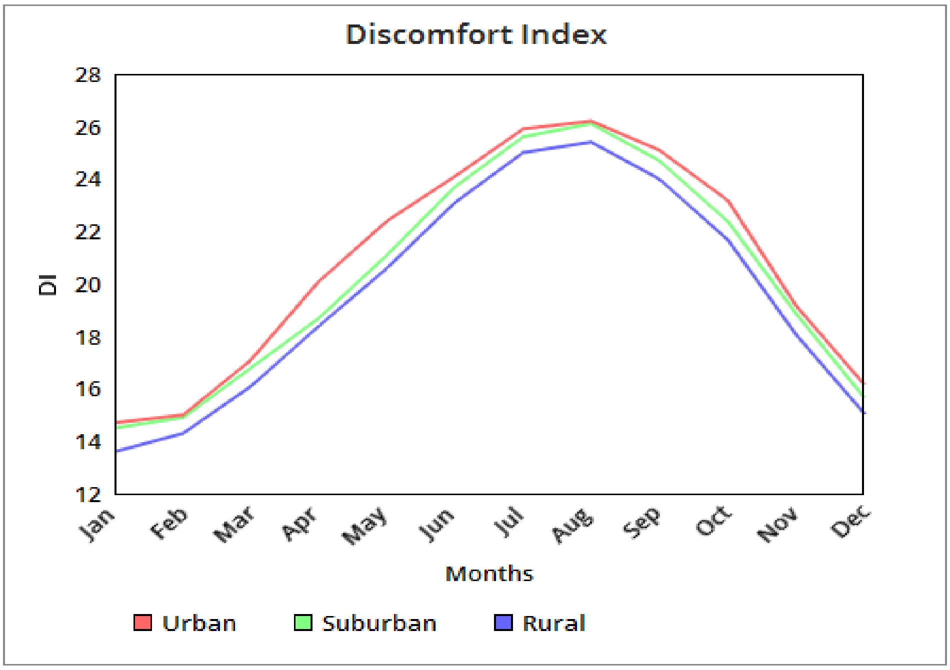


Figure 4: Average monthly pattern of discomfort index of three selected stations for the years 2000-2014.

In May, the DI value indicated that less than 50% of the total population perceived warm discomfort in both urban and suburban area, while the rural area was thermally comfortable. More than 50% of the total population suffered from thermal discomfort during July to September in urban and suburban areas;

and during July and August in the rural area, too. Comparing the seasonal values of DI (Table 4), in urban and suburban areas more than 50% of the total population experienced discomfort in summer months, while less than 50% of the total population felt discomfort in autumn months. In contrast, within the rural area less than 50% of the total population felt discomfort in summer and autumn months. [27] found in Greece, that most people felt uncomfortable when DI exceeded 24°C.

Table 4: Seasonal values of discomfort index (in °C) at selected stations.

Season	*DI(urban)* *LCZ* 2_{4B}	*DI(sub-urban)* *LCZ* 8_{10A}	*DI(rural)* *LCZ* 6_{8E}
Winter	15.2	15.0	14.3
Spring	19.9	18.7	18.4
Summer	25.4	25.1	24.4
Autumn	22.5	21.9	21.2

The UTCI is a function of air temperature, mean radiant temperature, wind speed and relative humidity or humidity expressed as water vapor pressure. The different values of the UTCI are classified in terms of thermal heat stress.

Table 5: Seasonal values of universal thermal climate index(in °C) at selected stations for the period 2000-2004.

Season	*UTCI (urban)*	*UTCI (sub-urban)*	*UTCI (rural)*
Winter	15	9.7	9.7
Spring	21	16	15.1
Summer	29.1	26.6	25.4
Autumn	24.9	21.6	20.9

The different values of the UTCI are categorized in terms of thermal stress. UTCI values between 18 and 26°C may comply closely with definition of the thermal comfort zone supplied in the Glossary of terms for thermal physiology [28] as: the range of ambient temperature, associated with mean radiant temperature, humidity and wind speed. The thermal human comfort indices analyzed in this study provide nearly similar results and are representative of the climate conditions (thermal sensations) in the three different local climate zones (Figure 6). Table 6 suggests that DI and UTCI indicate a higher number of comfortable months compared to PET, for which the winter months are comfortable in the urban area.

