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تأثير تغيرات سطح الأرض على درجات حرارة الهواء في بغداد

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الملخص

يشير هذا البحث إلى أن المقارنة اليومية بين درجات حرارة الهواء السطحي الصغرى والعظمى في الفترة ما بين 2000–2015 على مدينة بغداد، توضح انعكاس معدل التحضر بوضوح على معدل تغير المناخ الحراري للمدينة. شهدت بغداد، بدءاً من عام 2003، عملية تحضر سريعة للغاية أدت إلى تأثيرات سلبية على المناخ المحلي، يتم تدارسها في صورة بيانات يومية عن درجات الحرارة الصغرى والعظمى على 2m. كما يشير البحث إلى ارتفاع متوسط درجة الحرارة الصغرى الشهرية ب 3 درجات مئوية، بينما ارتفعت درجة الحرارة العظمى الشهرية بدرجتين مئويتين في الفترة ما بين 2000–2015. يؤكد البحث في النهاية زيادة تغير درجة الحرارة اليومية اثناء النصف الثاني من عام 2015.

Impact of land surface changes on air temperatures in Baghdad

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Abstract

An intercomparison of daily minimum and maximum surface air temperatures between two years (2000 and 2015) over Baghdad city suggests that the rate of urbanization is fairly reflected in the rate of the change in the thermal climate about the city. Since 2003, Baghdad has experienced a very rapid urbanization process leading to a negative effects on its local climate, investigated in terms of daily data of minimum and maximum temperatures at 2 m. The average monthly minimum temperature has warmed by 3 °C, while the average monthly maximum temperature increased by 2 °C during 2000 and 2015. Finally, diurnal temperature range clearly increased during the second half of the year 2015.

Keywords: Air temperature; Baghdad; land changes; local climate; urbanization effect.

1. Introduction

Since the political system change occurring in the 2003 invasion of Iraq, many local people have been settled in open random areas as small housing groups in urban Baghdad city without getting permission, as the Iraqi government and the law have been nearly absent. Furthermore, many personal and public lands principally occupied by agriculture with natural grass lands have been transformed to residential areas.

These surface changes above, of course, have potential impacts on local thermal climate, air quality and human biometeorological conditions over urban cities (Findell *et al.* 2017; Ndetto & Matzarakis, 2015). The surface altering within urban cities such as increasing land uses and decreasing land cover influences the energy balance. The transformations to built-up surfaces that have a high heat capacity, like concrete and asphaltic etc., that absorb incoming solar radiation, heat up and then re-radiate heat at night as longwave radiation have negative effects on human health and atmospheric environments. This leads to a significant rise in air temperature (Oke, 1981), decreasing wind speed (Varquez *et al.* 2015) and even changing boundary layer properties (Liu *et al.* 2017), air humidity (Lee, 1991) and precipitation (Zhang *et al.* 2007; Kaufmann *et al.* 2007), which are different from the surrounding countryside, consequently developing phenomena such as urban heat islands.

Knowledge of the urbanization level and its environmental impacts is essential in sustainable cities. Besides, the human physiological feeling is also significantly influenced by urban climate and is a relevant factor in urban planning and quality of life issues (Mukhelif *et al.* 2016). In the last decade, many studies investigating the effect of urbanization on local climate have been carried out worldwide, especially in China (e.g. Kaufmann *et al.* 2007; Tao *et al.* 2015; Yan *et al.* 2010; Yu *et al.* 2013; Zhou *et al.* 2004) because of the reform and opening strategy applied in the early 1980s leading to rapid economic growth and then reflected in the rapid urbanization process. These references illustrated rapid urbanization's effect on the urban meteorology, precipitation, water resources, surface aerodynamic characteristics, urban climate, human biometeorology and air pollution and its quality.

