

Determination of Difference Amount in Reference Evapotranspiration between Urban and Suburban Quarters in Karbala City

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ABSTRACT

Evapotranspiration represents one of the main parameters in the hydrological cycle. It is usually expressed by the term reference evapotranspiration (ET_o) that is affected by certain meteorological parameters. This study aimed to find the difference amount in ET_o between urban and suburban quarters in Karbala city. The study methodology involved selecting once urban area and four suburban quarters. Two methods of determining the reference evapotranspiration were applied: first, a direct method which measured ET_o at selected fields by using a hand-held device, and second, an indirect method using the Penman-Monteith equation. The findings showed that the magnitudes of ET_o by the Penman-Monteith equation are higher than the values measured by the direct method for urban and suburban quarters. Moreover, it was found that the absolute percentage of difference in the average amount of ET_o between urban and suburban quarters is 13% by using the direct method and 61% by using Penman-Monteith equation. The study conclusion is that suburban area has higher magnitude of ET_o than urban quarter by using any of direct method and indirect method (Penman-Monteith equation).

Keywords: reference evapotranspiration, Penman-Monteith equation, urban area, suburban area.

INTRODUCTION

Water demand at a basin level is influenced by many factors, such as meteorological variables, soil moisture, vegetation type and irrigation system. Among them, climate is the major driver, because weather conditions determine energy balances and vapor pressure deficit that affect the magnitudes of vapor flux from surface to atmosphere. Therefore, the need for climate data through weather stations has become a high priority within the policies of world countries. Unfortunately, weather stations are scarce due to their high cost as well as their expensive maintenance; this caused shortage in the required climate information, such as evaporation in form of Evapotranspiration that consists of evaporation and transpiration processes

and considers an important component of the hydrologic budget (Senay et al. 2008; Silva et al. 2010). Therefore, using mobile devices give more space to investigate the relationship between temperature and evapotranspiration in different places. In particular, the evapotranspiration amount was extremely affected by the climate change during the recent decades and impacted more areas worldwide. Thus, monitoring evapotranspiration by using specific and costly equipment is a great challenge during this era (Algretawee & Alshama, 2021). However, determining reference evapotranspiration (ET_o) by using a hand-held device with low cost is a good method to overcome this challenge. As an alternative, agronomists and engineers use semi-empirical equations, such as the Penman–Monteith formula to estimate ET_o

based on surface weather observations. Reference evapotranspiration can be calculated based on climatic variables, i.e., solar radiation, air temperature, wind speed, and relative humidity. Examination of the trends in ETo can provide the means to understand how climatic changes affected evapotranspiration rates over a region (Dadaser-Celik et al. 2016). The temperature, which has been greatly affected by the climate change, is clearly the main factor affecting reference evapotranspiration values. Urban, suburban, and rural areas have completely different temperatures that depend on the climate and nature characteristics of these areas. Although many studies mentioned to find the evapotranspiration variation for different areas, there is no specific study mentioned to determine ETo between urban and suburban areas which involve the effect of different temperatures between these areas. Recent studies suggested that plant growth form is another important factor controlling total evapotranspiration in urban areas, with the turfgrass-dominated areas showing higher water fluxes than the tree-dominated areas (Offerle et al. 2006; Balogun et al. 2009); however, these studies focused on evapotranspiration, whereas this study focused on ETo. The spatial heterogeneity of urban landscapes, however, greatly complicates the extrapolation of these ecosystem-scale measurements to other urban and suburban areas, as vegetation composition varies widely within and between cities. Therefore, in this study, specified points in urban and suburban areas were selected to measure ETo directly and indirectly as well as show the effect of temperature, which is considered of the climate change drivers on the magnitude of ETo.

Determining ETo magnitudes were affected by spatial factors, such as the densely built-up city centers or downtown areas with high impervious surface cover tend to have lower evapotranspiration rates and smaller evaporative fractions than residential areas with short buildings and high vegetation cover (Peters et al. 2011). Moreover, the difference in temperature between air and surface land affected ETo (Majozi et al. 2021; Djaman et al. 2015). The effect of spatial parameter was mentioned in this study to show the difference in ETo between urban and suburban areas. Estimating reference evapotranspiration by using ground weather stations was adopted in many countries, such as Turkey

(Dadaser-Celik et al. 2016). They analyzed weather data for many last years by adopting the Penman–Monteith equation. In addition, the Penman–Monteith equation is the most accurate method to estimate ETo (Liuzzo et al. 2016; McColl 2020; Hargreaves and Samani 1985; Rodrigues and Braga 2021) and building a model to predict ETo (Djaman et al. 2020; Tran and Honti 2017). Therefore, this study adopted the Penman–Monteith equation to calculate reference evapotranspiration as an indirect method; however, these studies used fixed metrological stations which are limited to some places.

Loss of evaporation has become a concern in some cities through Italy (Elferchichi et al. 2017). Moreover, evapotranspiration is sensitive to weather parameters, particularly high magnitudes of temperatures (Ndiaye et al. 2017; Song et al. 2018; Quej et al. 2019). Therefore, this study focused on a day in summer, which recorded maximum temperature during the whole year, to calculate reference evapotranspiration ETo.

Many studies showed that the value of reference evapotranspiration is varied according to the methods of estimating this value. These methods have two ways to obtain ETo, either by using the direct method or indirect method. However, there is no study using both the direct and indirect methods in urban and suburban cities to recognize the difference in ETo. In this study, the reference evapotranspiration amount in urban and suburban quarters in Karbala city was determined by using the direct method (hand-held device) and indirect method (Penman–Monteith equation) in order to indicate the difference between these quarters, and show the effect of temperature on ETo.

