INTEGRATIVE USE OF PENMAN-MONTEITH EQUATION WITH REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEM TECHNIQUES TO ESTIMATE EVAPOTRANSPIRATION VRIANCES IN IRAQ

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ABSTRACT

This research was aimed to construct an integrative system which is capable of accurate determining and analyzing evapotranspiration rates in Iraq for long period , Since high evapotranspiration rates and extreme shortage in precipitation are the main causes of aridity, which considered principal reason for land degradation and land desertification eventually. FAO Penman-Monteith method was adopted because it's the international standard method. In this work meteorological readings of nine stations with comprehensive covering for Iraq's area were taken for every ten years in a long-term range (31 years). The daily evapotranspiration values had been calculated, then after the annual summation value determined for the years (1987, 1997, 2007, and 2017). The use of spatial analysis schemes proved that generally eighties decade of the last century had climax (Etr) values, then ETr rates rapidly decreased in whole Iraq except some anomalies. There were two reasons for this decrement, firstly air temperature value decent which increase relative humidity. Secondly wind speed rates falling (which considered the principal cause for reference evapotranspiration rates descending in this case).

Keywords: aridity, desertification, global warming, and urban heat islands
Part of M.Sc. thesis of the 2nd author

الأستعمال التكاملي لمعادلة بينمان– مونتيث مع تقنيات التحسس النائي و نظم المعلومات الجغرافية لتقدير تغايرات التبخر–نتح في العراق

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مدرس **باحث**
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المستخلص

ان هدف هذا البحث قد تمثل ببناء منظومة تكاملية قادرة على الاحتساب والتحليل الدقيقين لنسب التبخر– نتح في العراق لامد طويل لان نسب التبخر العالية والتناقص الحاد في الساقط المطري هما السببان الرئيسيان للجفاف، والذي يعد العامل الاساسي في تدهور الارض وتصحرها بالنهاية, تم استعمال طريقة FAO Penman–Monteith كونها الطريقة المعيارية عالميا. في هذا العمل تم اخذ قراءات لتسع محطات انوائية تمتلك تغطية شمولية لعموم مساحة العراق عند كل عشر سنوات في امد طويل (31 سنة). قيم التبخر اليومية احتسبت، ثم وجد المجموع السنوي للتبخر للسنوات (1987، 1997، 2007، 2017). ان استعمال طرق التحليل المكاني اثبتت بان عقد الثمانينيات من القرن المنصرم هو الاعلى بنسب التبخر– نتح المرجعية عموما. بعد ذلك نسب التبخر– نتح تناقصت سريعا في العراق مع وجود الشذوذ لبعض الاماكن. هنالك سببان وراء هذا التناقص، الاول قلة حرارة الهواء التي ادت الى زيادة الرطوبة النسبية. الثاني التقهقر في نسب سرعة الرياح (والذي عد المسبب الرئيس وراء قلة نسب التبخر– نتح المرجعي في هذه الحالة)

الكلمات المفتاحية: الجفاف, التصحر,الاحتباس الحراري, وجزر الحرارة الحضرية
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INTRODUCTION

The global warming phenomenon refers to temperature reservation in the atmosphere system of the Earth globe. The reason beyond this phenomenon is the "Greenhouse gases" (8,12), releasing especially carbon dioxide and methane to the air due to fossil fuel consumption(3), these gases prevent thermal radiations [Far Infra-Red (FIR) band radiations that are reflected or missioned from earth's surface] from leaving to space (7). The environmental results are expected to be catastrophic ones as planet's surface average temperature increment, sea level raising, short-range weather non-stability(5), and land vegetation and animal cover variations(11). The air temperature ascent leads to evapotranspiration rates increasing is a no doubt issue, this difference influence the water projects planning such as dam's reservoirs construction and irrigation cannels distribution(9). It also affects the most hydrological mathematical models simulation (since their mainly dependence on rainfall and evapotranspiration). According to utilized variables, the potential evapotranspiration calculation schemes classified into five classes, as follow:

1- Temperature-based schemes
2- The mass-transferring schemes
3- Radiation schemes
4- Combination schemes
5- Water budget ones.