In other cities, such as Dar es Salaam, Tanzania, which is one of the fastest growing cities in the world, the urban air pollution and the thermal climate have been studied (Ndetto & Matzarakis, 2015). Morris *et al.* (2017) researched the increase in urban expansion within Kuala Lumpur, Malaysia, and its associated impact on the interactions of the urban climate and human thermal comfort, using the data generated by models of weather research and forecasting, urban canopy and Noah land surface. Pauleit *et al.* (2005) investigated the changes in land use and land cover of 11 residential areas in Merseyside, UK, using aerial photographs taken in 1975 and 2005, and the effect of these changes on surface temperature, runoff of rainfall and greenspace diversity. Lastly, Hausfather *et al.* (2013) quantified the effect of urbanization on temperature trends at urban and non-urban (rural) stations using four different proxy measures of urbanity.

This paper reanalyzes some land use and land cover data measured for Baghdad city before and after 2003 that were found in some local studies such as Al-Maliki (2011). This year was selected because the invasion of Iraq began on 19 April, 2003, leading to the changes in the demography of Baghdad`s surface. Only the years 2000 and 2015 were selected as pre- and post-2003 to see the negative effects caused by the invasion on thermal climate. To assess these changes resulting from the rapid population growth in Baghdad, the study also discusses the demographic characteristic of the city with respect to its underlying surface, such as transforming from land and agricultural land to built-up surfaces. To confirm these land changes, satellite images of Baghdad city in 2000 and 2015 were collected to analyze vegetation degradation and urban expansion.

In order to understand how urbanization expansion affected the local climate, daily data of minimum and maximum air temperatures were collected over two years, 2000 and 2015, i.e. before and after 2003. Diurnal air temperature ranges are also calculated for these years. Lastly, an intercomparison between these parameters and even the effect of land use changes on the monthly averages of air temperature are also examined.

2. Study area

Baghdad is the capital of the Republic of Iraq and is located in the middle of it along the Tigris River, which splits Baghdad into two parts: the eastern part, known as Risafa, and the western part, known as Karkheh (see Figure 1). Geographically, Baghdad is situated at latitude 33.22–33.48^{o} N, longitude 44.17 – 44.50^{o} E and 30–38 m above mean sea level (msl). It covers an area of 857.3 km^2 and forms 0.2 percentage of the overall area of Iraq and is in the heart of ancient Mesopotamia. The land is almost entirely flat and low-lying.

The climate of Baghdad is subtropical desert, i.e., mostly arid (Köppen climate classification BWH), featuring an extremely hot, dry summer and a mild, damp winter (Roth, 2007). The mean annual range of air temperature is 15–34 ^{o}C with the mean of 25 ^{o}C, while the annual range of the mean daily sunshine duration is about 10–14 hrs with a mean of 7.5 hrs.

The air humidity is typically under 30 percent in summer due to Baghdad's distance from marshy southern Iraq and the coast of the Persian Gulf, and dust storms from the deserts to the west are a normal occurrence during the end of spring and summer. Rainfall has never been recorded during the summer and annual rainfall is almost entirely confined to the period from November through April, averaging approximately 150 mm. Finally, wind speed in the area is generally light the whole year round.