STUDY AREA

Karbala city in Iraq was selected as a case study. City center quarter (Bain Al-Haramain) was selected as an urban area, and four quarter quarters (Alhur, Saif Saad, Fraiha and Alnasor) were adopted as suburban quarters (Figure. 1). The distances between the urban quarter (Bain Al-Haramain) and suburban quarters were as follows: Fraiha quarter 3250 m, Saif Saad quarter 4325 m, Al-Nasor quarter 5400 and Al-Hur quarter 6500 m.

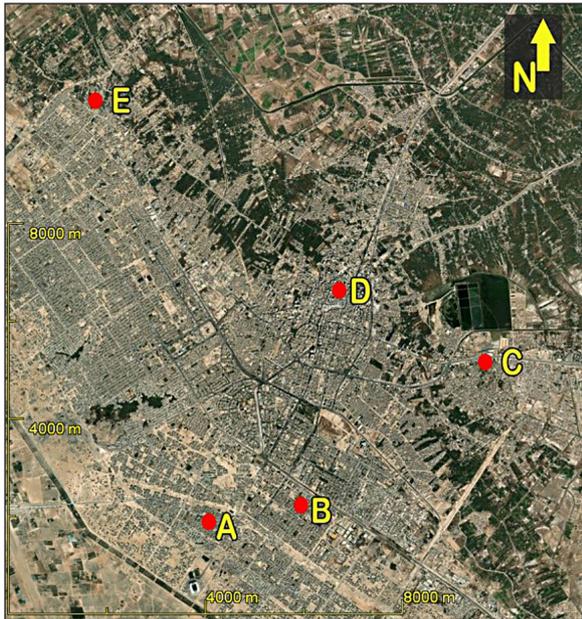


Figure 1. Study area (Karbala city-Iraq) consists of: (A) Al-Nasor quarter, (B) Saif Saad quarter, (C) Fraiha quarter, (D) City centre (Bain Al-Haramain), and (E) Al-Hur quarter

METHODOLOGY

In this study, one point was selected in urban area (Bain Al-Haramain), and three points were selected in suburban quarters. All essential data was collected by using a hand-held device through a day in summer because temperature in this day recorded the highest magnitude during the year.

Data

To calculate reference evapotranspiration a Kestrel 5200 series hand-held and environmental meter device (Fig. 1) was used to collect all weather data, including: maximum and minimum air temperature (with a temperature accuracy of ± 0.05 °C), wind speed at 1.5 m (changed to 2 m) (Allen et al. 1998), density, radiation, pressure, and dew point. In this study, three points were selected for each area (one urban area and four suburban quarters). All weather data were recorded through the device, after waiting for 2 to 5 minutes till the reading becomes constant. These measurements were sampled once during summer season at daytime. The methodology of the study depended on both ways, direct and indirect methods by reading ETo directly from the device, as well as using the Penman-Monteith

equation. To obtain the difference in evapotranspiration between urban and suburban quarters, city center in Karbala (Bain Al-Haramain quarter) was chosen as an urban area, which has the highest population in the Karbala province. To obtain high precision, four suburban quarters were selected towards four directions (Alhur towards North, Fraiha towards south, Saif Saad towards West and Alnasor towards North-West). Population rate was the reason to select these quarters; however, the east side was rural area (AlHusseiniya quarter), which is very close to the central urban area in Karbala.

All measurements were executed for urban and suburban quarters within the same day during daytime hours. The reason behind that is to choose a day in summer, in which the maximum temperature of 47 °C was recorded during daytime hours. Moreover, some studies reported that the best season to determine ETo is summer (Chen et al. 2013; Vicente-Serrano et al. 2014). The necessary weather data was recorded in this day for each selected point in the urban and suburban quarters of the study area. Three points were selected with short distances between them for every quarter to save the time and finish all the observed quarters within daytime hours.

Urban area

Karbala city center (Bain Alharamain quarter) was selected as the urban area in this study. Three points were selected in this area (Fig. 3); coordinates of the points are shown in Table 1.

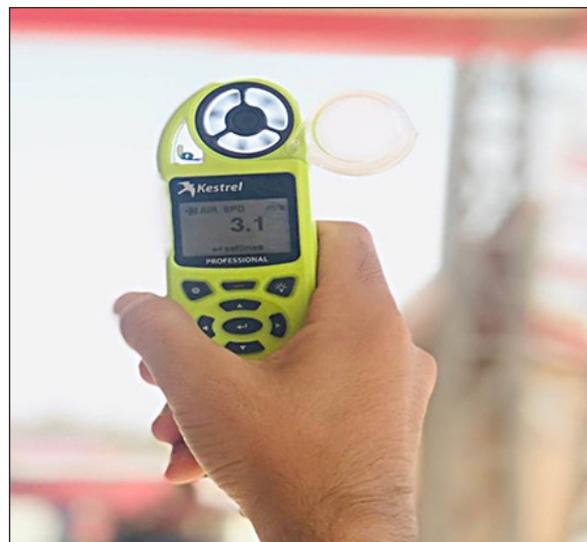


Figure 2. Hand-held device (a Kestrel 5200 series) (Algretawee & Alshama, 2021)