MATERIALS AND METHODS

Study area

Iraq located in northeastern portion of WANA region (West Asia and North Africa)(1), that is well-known as MENA one (Middle East and North Africa)(4). Iraq extends between 38º 45' to 48º 45' East longitudes and 29º 5' to 37º 22' North latitudes covering 438,320 square kilometers with 0.21% of it as water planes (rivers, lagoons, and marshes) as illustrated in Figure 1. The general climate of this area is arid since average precipitation do not exceed 300 mm/ year, although the scarcity of precipitation 70% of WANA area agricultural land is rainy-feeding lands (6). The global warming phenomenon provokes climate changes in this region, the futuristic climatological scenarios expect these changes to be as heat rapid increasing and sea level to upraised 0.5 meter than now. For Iraq it means water resources shortage and evapotranspiration rates increasing with reducing of its agricultural and animal fortunes.

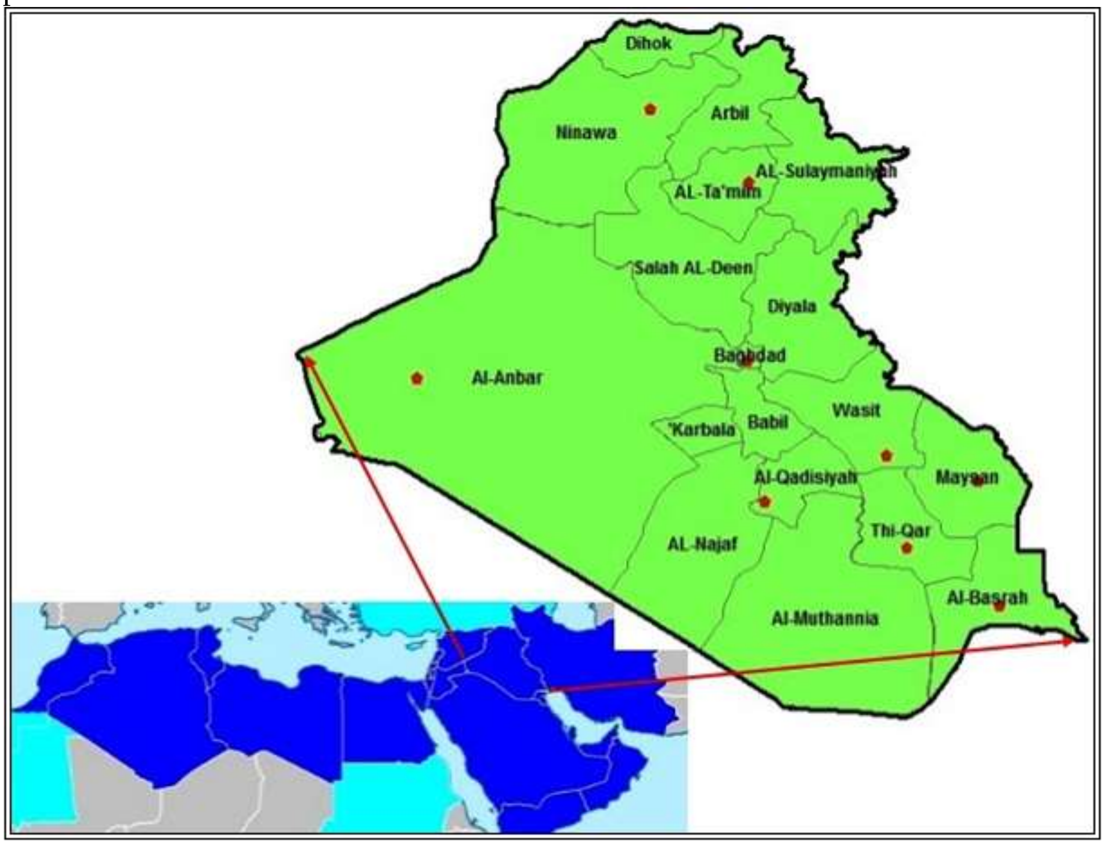


Figure 1. geographical location of study area in WANA region.

In this research "Penman-Monteith" scheme is adopted which belongs to the fourth class of calculation schemes(10). It was chosen because it was recommended by American Society of Civil Engineers (ASCE) as the unique standard scheme for estimating reference evapotranspiration (ETo)(13). the reason beyond this decision is probability strength for accurate estimating ETo in most climates and regions all over the world and its usage validity for short term data cases. The Penman-Monteith equation(2) is:

Where:

ETo or (**ETr**) is the reference evapotranspiration [mm.day^{-1}].