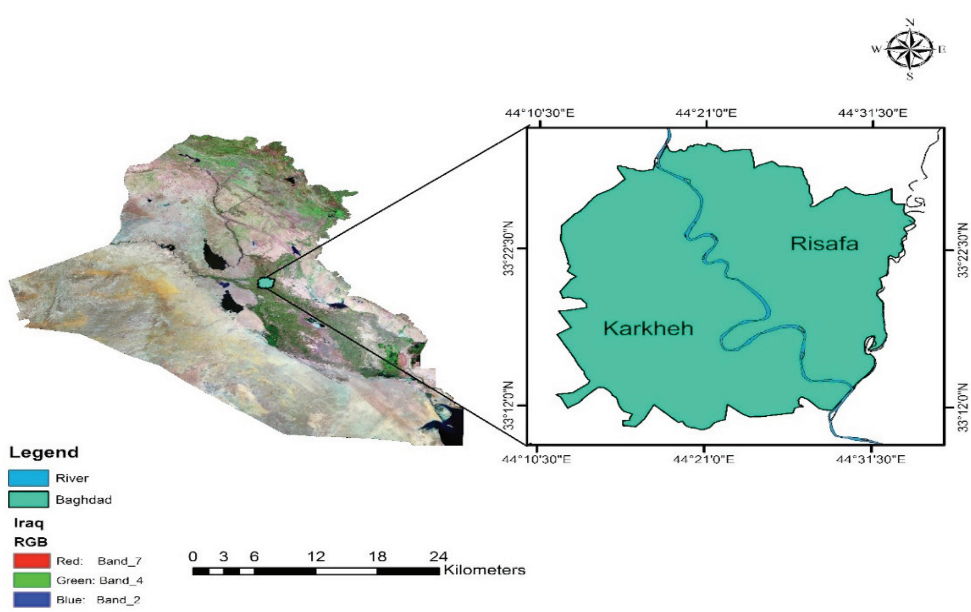

Fig. 1. Map of Baghdad.

3. Meteorological data

Although there is a classical weather station located at International Baghdad Airport, the climatic reanalysis data from the US National Center for Environment Prediction-National center for Atmospheric Research (NCEP-NCAR) were used to execute this study. This is because the Baghdad station is far away from the urban center, about 22 km southeast of the city. Therefore, this station is not convenient for investigating the changes in urbanization and their effect on the heat behavior of the local climate. Reanalysis data for daily minimum and maximum surface air temperatures at 2 m at a point within the center of Baghdad were downloaded for all the days of the years 2000 and 2015. This point has the geographical dimensions latitude 33.37º N, longitude 44.25° E and 33 m above msl. Average daily air temperature (T °C) was calculated as

$$T = \frac{Tmax+Tmin}{2} \qquad (1)$$

4. Population and gross domestic

Baghdad is the largest Iraqi city and one of the most populous urban agglomerations in the Middle East. Figure 2 shows the population of Baghdad from 2000 to 2015, according to the Central Organization for Statistics, Ministry of Planning. As is clearly shown, the population was continually increasing, except in 2005, 2010 and 2015, owing to the internal war events, political instability, and emigration. The ratio of the population of Baghdad to the total Iraq population is nearly 20%. To reflect the pace of city development, the gross domestic product (GDP) data were also collected for the same periods and also presented in Figure 2. It is the best way to measure a country's economy, and the Iraq GDP is 130.32 percent of the world economy. These data reveal slow growth for the first period (2000 to 2004) with a mean value of about 30 billion and a rapid increase in population. In that period, Iraq didn't have trade with most nations, because it was subject to sanctions from the invasion of Kuwait in 1991. From 2005 to 2014, as shown by Figure 2, GDP data increase rapidly from 30 to 234 billion.

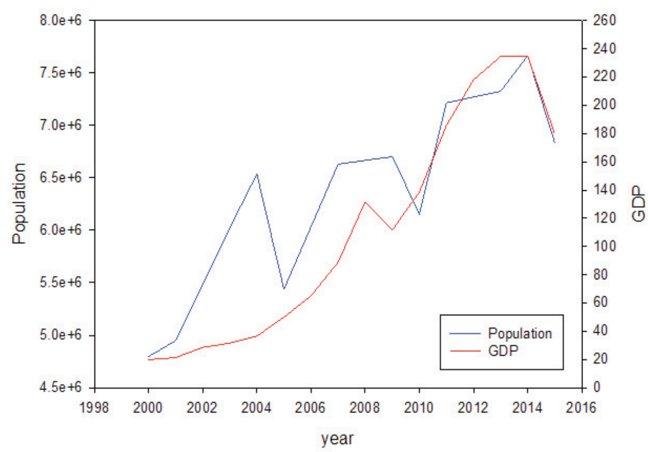

Fig. 2. Gross domestic product (GDP) in billons and population in Baghdad.