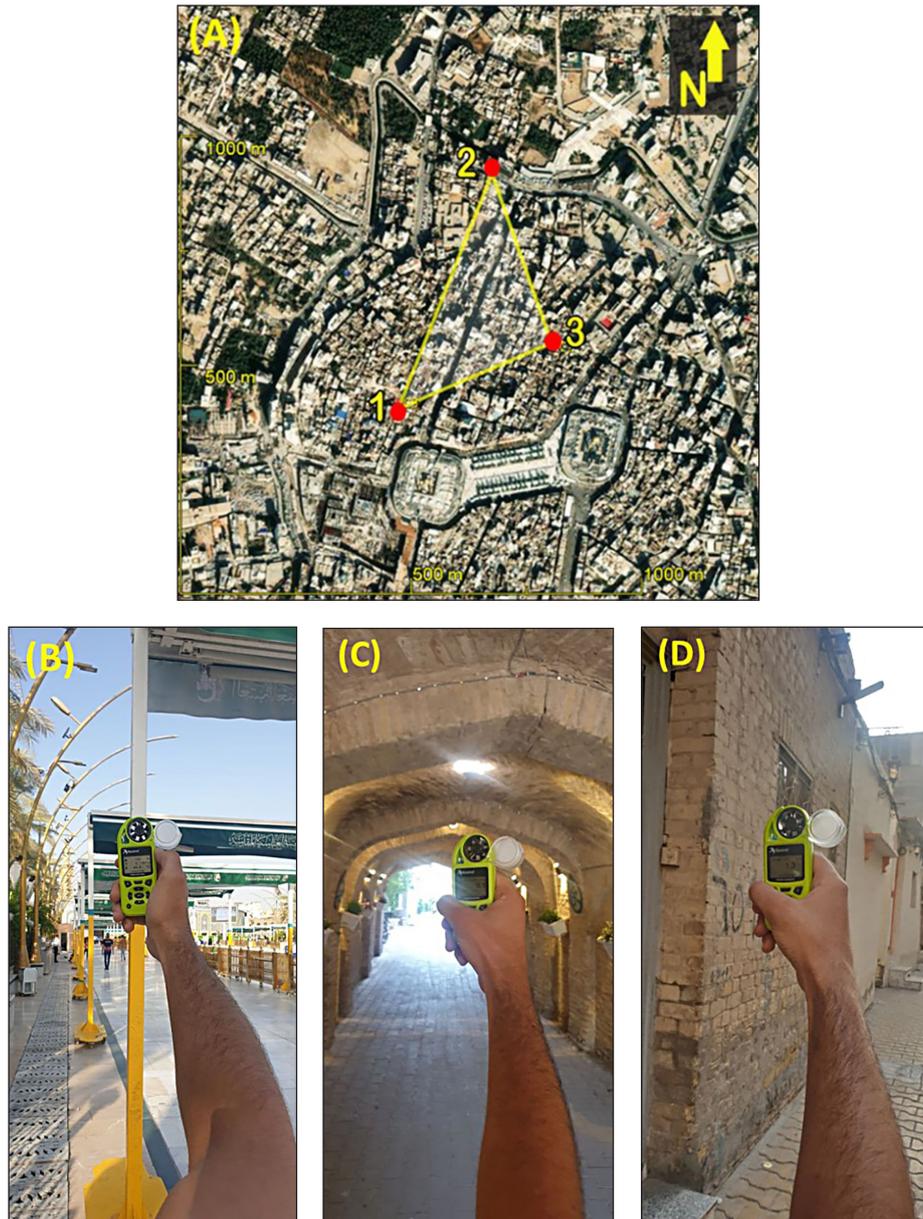


Figure 3. (A) Aerial photo for urban quarter (city center – Bain Alharamain), (B) Point 1, (C) Point 2, and (D) Point 3

The chosen points were close to vegetation, such as bushes or turfs. Points 1, 2 and 3 represent triangular head corners. The distance between points 1 and 3 is equal to 400 m, which is equal to the distance between points 2 and 3; however, the distance between points 1 and 2 is equal to 600 m.

Table 1. Coordinates of points in an urban quarter are city center (Bain Alharamain)

Point	1	2	3
North (N)	32°.26.438'	32°.37.133'	32°.37.067'
East (E)	44°.04.045'	44°.02.129'	44°.01.913'

Suburban quarters

Four suburban quarters were chosen in this study which are: Saif saad quarter, Fraiha quarter, AlHur quarter and AlNaser quarter.

Saif Saad quarter

Three points were selected in this area (Fig. 4); coordinates of the points are shown in Table 2. Three points were selected in this quarter; these points represent triangular head corners. The distance between points 1 and 3, and 2 and 3 is the same and it is equal to 500 m, but the distance between 1 and 2 is equal to 1050 m.