Rn surface net radiation [MJ. m^{-2}. day^{-1}]

G heat flux density of the soil [MJ. m^{-2}. day^{-1}]

T the daily air temperature mean value at two meters[°C]

U2 wind speed at two meters [m.s^{-1}]

es the pressure of saturation vapour [KPa]

ea the pressure of actual vapour[KPa]

es - ea saturation vapour pressure defect [KPa]

Δ the vapor pressure curve slope [kPa.°C^{-1}]

γ psychometric constant [kPa. °C^{-1}].

The worldwide effects of global warming get to climax and became lucid at the eighty decade of the twentieth century, so that the concern of this research is to quantitatively reveal the ascending or descending of these effects in the next three decades for Iraq evapotranspiration rates. To achieve this mission two types of data acquired, 1st type was specified meteorological readings of nine stations (which were available and had comprehensive distribution all over Iraq region) were adopted for every ten years in the interval (1987 – 2017), as shown in Figure 2.

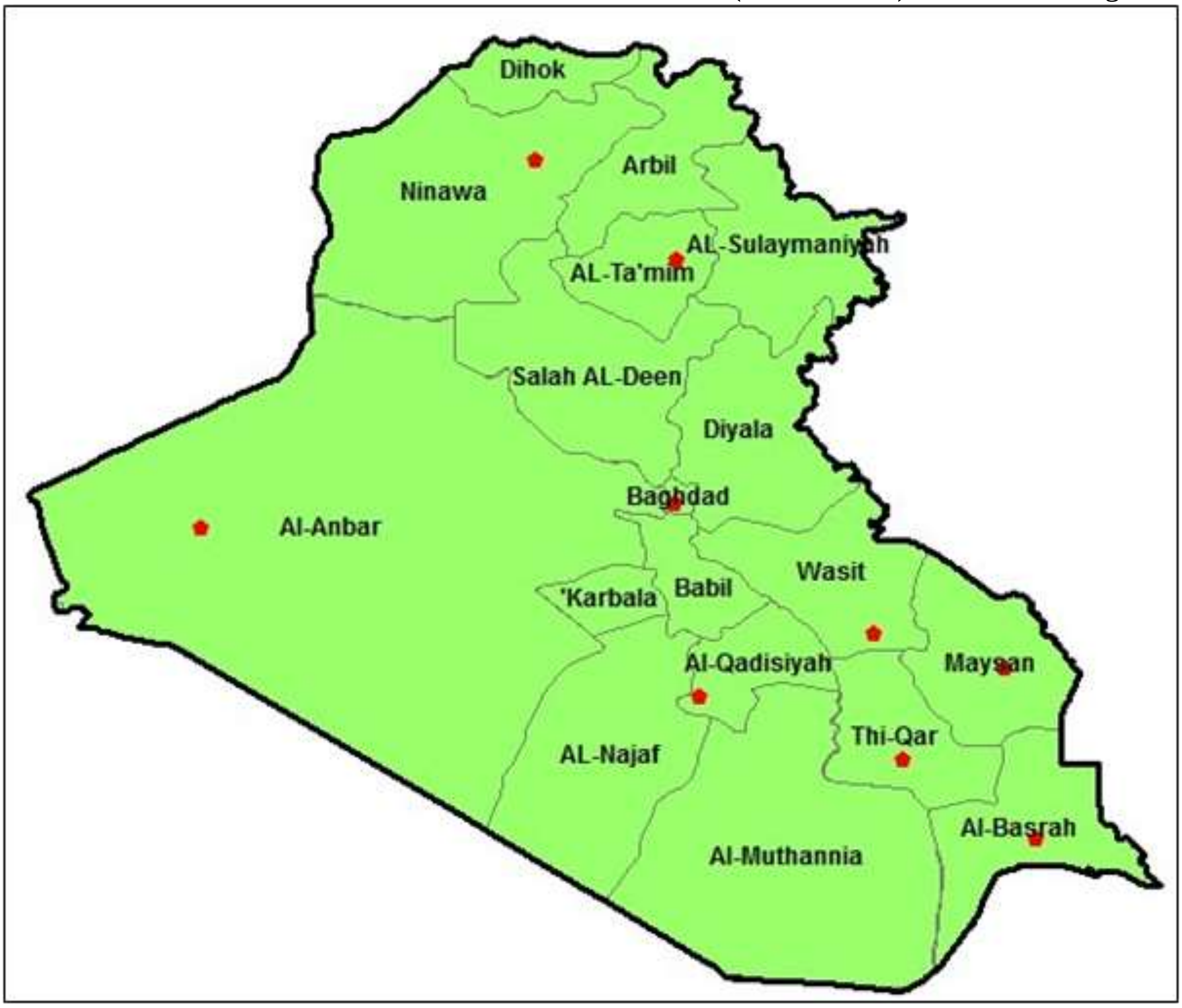


Figure 2. Geographical locations of the meteorological stations which ensure comprehensive distribution in Iraq area