5. Land changes in Baghdad

To assess land change including land use and land cover within urban Baghdad city, the measurement of the area for residences (or housing), agriculture and other uses (e.g. industries, transportation, open areas and bare lands, etc.) was required. With respect to these structures, urban data retrieved from satellite observations such as Landsat satellite images were obtained to update the geodatabase of land use. Two types of satellites were used in this work: Landsat-7 ETM+ satellite image (2000) and Landsat-8 ETM+ satellite image (2015) with Path 168/Row 37. Both images were downloaded from the USGS Earth Explorer database (http://earthexplorer.usgs.gov/) with spatial resolutions of 30 m. These images can be clearly shown in Figure 3 for two separate years, 2000 and 2015.

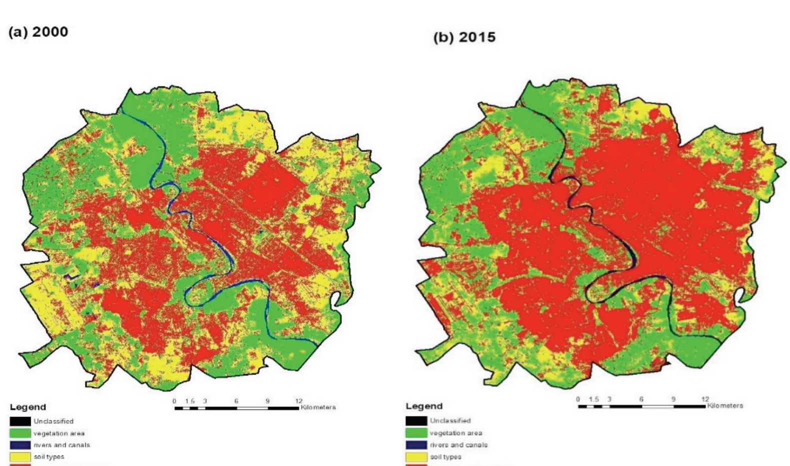

Fig. 3. Evolution of land use in (a) 2000 and (b) 2015.

Using ArcMap 10.6 technique, the built-up, agricultural and other areas were calculated for the previous years, which are listed in Table 1. The rapid excess in built-up area was doubled in 2000 to relatively flat in 2015. This can be verified by the degradation in vegetation cover, which reduced by half from 2000 to 2015.

Table 1. Population and the areas of housing, agriculture and other with their percentages.

Year	Population	Housing		Agriculture		Other	
		Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
2000	4,797,000	192.8	22.7	595.5	70	62.4	7.3
2015	7,665,000	437.2	51	297.5	34.7	122.6	14.3

The other uses for land the less area were also double from 2000 to 2015. On the other hand, Figure 4 shows the percentages for housing, agricultural and other sectors for each year. In 2000, the surface of Baghdad was dominated by green cover, which formed more than 70% of the total area, with the remainder being residential areas and other. Since 2003, so many agricultural sectors such as orchards, lands and even private gardens had been transformed to random small groups for housing use. This process, of course, raised the percent of housing and other sectors to about 50%. The change in the surface properties is most important particularly to assess how this change can affect local climate.

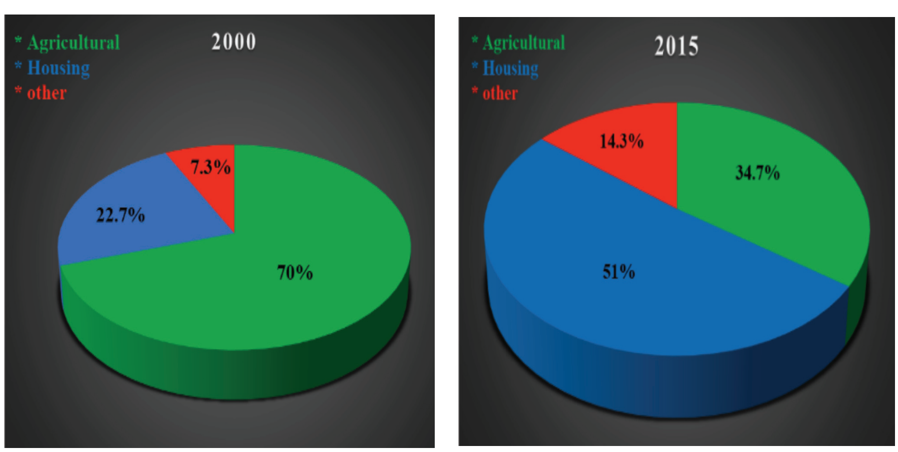

Fig. 4. Percentages of land uses as housing, agriculture and other of Baghdad at 2000 and 2015.