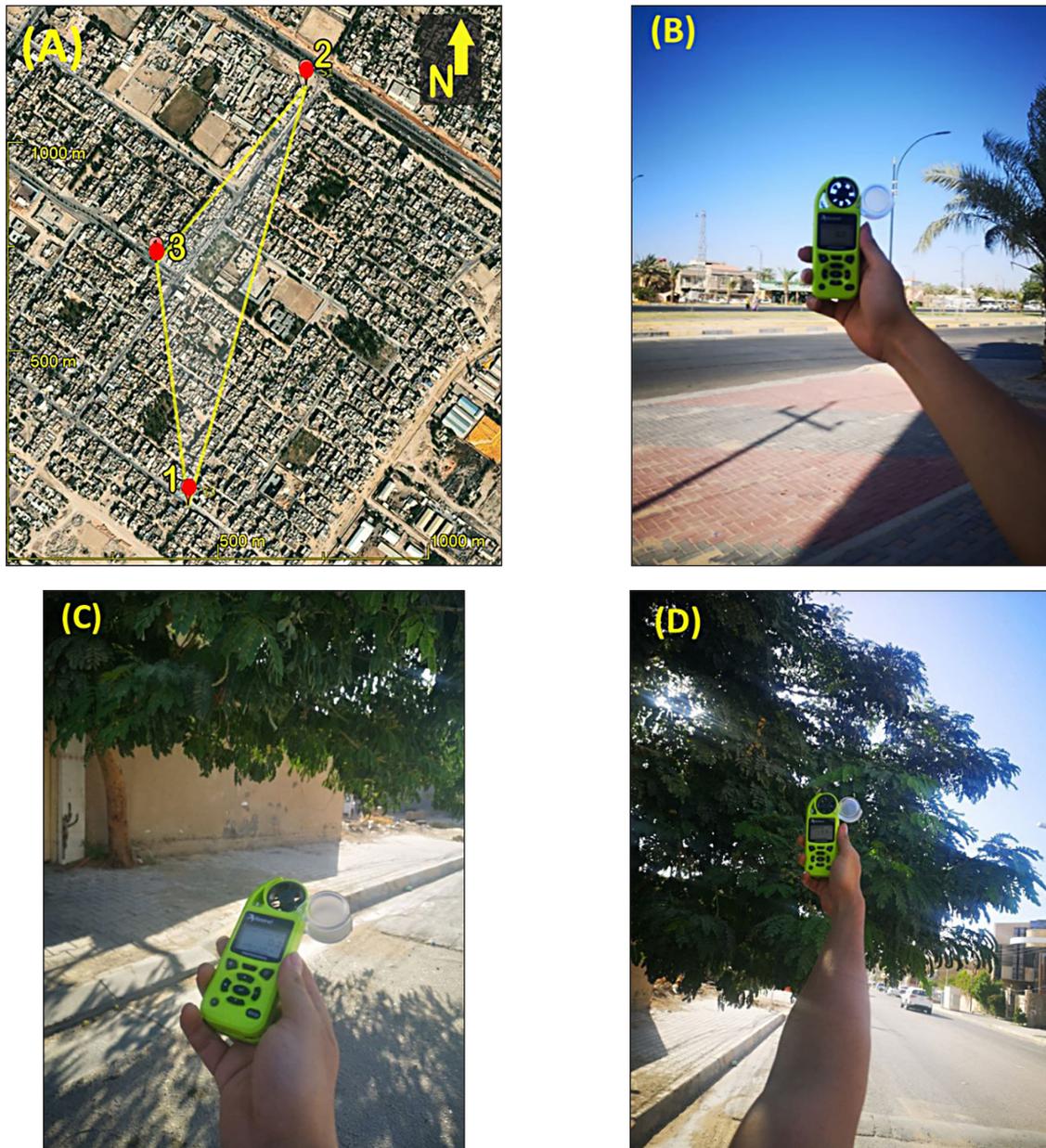


Figure 4. (A) Aerial photo for Saif Saad quarter: (B) Point 1, (C) Point 2, and (D) Point 3

Table 2. Coordinates of points in the suburban area (Saif Saad quarter)

Point	1	2	3
North (N)	32°34.918'	32°34.689'	32°34.375'
East (E)	44°01.788'	44°01.561'	44°01.609'

Table 3. Coordinates of points in a suburban area (Fraiha quarter)

Point	1	2	3
North (N)	32°36.315'	32°36.210'	32°36.438'
East (E)	44°05.413'	44°05.906'	44°04.095'

Fraiha quarter

Three points representing triangular head corners were selected in this area (Figure 5), coordinates of the points are shown in Table 3. The distance between points 1 and 3, 2 and 3, as well as 1 and 2 is equal to 625 m, 563 m, and 900 m, respectively.

Al-Hur quarter

Three points representing triangular head corners were selected in this area (Figure 6), coordinates of these points are shown in Table 4. The distance between points 1 and 3, 2 and 3, as well as 1 and 2 is equal to 850 m, 1050 m, and 1500 m, respectively.

