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The assessment of outdoor thermal comfort inside oasis settlements in North Africa - Algeria

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Abstract. Oasis settlements are the most common form in the Saharan regions of North Africa, identified by a strong harmony between urban forms and palm groves, which present the economic capital for these regions. On the other hand, these oases are significantly growing and impacting the people's livelihood and thermal well-being, especially during summer season. This study aims at first to identify the close correlation between cultivated area (palm grove) and the built-up area throughout the Tolga Oasis Complex in Algeria, which is recognised by its palm groves and well-known as one of the largest oasis settlements of the Saharan regions in North Africa. Furthermore, the current work assesses the impact of palm groves by investigating the 'oasis effect' on the thermal heat stress levels during July and August daytime hours within 9 conducted stations. Suprisingly, the so-called oasis effect generated by palm groves was insignificant during the extreme hot days. On the other hand, the palm groves were extremly hot affected by a warming effect during daytime hours.

1. Introduction

The oases settlements show a strong integration in the rural world where urban areas are closely attached to palm groves that as a rule surround the urban area [1,2]. However, the overheating in oases settlements is critical to the human body and has a significant impact on inhabitants' well-being, productivity, and satisfaction. With climate change and the recurring heat waves, human health in oases settlements can be subject to increases in morbidity and mortality [3]. According to the World Bank, urbanization and climate change are the two most important transformations the Saharan oases will undergo this century. At the same time, the outdoor environment is deteriorating in many oasis settlements, where most of human activities take place. People cannot find shade in the middle of the day and excessive heat build-up during the day results in shifting the human activities to the night and halting any economic activity during summer.

Therefore, there is a need to understand the close link between the cultivated area (palm grove) and the built-up area [4,5], as well as to assess the outdoor thermal comfort in oases settlements and investigate the means to provide liveable urban environments for their inhabitants. In this study, we investigated outdoor urban comfort in the Tolga Oasis Complex in Algeria defined as a fertile spot in a desert, where water is found and more than 1,000,000 date palm trees [6]. More specifically, the study tested the validity of the so-called 'oasis effect' which refers to the phenomenon of a cooling effect caused by vegetation in the desert regions [7] following a comparative field measurement and calculation approach.

2. Materials and methods

This study is conducted in the Tolga Oasis Complex (34°43'00"N and 5°23'00"E) [6], in the Biskra province [8], Algeria, and 363 km south-east of the capital Algiers (Figure 1). This oasis settlement territory is considered as one of the largest oasis complexes of the Sahara Desert in North Africa [8]. The Oasis Complex is composed of 6 oases: Tolga, Lichana, Bouchagroune, Bordj Ben Azzouz, Foughala, and Ghrous, but polarized by the Tolga oasis, which presents the largest urban area of the whole Oasis Complex [5].

The Oasis Complex has a population of 150,036 according to the census of 2017. On the other hand, the study area has a hot arid climate (Koppen BWh) with a variation between summer and winter temperatures. The Tolga Oasis Complex is well-known internationally for high-quality dates (Deglet Nour) with a production of 1,356,202 Quinto of dates in 2017. It has more than 1,006,600 date palm trees.