From Table 1, the differences in the areas of land use for the two years 2000 and 2015 were computed and then divided by the total area of Baghdad to obtain the percentages of change ratio (see Table 2). There was a significantly positive difference between these years with +244.4 m^2 for housing, namely, an increase in built-up areas, with a change ratio of 28.5%, while there was a target negative difference in farmland (-298 m^2) with a ratio of 34.8%. The small difference, as well as the ratio, for the others is relatively flat.

Table 2. Change values and their ratios in % for housing, agriculture, and others.

Year	Housing (km^2)	Ratio	Agriculture (km^2)	Ratio	Other (km^2)	Ratio
2000-2015	+244.4	+28.5	-298.0	-34.8	+60.2	+7.0

The largest ratio in land change (i.e., in the agricultural sector) was more serious in the period that included the political events of 2003. The changes in vegetation cover can also be described by the normalized difference vegetation index (NDVI). This index quantifies vegetation by measuring the difference between the reflections in near-infrared (NIR) and red (Red) light as follows:

$$NDVI = \frac{NIR - Red}{NIR + Red} \tag{2}$$

NDVI is always from +1, i.e., vegetation that strongly reflects, to -1, i.e., vegetation that absorbs (Al-Jassar & Raoa, 2016). In this work, it is used because the Landsat satellites mentioned at beginning of this section can also produce red and near-infrared images. In addition, it is preferable to other indexes such as the normalized difference building index (NDBI), because the build-up and bare soil reflect more short-wave infrared than the NIR.

Figure 5 shows the variation in NDVI over Baghdad in 2000 and 2015, which can depict the reduction in vegetation cover and urban growth in Baghdad. The NDVI data retrieved from lands with thematic mapper data have a negative value that indicates water bodies; ±0.15 value represents bar soil and urban land and a greater number refers to larger green coverage. Therefore, the number of values of large NDVI reported in Figure 5a are greatly lower and becoming a dense built-up area in Figure 5b, especially in the middle of the city, in which green and bare spaces have been transformed to red ones.

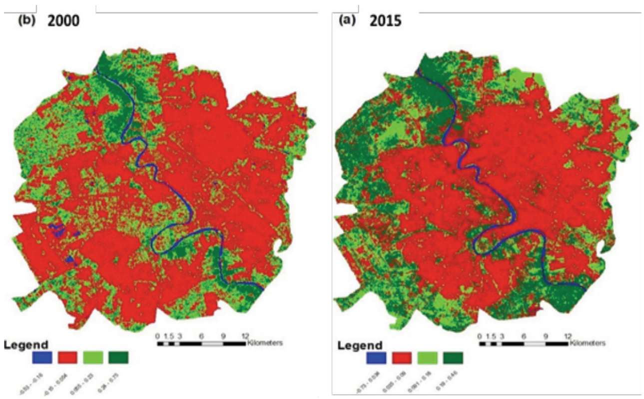

Fig. 5. Spatial distribution of NDVI for Baghdad city during 2000 and 2015.

6. Effect of land change on air temperature

6.1. Daily air temperature

Daily data of minimum, maximum and mean air temperature (Tmin, Tmax and T °C) measured at 2 m for both years 2000 and 2015 are presented in Figures 6a-6c, respectively. Peaks of Tmin, Tmax and T values during the years are found to be in July, while their lowest values are in January. Another significant feature that can also be seen from these figures is that there is a difference between daily Tmin, Tmax and T values along all days of 2000 and 2015. This difference clearly appears at summer times and is large for Tmin.