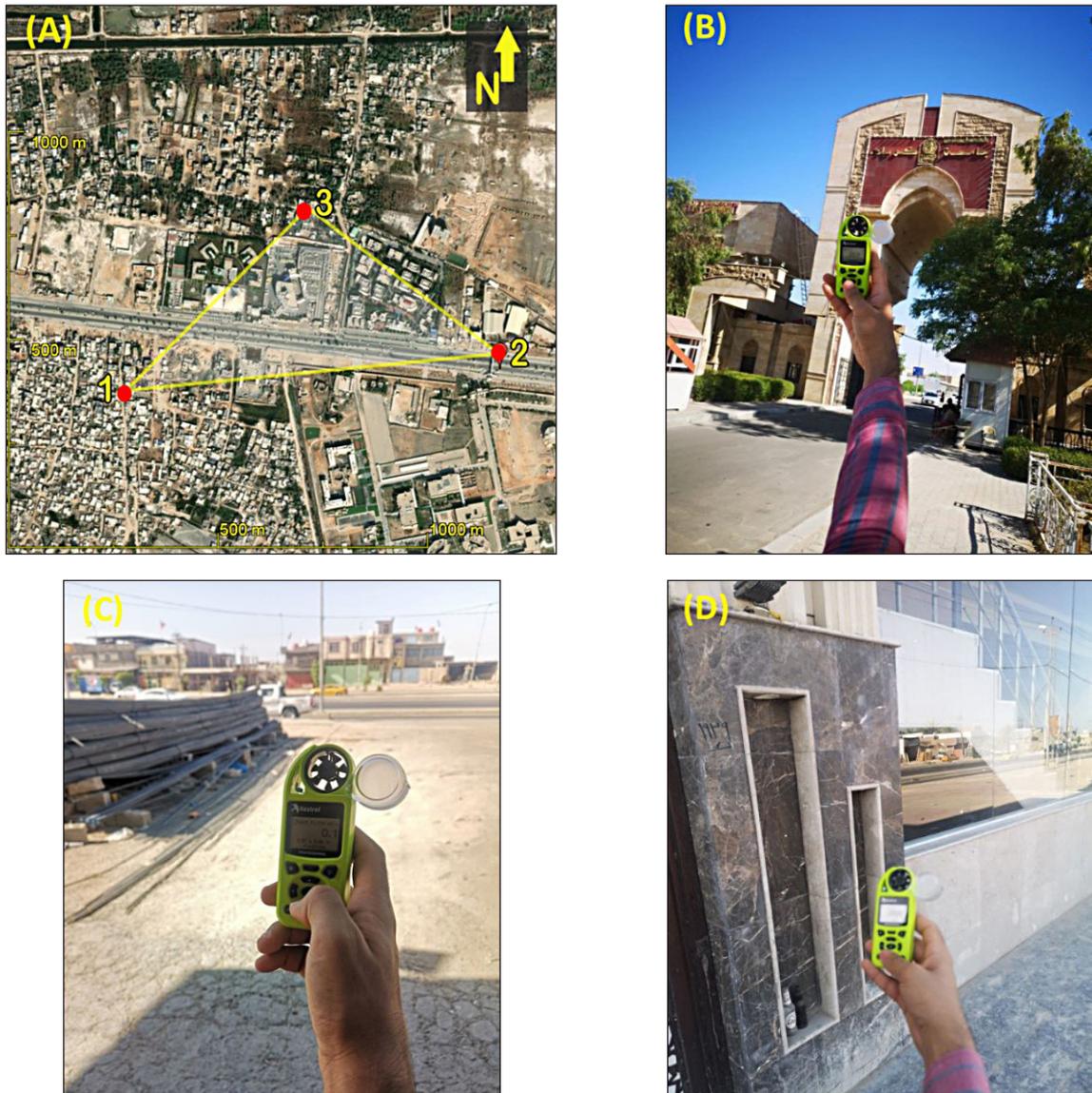


Figure 5. (A) Aerial photo for Fraiha quarter: (B) Point 1, (C) Point 2, and (D) Point 3

Al-Naser quarter

Three points representing triangular head corners were selected in this area (Figure 7), coordinates of these points are shown in Table 5. The distance between points 1 and 2, 2 and 3, and 1 and 3 is equal to 750 m, 660, and 1180, respectively.

The surroundings of all points in Figures 4, 5, 6, and 7 have vegetation such as, bushes and/or turfs.

RESULTS

This section includes the results of reference evapotranspiration magnitudes which obtained by direct (hand-held device) and indirect methods (Penman-Monteith equation) for urban and suburban quarters.

Direct and indirect methods

In this study, the results from the direct method by using hand-held device were adopted at all points in urban and suburban quarters. In terms of the indirect method, the Penman-Monteith equation was used to calculate reference evapotranspiration, which can be written as (Balogun et al. 2009):

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where: ET_o – reference evapotranspiration (mm/ day);
 Δ – the slope of vapor pressure curve (kPa/ °C);
 R_n – the net radiation at the crop surface (MJ/ m² d);



Figure 6. (A) Aerial photo for AlHur quarter: (B) Point 1, (C) Point 2, and (D) Point 3

Table 4. Coordinates of points in a suburban area (Al-Hur quarter)

Point	1	2	3
North (N)	32°39.398'	32°39.290'	32°39.072'
East (E)	43°59.602'	43°58.602'	43°59.083'

G – the soil heat flux density (MJ/ m² d);
 T – average air temperature at 2 m height (°C) computed from maximum and minimum air temperature (T_{max} and T_{min} , °C);
 $e_s - e_a$ – the saturation vapor pressure deficit (kPa);
 U_2 – is wind speed at 2 m height;
 γ – psychrometric constant [kPa/ °C].

$$e_s = \frac{e(T_{max}) + e(T_{min})}{2} \quad (2)$$

where:

$$e(T_{min}) = 0.610 \exp\left(\frac{17.27T_{min}}{T_{min} + 237.3}\right) \quad (3)$$

$$e(T_{max}) = 0.610 \exp\left(\frac{17.27T_{max}}{T_{max} + 237.3}\right) \quad (4)$$

$$e_\alpha = \frac{RH_{mean}}{100} \left[\frac{e(T_{max}) + e(T_{min})}{2} \right] \quad (5)$$

$$\Delta = 4098 \left[\frac{0.6108 \exp\left(\frac{17.27T}{T + 273.3}\right)}{(T + 273.3)^2} \right] \quad (6)$$

$$\gamma = 0.665 \times 10^{-3} P \quad (7)$$

where:

$$P = 101.3 \left(\frac{293 - 0.0056Z}{293} \right)^{5.26} \quad (8)$$

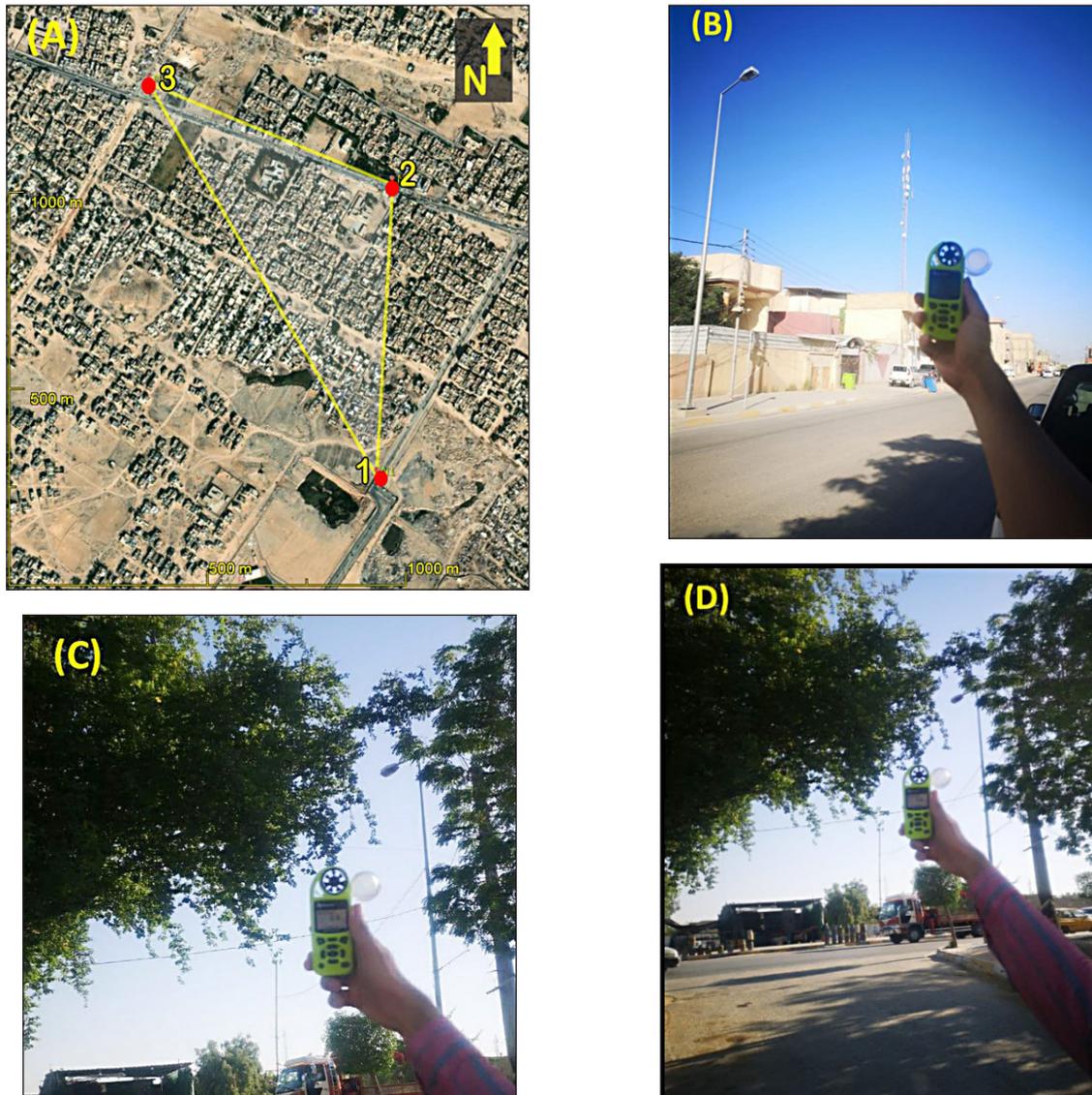


Figure 7. (A) Aerial photo for Al-Naser quarter: (B) Point 1, (C) Point 2, and (D) Point 3

Table 5. Coordinates of points in a suburban area (Al-Naser quarter)

Measuring points	1	2	3
North (N)	32°34.247'	32°34.646'	32°34.768'
East (E)	44°00.481'	44°00.507'	44°00.114'

$$R_n = R_{ns} - R_{nl} \quad (9)$$

To apply Penman-Monteith equation, all place points (1, 2 and 3) for urban and suburban quarters where turf has average height that can be estimated as 12 cm. To calculate soil heat flux at daytime, equation 2 is adopted (Balogun et al. 2009).

$$G_{nr} = 0.1 R_n \quad (10)$$

Table 6. Reference evapotranspiration in an urban area (Bain Al-Haramain)

Points	1	2	3	Average
$ETo_{(direct)}$ (mm/day)	2.4	4.56	0.96	2.64
$ETo_{(Penman-Monteith)}$ (mm/day)	2.9	1.41	2.17	2.16

The obtained results from indirect methods at three points in suburban quarters are shown in Table 6.

Urban quarter

In this area, reference evapotranspiration (ETo) was calculated by direct and indirect methods. The results are shown in Table 6 and Fig. 8.