Summarizing the results, it was found that temperatures in Tulkarm's LCZ were higher than in rural and suburban areas throughout the years. The difference in the mean monthly air temperature between urban and rural areas was on average 1.5 ºC. That peaked in May with 2.4 ºC, and decreased in February to 0.9 ºC. The minimum mean monthly air temperature was higher for urban stations comparing to the suburban and rural stations. **The minimum mean** monthly air temperature had higher rates of change compared to **the mean** monthly air temperature. The urban temperatures had elevated during the night time because of the urbanization. The difference in **minimum mean** monthly air temperature between urban and suburban areas is 2.3ºC, while the difference between the means monthly air temperature between urban and suburban areas was 0.7 ºC. It is known that the temperature is a major factor of climate changes. Thus, in this study was found that the temperature increases were higher during the night time than the daytime. Moreover, the daily minimum temperatures increased at a faster rate or decreased at a slower rate than the daily maximum, resulting in a reduction of the diurnal temperature range for many parts of the world [29].

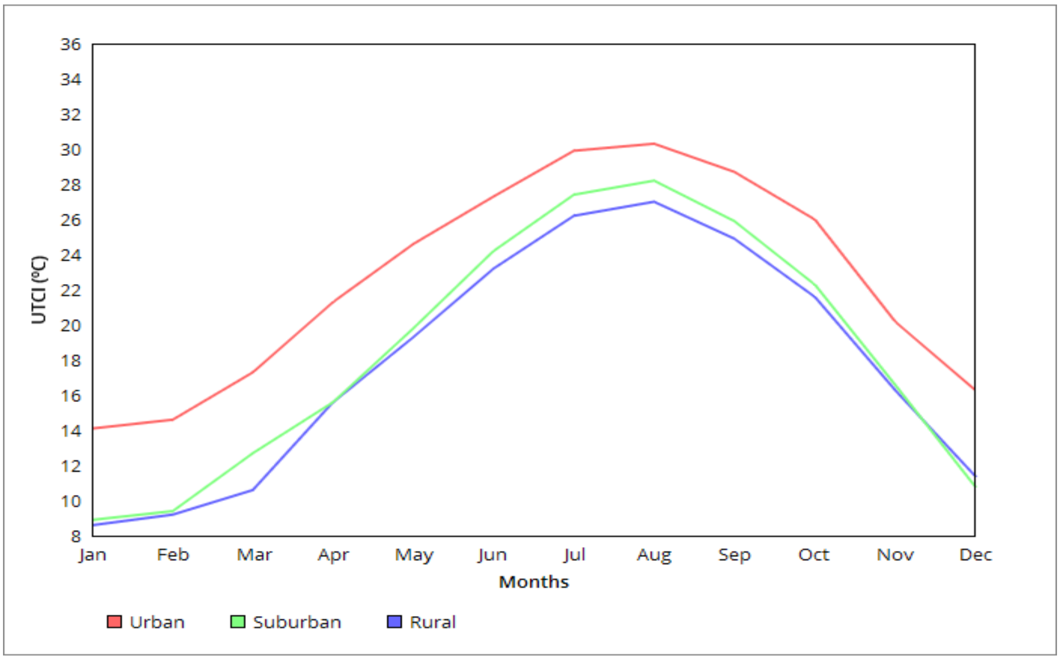


Figure 5: Average monthly pattern of Universal Thermal Climate Index (in °C) in the three studied LCZs for the years 2000-2014

Table 6: Percentage of comfortable months in the urban area as estimated by the three indices during the study period.