The highest Tmin values reach 36 °C in 2015 and 34 °C in 2000 (Figure 6a) while those of Tmax are 51 °C in 2015 and 37 °C in 2000 (Figure 6b). In the same manner, the lowest Tmin values are almost the same (~7 °C) in these years, especially in December, but this is different for Tmax, where it is larger in 2015, with about 17 °C and 8 °C in 2000. Mean air temperature computed by Equation 1 is largest with about 43 °C in July and smallest in January with about 12 °C as shown in Figure 6c.

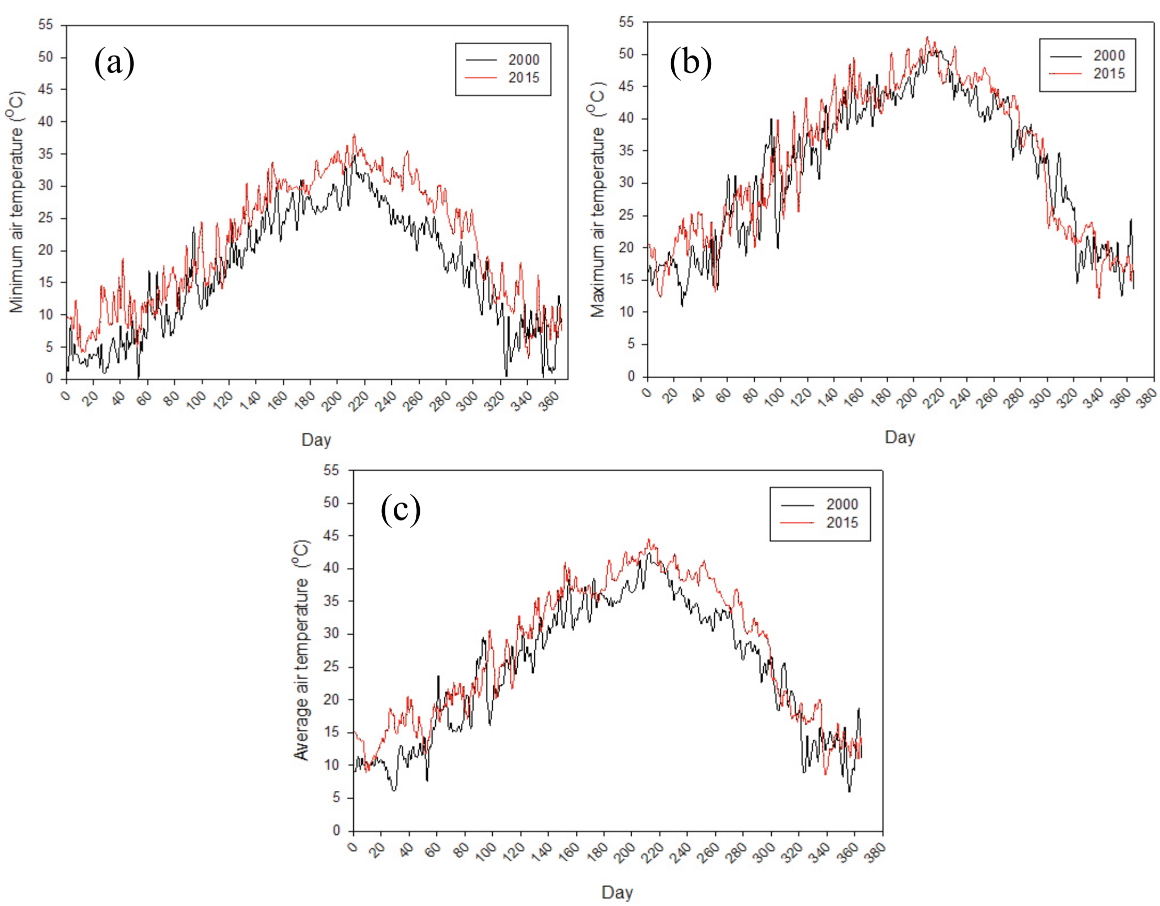

Fig. 6. Daily variations of (a) minimum, (b) maximum and (c) mean temperature in 2000 and 2015.