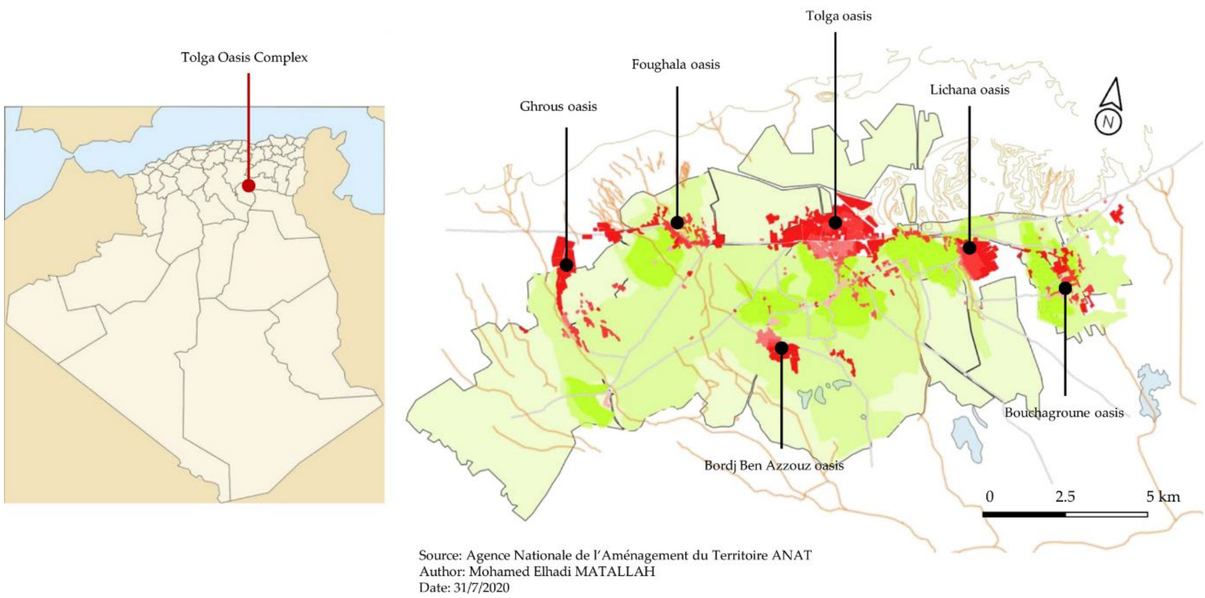

Figure 1. Tolga Oasis Complex location in Algeria

2.1. Correlation between cultivated area (palm grove) and built-up area

According to several studies, the urban pattern of an oasis network presents a close link between the cultivated area, which is the palm groves' zone, and the built-up area, and this within different forms such as old oases settlements (village, ksar, or medina), or the recent urban fabrics [4,5]. Furthermore, the built environment growth is consistently related to palm grove development influenced by many environmental, social, and economic factors. In this study we tried to establish a surface correlation between the cultivated area and built-up area by analysing the surfaces sprawl of each of the mentioned areas. Thus, the work is mainly based on maps' georeferencing of the study context to understand its spatial evolutions during 120 years (from 1900 till 2020), whereas the methodological path is based on GIS Qgis software. Otherwise, the mapping is for the surfaces' calculation which are illustrated in Table 1, as well as to identify the development of Tolga Oasis Complex. Consequently, results show that the built-up area covers only a small part of the total oasis with a mean percentage of the built-up area is equal to 5% of the palm grove area. In order to understand these results, we should indicate that inside an oasis network the relationship between the built environment and the palm grove is of major importance for the sustainability of the oases settlement patterns over time, which are essential components of the oasis trilogy based on water, palm grove, and the built environment.

Table 1. Built-up and palm grove surfaces of the Tolga Oasis Complex from 1900 to 2020

Oasis	Surfaces 1900 (ha)		Surfaces 1940 (ha)		Surfaces 1980 (ha)		Surfaces 2020 (ha)	
	Built-up surface	Palm grove surface	Built-up surface	Palm grove surface	Built-up surface	Palm grove surface	Built-up surface	Palm grove surface
Tolga	13.75	499.24	73.51	540.17	230.53	3195	1088.2	4940.54
Lichana	2.65	124.30	10.33	512.98	97.14	671	249.94	2631.8
Bouchagroune	5.00	252.37	10.47	538.66	18.32	1317.2	178.86	1516.43
Bordj Ben Azzouz	5.68	247.4	30.54	478.84	64.56	2434.82	180.0	3347.5
Foughala	7.42	269.59	10.46	451.66	75.1	1456.7	231.0	2192.14
Ghrous	6.73	134.17	15.56	262.51	53.62	2097.11	227.41	5933.71

Accordingly, the built environment surface has always been very limited compared to palm grove surface in long-term period, although the ratio changed from 2% in 1900 to 11 % in 2020; this relationship refers to the specificity of spatial morphology inside an oasis territory. Figure 2 below illustrates percentages (ratios) of the built-up surfaces compared to palm grove surfaces.