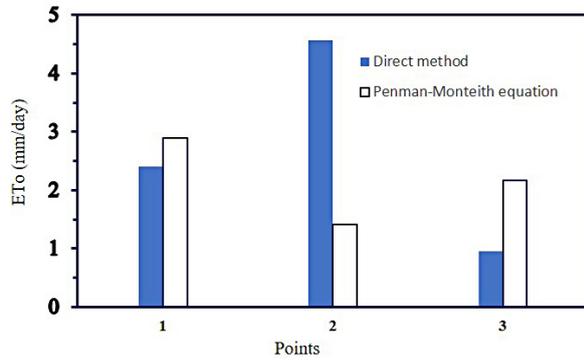


Figure 8. Reference evapotranspiration magnitudes for measuring points in the Bain Al-Haramain quarter

Suburban quarters

Four suburban quarters: Saif saad quarter, Fraiha quarter, AlHur quarter and AlNaser quarter were selected as suburban quarters. In each of these quarters, reference evapotranspiration was obtained in three points by using direct and indirect methods and the results are shown in Table 7 and in Figs 9 to 12.

DISCUSSION

Urban quarter (Bain Al-Haramain)

The magnitudes of ETo estimated by Penman-Monteith were higher than those obtained by

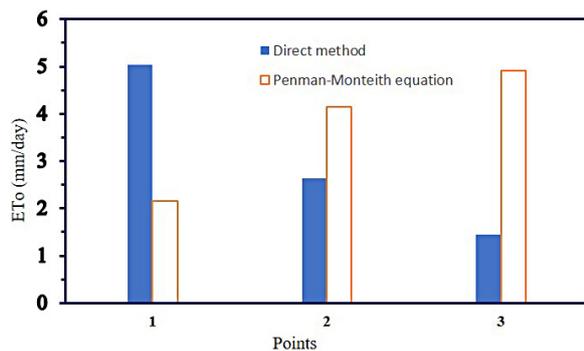


Figure 9. Reference evapotranspiration magnitudes for measuring points in Saif Saad quarter

means of direct method at points 1 and 3; however, the ETo magnitude by using direct method was higher than that calculated by Penman-Monteith at point 2. There is a variance between the results of direct and indirect ETo, and this is mainly due to the difference in how to obtain the measurements. The difference in results caused by different methods of calculating reference evapotranspiration (Temesgen et al. 2005). Moreover, the Penman-Monteith method gives higher ETo values than those recorded by means of the direct method, which are similar to (Chen et al. 2013). Another reason is that the ETo magnitudes by the direct method were taken in the open air and not under the roof, as at points 1 and 3, while the ETo reading by the direct method for the location under the roof as shown in Figure 3-C gives

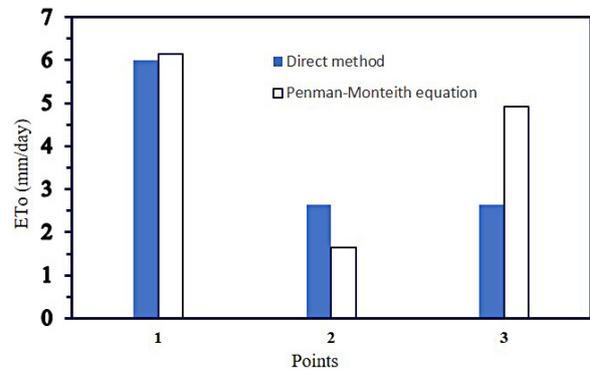


Figure 10. Reference evapotranspiration magnitudes for measuring points in Fraiha quarter

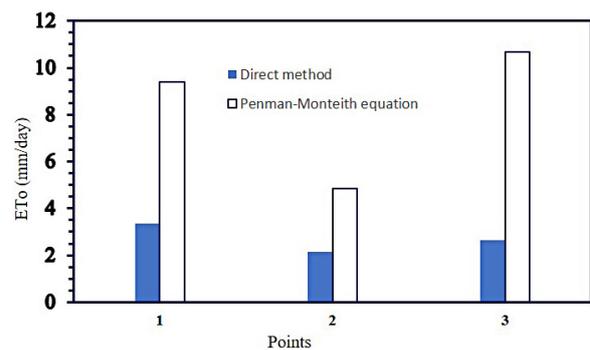


Figure 11. Reference evapotranspiration magnitudes for measuring points in AlHur quarter

Table 7. Reference evapotranspiration in suburban quarters by using direct and indirect methods

Suburban area name	Saif Saad quarter			Fraiha quarter			AlHur quarter			AlNaser quarter		
	1	2	3	1	2	3	1	2	3	1	2	3
Points												
ETo (direct) (mm/day)	2.9	2.4	2.6	5.0	2.6	1.4	6.0	2.6	2.6	3.4	2.2	2.6
Average	2.6			3.0			3.8			2.7		
Eto (Penman-Monteith) (mm/day)	4.7	6.0	7.2	2.2	4.1	4.9	6.1	1.7	4.9	9.4	4.9	10.7
Average	6.0			3.7			4.2			8.3		

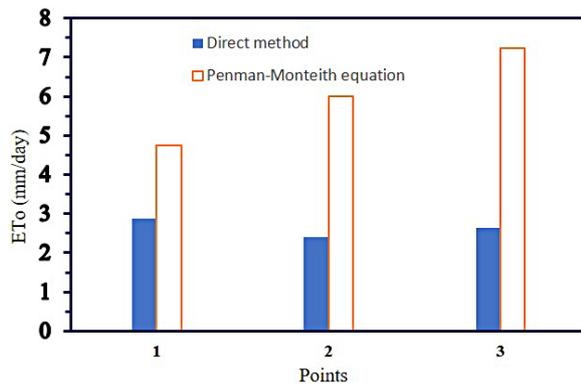


Figure 12. Reference evapotranspiration (ETo) magnitudes for measuring points in AlNaser quarter

higher values than those estimated by the Penman-Monteith method. The differences in magnitude between the Penman-Monteith equation and the hand-held device are similar to most studies (Valipour 2014; George et al. 2002; Vicente-Serrano et al. 2014) which adopted different methods to estimate reference evapotranspiration (ETo).