6.2. Daily temperature range

To confirm the effect of land changes over Baghdad on air temperature near the surface throughout the day, the daily temperature range (DTR) during daytime was calculated for all days in the two years, using the formula:

$$DTR = Tmax - Tmin \quad (3)$$

This variable is useful to show how the extent of contrast between Tmax and Tmin does change during the year. The results of DTR are displayed in Figure 7, which shows high fluctuation in DTR values for the years 2000 and 2015. That was expected, since Baghdad city is considered an arid environment (Sondos & Al-Jiboori, 2018). The change in the land use in this city saw an increase in DTR values during most of the days of the years studied, especially during the second half of the year, as shown in Figure 7, in which DTR values in 2015 show more warmth compared to 2000. Comparison between Figures 6 and 7 shows that the rising in DTR is mainly resulting from the rise in both daily Tmin and Tmax.

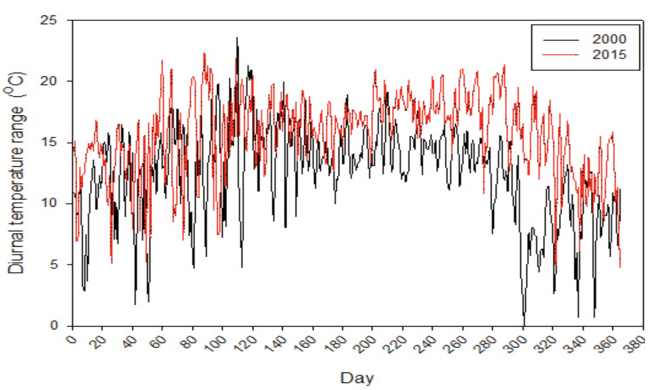

Fig. 7. Variation of daily temperature range in 2000 and 2015.

6.3. Monthly means of daily Tmax and Tmax

Monthly averages of daily Tmin and Tmax are computed by summing their values divided by their numbers. This helps in investigating the effect of urbanization expansion on the local climate within the changing surface of Baghdad. Figure 8 exhibits the results for these averages for both years, 2000 and 2015. This effect is observed to be more concentrated for Tmin in the first half of the year, in which the curve of Tmin in 2015 has values larger than that of 2000, while it is little at October and November (Figure 8a).

The difference between Tmin 2000 and 2015, ΔTmin, is highest in January and July with a value of ≈5 °C. Also, Figure 8b shows that the difference between Tmax (2000) and (2015), ΔTmax, is less throughout the months of the year, except in January and December (ΔTmax≈3 ºC). In this figure, it can also be noted that values of Tmax are the same in March. However, this effect will be discussed further in the following subsection. It can be concluded that urbanization expansion leads to Tmin being more affected than Tmax.