Indices	*Comfortable Months*	*Percentage of comfortable time*
Discomfort Index (DI)	Mar, Apr ,Nov ,Dec	33 %
physiological equivalent temperature (PET)	Dec, Jan, Feb	25 %
Universal Thermal Climate Index (UTCI)	Apr, May, Oct, Nov	33 %

Furthermore, the local effects such as urban growth, irrigation, desertification, and variations in local land use may all affect the diurnal temperature range. The large-scale climatic effects on the diurnal temperature range (DTR) include increases in cloud cover, surface evaporative cooling from precipitation, greenhouse gases, and tropospheric aerosols [30]. The urban area was drier than rural area throughout the whole year. The mean difference in mean monthly value of DPD between urban and rural areas is 0.7ºC, which peaks in January with 1.2ºC. The mean difference in mean monthly relative humidity between rural and urban areas is 2.2 %. The maximum difference in relative humidity takes place on January with 5.3 %, while the minimum difference occurs in March with 0.9 %. Also the mean difference in relative humidity between suburban and urban is 3.2%, and takes place on June with 4.3%, while urban area more humid from November to March reach its maximum in February with 4.3%. The wind speed in rural and suburban areas is higher than in urban areas throughout the years. The mean difference in mean monthly wind speed between rural and urban areas is 6.9 km/h, the maximum difference take place on March with 9.8 km/h, while minimum difference in November with 5.4 km/h.

The difference in mean monthly wind speed between suburban and urban areas at winter months was 8.1km/h, while in summer months shows 7.2km/h at the same area. The buildings affect the winds due to their size, shape and space they take. The analysis of the Physiologically Equivalent Temperature (PET) showed that there was a big difference between the highest and lowest PET values, the highest values restricted of the urban station especially during summer months (42.3 °C), while the lowest PET we get at rural station during winter (13.7 °C). When comparing the seasonal values of PET between the rural and suburban areas, they fell under moderate heat stress while urban area shows extreme heat stress during summer months. In spring months, rural and suburban areas shows comfortable while urban area fell under warm. Moreover, in the comparison of the seasonal values of Discomfort Index (DI) between the urban and suburban areas, more than 50% of the total population was feeling discomfort in the summer months, while less than 50% of the total population was feeling discomfort in the autumn months. In contrast to the rural area, less than 50% of the total population felt discomfort in the summer and the autumn months. There is a need to adapt to climate change. Cities, with strong management and planning systems, are especially useful for restructuring and reorganizing the urban life over time [31]. The study supports the LCZ framework in evaluating urban heat islands. This framework delivers a scientific approach to analyze UHIs within complex urban structures. The importance of LCZ subclasses was demonstrated when heat patters were considered in heterogeneous urban regions (Figure 5). Thermal discomfort of similar level was observed in the compact mid-rise regions (LCZ 2) in Brno on the basis of the urban microclimatic model MUKLIMO_3 [32], especially in the afternoon hours. These manufacturing sites west of Tulkarm have long been a source of extreme pollution (Palestinian Ministry of Environmental Affairs), considerably weakening air quality. [33] performed a qualitative analysis of the pollution impact, which was generated by agrochemical industries operating near Tulkarm. From their study they found that the pollution was associated with acute health problems (respiratory diseases, cancer, asthma). In particular, it was observed that there was a correlation between the elevated local air contamination and the higher level of respiratory problems found among children [34]. In addition, local traffic and household emissions have been pointed out as contributors to the development of air pollutants and greenhouse gases [35].

Conclusion

In Tulkarm, West Bank, the urban climate was characterized by higher values of mean temperature, and lower values of wind speed and relative humidity compared to the two reference sites in Haifa (suburban) and Ben-Gurion (rural). A huge portion of the land in the west part of the city, which was originally used for agricultural activities, was confiscated for the construction of the Separation Wall. At the same time, the city expansion was restricted due to the existence of the Separation Wall along the west side of the city. Random urbanization and bad planning policies in Tulkarm might have influenced the wind speed. The study reports that open and sparsely built structures LCZ 810A and LCZ 68E regions are cooler compared to the compact urban built structures (LCZ 24B) even when the ground is mostly paved. On the contrary, the lower values of UTCI and PET in the open and less built structures (LCZ 810A and LCZ 68E) are associated with shorter periods of heat stress throughout the year. Besides the regional climate change and the urban structure of Tulkarm that is impaired by the Separation Wall, the local climate is presumably also affected by nearby pollution sources. Many industrial villages (Kibbutzim) harbouring dense industrial activities, are located near the Tulkarm district and following the sea breeze, their emissions of fine (metallic) dust disperse in the lee. A rigorous monitoring of environmental exposure data in this region can help the assessment of the effects of the local pollution on the human health as well as on the local climate.

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