Suburban quarters

In the first suburban quarter, Saif Saad quarter, the magnitudes of ETo obtained by means of the Penman-Monteith equation were higher than those obtained by using the direct method at all points 1, 2 and 3. On the other hand, ETo magnitude by using Penman-Monteith at point 3 was the highest. These differences in the values of ETo between the two methods are mainly due to the difference in obtaining ETo between the two methods.

In the second suburban quarter, Fraiha quarter, the magnitudes of ETo obtained by the Penman-Monteith equation were higher than those by using the direct method at all points except point 1. On the other hand, ETo magnitude by using the Penman-Monteith method decreased semi-gradually from point 3 to point 2 to point 1. In contrast, the magnitude of ETo by using direct method increased semi-rapidly from point 3 to point 2 to point 1. Moreover, indirect ETo magnitude at point 3 was the highest, but direct ETo magnitude at point 1 was the highest.

In the third suburban quarter, AlHur quarter, at points 1 and 3, the ETo values obtained by the Penman-Monteith method are higher than those by the direct method. In contrast, the ETo values obtained by means of the Penman-Monteith equation at point 2 are lesser than those by the

direct method. The maximum and minimum values of ETo by using the two methods were obtained at points 1 and 2, respectively.

In the last suburban quarter, AlNaser quarter, the magnitudes of ETo obtained by the Penman-Monteith equation were higher than those by direct method at all points 1, 2, and 3. The highest value of ETo was obtained at point 3 by using the Penman-Monteith method. However, the lowest value of ETo was found at point 2 by using the direct method. These results differ than those of other suburban quarters.

Generally, there is a variance between the results of direct and indirect ETo at all suburban quarters due to the difference in the methods of calculating ETo. Table 6 shows that the average ETo of the three points in urban quarter obtained by the direct method is higher than that by the indirect method. On the other hand, Table 7 presents that the average reference evapotranspiration of the three points obtained by the indirect method is higher than that by direct method for all suburban quarters. This may be referred to the fact that the parameters of the Penman-Monteith equation are affected by suburban quarters more than by urban quarter, i.e. this equation gives the ETo values in suburban quarters higher than that in urban quarter. Another explanation for the highest magnitudes of ETo at suburban quarters could be due to the high sensitivity to air temperature (Vicente-Serrano et al. 2006).

The average value of ETo by means of the direct method at all suburban quarters and urban quarter is 3.04 mm/day and 2.64 mm/day respectively, while by the Penman-Monteith equation, the average value of ETo is 5.57 mm/day and 2.16 mm/day in all suburban quarters and urban quarter, respectively. The absolute percentage of difference in the average amount of ETo between suburban and urban quarters is about 13% by using the direct method and about 61% by using the Penman-Monteith equation. The different ratios could be due to the fact that the Penman-Monteith equation adopts many parameters which have estimation factors that could increase the value of ETo, but the direct method only depended on the device reading which directly measures the ETo without any assumptions. Irrespective of the calculating ETo method, the differences between the magnitudes of ETo relative to the points are significant, which could refer to the change in specifications around every point. The magnitudes of ETo by using the Penman-Monteith equation at point 3 were higher

than those at points 1 and 2 at all suburban quarters except the Al-Hur quarter. The reason may be due to the location of point 3 which is far from the other points and surrounded by suitable vegetation quantity except at the Al-Hur quarter.

By comparing the magnitude of ETo between the direct and indirect methods relative to measuring points 1, 2 and 3, it can be observed that the magnitude of ETo by adopting direct method at point 1 was lesser than that calculated by the indirect method for all urban and suburban quarters except the Fraiha quarter. In contrast, the magnitude of ETo by adopting the direct method at point 2 is higher than that calculated by the indirect method at urban and one of suburban quarters, which is the Al-Hur quarter. In turn, at point 3, the magnitude of ETo by adopting the direct method was lesser than that calculated by the indirect method at all urban and suburban quarters. The maximum magnitude of ETo was observed at point 3 in the Al-Nasir quarter, because the distance between this quarter and the city center is 5400 m; however, the Alhur quarter is 6500 km away. Therefore, the features around point 3 at Al-Hur have high intensity of greening area and bushes that increased the reference evapotranspiration. Although many contemporary researchers used the Penman-Monteith equation, they adopted fixed meteorological stations (Gong et al. 2006; Xu et al. 2006; Croitoru et al. 2013; Bandyopadhyay et al. 2009) for different last years to either estimate ETo or studying spatial and temporal variation on daily, monthly and yearly sensitive magnitudes of ETo. However, none of the recent studies used a mobile device to measure ETo directly and obtain weather data at specified points in urban and suburban places.

CONCLUSIONS

The objective of this study was to determine the amount of reference evapotranspiration in urban and suburban quarters by using direct and indirect methods. The results showed that the ETo values estimated by the Penman-Monteith equation are higher than those recorded by the direct method for urban and suburban quarters. It was also found that the absolute percentage of difference in the average amount of ETo between suburban and urban quarters is about 13% by using the direct method and is about 61% by using the Penman-Monteith equation. Generally, the

results revealed that a suburban quarter has higher magnitude of reference evapotranspiration than a urban quarter by using either the direct method or Penman-Monteith equation. Summing up, it can be concluded that the amount of reference evapotranspiration by direct and indirect methods in suburban quarters is higher than that in an urban quarter.

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