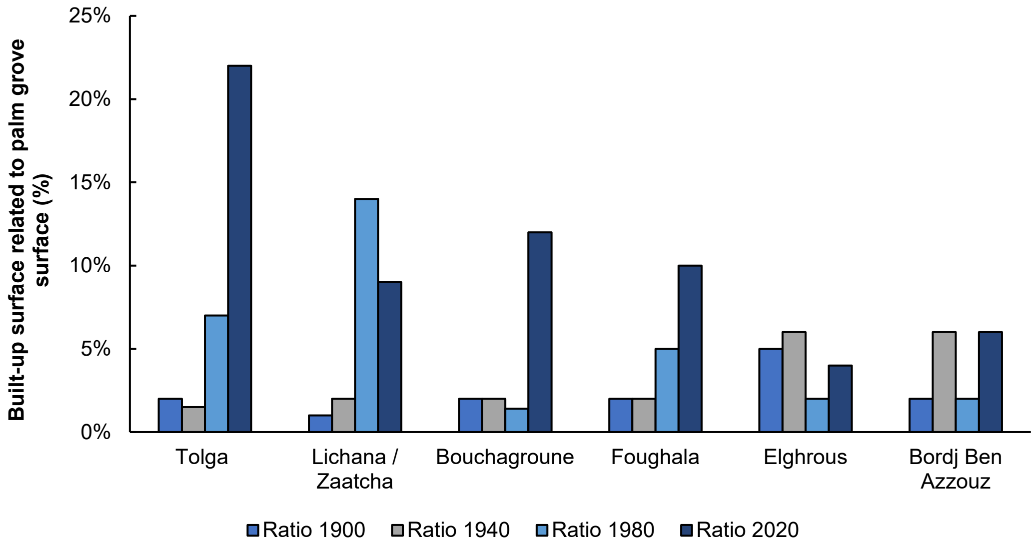

Figure 2. Ratios between built-up surfaces and palm grove surfaces in Tolga Oasis Complex from 1900 to 2020

2.2. Outdoor thermal comfort assessment

For the following study stages, four sites were selected to conduct a measurement campaign in order to assess outdoor thermal comfort and investigate the oasis effect [9] in the Tolga Oasis Complex. The selection of the study sites is based on four main criteria: (i) level of vegetation and oases settlement fabric (ii), the age of the oases settlement (iii), the size of the built-up settlement and (iv) the relation between the built-up and the palm grove. These details are presented in the Table 2 and Figure 3. The parameters measured for the outdoor thermal comfort assessment were: the air temperature (T_a), relative humidity (R_H), air velocity (V_a), and surface temperature (T_s). The measurements were performed between July, 20th to 29th (except 27th) and August, 10th to 17th, 2018, which represent the hottest period of the year [3,6]. In order, monitoring was conducted at 05:00 a.m., 09:00 a.m., 01:00 p.m., 05:00 p.m., and 09:00 p.m. The measurements were taken using a Testo 480 device. The sensors were kept at 1.40 m height from the ground to avoid the effect of surface contact [10]. Fish-eye images were taken using a Canon EOS 6D camera at each measurement point. The camera was oriented to the sky. To calculate the SVF degrees we needed to treat the images using the RayMan model [11,12,13]. On the other hand, we evaluated the outdoor thermal comfort by using the Physiological Equivalent Temperature (PET) [14,15] index basically on the monitored microclimatic parameters, and calculated with the RayMan model [12, 13].

Table 2. Morphological characteristics of the conducted sites in Tolga Oasis Complex

Sites	Area (ha)	Location	SVF	Street direction	Width of streets (m)	Height of the streets (m)
Old Lichana	4.20	1	0.02	E-W	2.20	3.20
		2	0.07	E-W	3.70	3.50
		3	0.27	N-S	3.50	5.75
Old Tolga	14	4	0.32	N-S	3.40	3.70
		5	0.18	E-W	3.15	7.10
		6	0.56	N-S	4.00	3.00
Farfar	2.50	7	0.05	N-S	2.30	3.10
		8	0.34	E-W	2.75	6.20
Palm grove	-	9	0.37	-	-	-

Figure 3. Fish-eye images of the conducted sites

3. Results and discussion

The assessment of the PET index shows that during the studied period there are five different thermal comfort zones (Table 3): Neutral, slightly warm, warm, hot, and very hot zone [14]. Results show an increase in the PET values during the daytime and after sunrise until sunset, in all monitoring points. The assessment of PET shows a peak zone over 42 °C at the daylight hours (from 9:00 a.m. to 5:00 p.m.) causing an extreme heat stress [14,15]. Additionally, minimum values of PET (< 26 °C), representing the neutral zone, were obtained in the palm grove at 5:00 a.m. in August (point 9). Results demonstrate a close similarity of heat stress levels in almost all measurement points during July and August at daylight hours.

The assessment of PET in July and August, shows that the July averages are higher than August during the daytime in all the measurement points with $PET_{ave.July}$ = 41 °C, $PET_{ave.August}$ = 36.2 °C. This decrease in August is mainly due to wind velocity, which influences the level of heat stress. Moreover, PET values are lower in August than in July in most other measurement points (1, 2, 3, 4, 5, 6, 7, 8, 9) $PET_{ave.July}$= 41.8°C, $PET_{ave.August}$= 35.4°C [3].