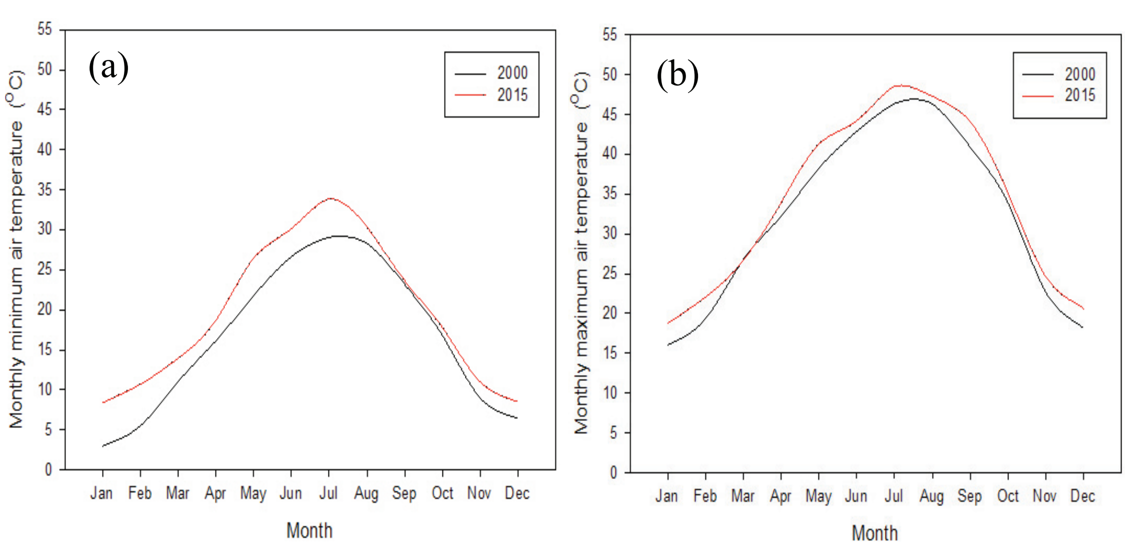

Fig. 8. Variation of monthly means of (a) minimum and (b) maximum air surface temperature in 2000 and 2015.

6.4. Heat effect of land surface changes

Heat production of land surface changes from 2000 to 2015 in Baghdad can be assessed by determining heat change, which is defined as the monthly difference between 2015 and 2000 (ΔTmin), as well as between Tmax in 2015 and 2000 (ΔTmax). If this difference has positive values it will be a warming effect, for negative values a cooling effect. According to the above criteria, the results of monthly ΔTmin and ΔTmax are presented in Figure 9, which illustrates that all differences are an increase in air temperature. Monthly minimum air temperature is more affected by land use change, especially in January, February, May, and July (ΔTmin>3 °C). Also, heat changes in ΔTmax are less intense, with values > 2 °C in January, February, May and July. This is expected, because of the transformation to building materials such as stone, concrete and asphalt, which have high heat capacity to absorb heating from the sun.

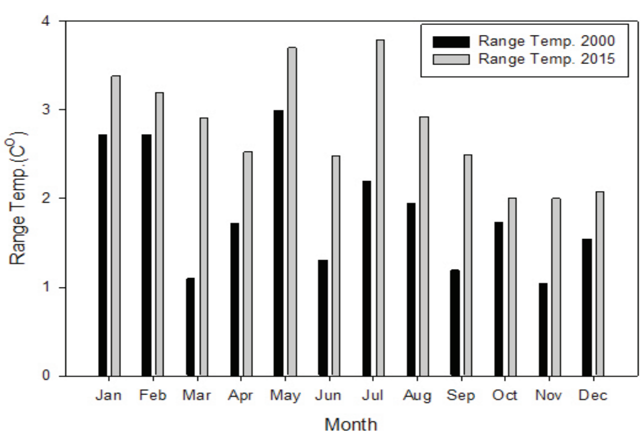

Fig. 9. Monthly heat differences in daily Tmin and Tmax.

7. Conclusion

This paper presents a detailed study of the effect of the surface changes of urban Baghdad city on the local climate, represented by surface air temperature. Data for population, gross domestic product, and the areas of residences, agriculture and others were used to evaluate their quantitative changes before and after 2003, the year of the political changes that occurred in Iraq. Two years, 2000 and 2015, were selected to study the effects of land use changes on air temperature. The rapid increase in population from $4.8x10^6$ to $7.7x10^6$, resulting often from internal immigration led to the occupying of many agricultural areas, which were then transformed to random housing areas. Urban areas in 2000 were 192.8 km^2 and expanded to 437.2 km^2 in 2015, while agricultural areas were 596 km^2 and then reduced to 298 km^2. These changes produced a rise in daily minimum, maximum and average temperatures, as well as diurnal temperature ranges. In 2015, the increase in minimum air temperature values was larger than that of maximum temperature, and even for average temperature. This rise also showed in a positive (or warming) difference between monthly averages of minimum air temperature in 2015 and 2000, with a value of 3 °C.

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