Table 3. Outdoor thermal comfort assessment in Tolga Oasis Complex

Site	Measurement Point	PET 5:00 a.m.		PET 9:00 a.m.		PET 1:00 p.m.		PET 5:00 p.m.		PET 9:00 p.m.	
		July	August	July	August	July	August	July	August	July	August
Old Lichana	1	30	27.3	39.9	38.5	49.7	43.8	47.3	37.8	36.7	29.3
	2	31.5	27.4	44.8	41.5	52.1	45.6	48.3	38.7	38.2	31.3
	3	31.3	26.4	45.3	39.1	55.1	45.7	53	41.9	37.4	29.2
Old Tolga	4	28.8	26.7	38.6	36.7	50.6	42.7	47.5	37.5	32.8	28.3
	5	28.8	26.1	40.2	35.3	47.6	39.4	48.3	40.5	33.8	28
	6	27.6	26.2	41.5	37.3	48.9	45	49.3	43.8	32.7	28.4
Farfar	7	35.1	28.4	42.1	36.5	50.4	42	46.9	36.2	38.5	29.8
	8	33.9	26.9	46.6	39.8	50.2	43.2	50.7	37.9	38.2	28
Palm grove	9	28.8	25.7	45.4	43.5	51.6	44.3	48.8	39.5	34	27.8

Thermal comfort stress level	17–26	26–28	28–37	37–42	>42
	Neutral No thermal stress	Slightly warm Slight heat stress	Warm Moderate heat stress	Hot Strong heat stress	Very hot Extreme heat stress

The study shows a close similarity of the heat stress levels (PET index) inside the oasis settlements fabrics and Palm grove in August $\Delta\ PET_{urban\ fabric.August}$ = 36.3 °C, $\Delta\ PET_{palm\ grove.August}$ = 36.2 °C. The heat stress level (PET index), evaluated in July, is slightly higher in the palm grove than in the oasis settlement fabrics, $\Delta\ PET_{palm\ grove.July}$ = 41.7 °C, $\Delta\ PET_{urban\ fabric.July}$ = 40.9 °C. The difference is mainly caused by the shading factor, which is higher in the oasis settlement fabrics, and slightly due to the variation of wind velocity between sites, which the $\Delta\ Vair_{urban\ fabric.July}$ = 0.6 m/s, $\Delta\ Vair_{Palm\ grove\ .July}$ = 0.1 m/s [3].

The influence of the oases settlements on the PET index was insignificant. Despite the large difference between the oasis settlements and the palm grove areas, our measurements and calculation did not identify any noticeable variation in thermal comfort throughout the built environment. We processed the housing materials such as albedo during the whole study period additionally to the SVF. Accordingly, the RayMan model took all the microclimatic parameters to calculate PET index, which makes it very sensitive to surrounding conditions (meteorological and thermophysical). RayMan represents a relevant model for the urban climate assessment. On the other hand, no significant impact of the SVF on the thermal heat stress was found. More surprisingly, the 'oasis effect' [9] on the outdoor thermal comfort was insignificant (during the study period).

We refer to the insignificant relationships between PET and SVF in the study period to illuminate three factors: (i) most of the measurement points are similar to oasis fabrics all over the Tolga Oasis Complex, with air conditioners practically in each house, which participate as heat resources inside streets; (ii) the building materials used by owners were not ideal; (iii) certainly there are a microclimatic thresholds like air temperature, relative humidity, and wind velocity thresholds that influence the oasis effect phenomenon, and have an impact on the thermal stress [3].

4. Conclusion

This study identified the relationship between the built-up area and the cultivated area (palm grove) inside an oasis network, as well as the impact of palm tree groves on the outdoor thermal comfort during summer in the Tolga Oasis Complex in Algeria. Despite the large scale of cultivated and irrigated area (palm grove) surrounding the built environment, which presents a small surface compared to palm groves, the so-called oasis effect was not significant during the extremely hot days. Also, the outdoor thermal comfort was affected strongly by extreme weather conditions, and created an extreme heat stress notably inside the palm grove generating a warming effect over daytime hours.

Based on the outcomes, we advise urban planners and landscape architects do not to overestimate the passive cooling effect of the oasis palm grove. Therefore, urban designers and city planners should ensure shading in public spaces and prepare the outdoor spaces to host people during extreme heat stress conditions in oases urban settlements. Natural ventilation or increasing the air-flow and providing outdoor shading are essential design element in the oasis urban fabric. The reflectivity of ground and facade surfaces should be considered too, although these recommendations are outside the scope of this study

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