These readings were (monthly mean maximum temperature, monthly mean minimum temperature, monthly mean relative humidity, monthly mean wind speed at 10 m height). 2nd type of data was the height (Z) in meters of the station Above Sea Level (ASL). The station height obtained from the ASTER Global-Digital Elevation Model (G-DEM) satellite imagery of Iraq with 30 meters spatially resolution pixels, as shown in Figure 3.

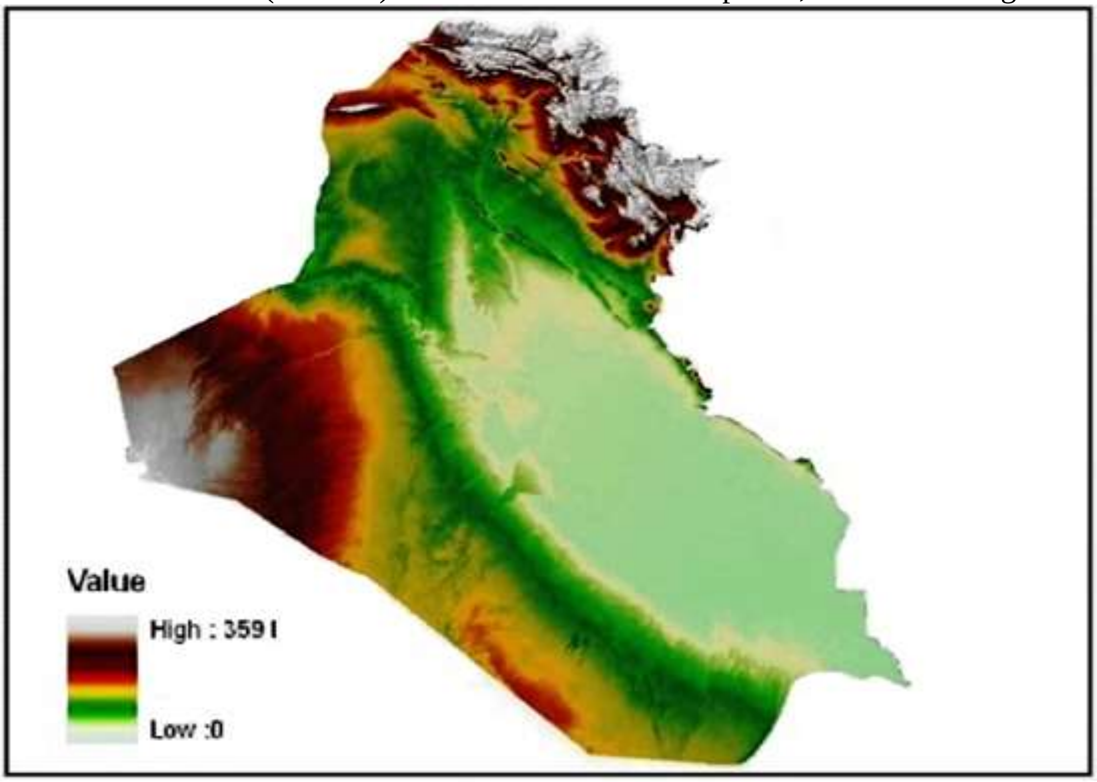


Figure 3. global Digital Elevation Model with 30 m pixel's spatial resolution of Iraq

Since Penman-Monteith equation utilized for daily evapotranspiration calculation, so every mean monthly value was expanded to be daily one (the average of values list could present each but not the reverse). The other demanded information were calculated, which are (**R_a, R_s, R_{so}, R_{ns}, R_{nl}, R_n, U_2, e_a,** and **e_s, and P)**, where remotely sensed obtained height (Z) utilized to calculate **R_{so}** and **P**. Table-1 is an example that illustrates the daily variables value used to determine evapotranspiration value for baghdad in(1-January-1987).

Table 1. Illustrative example of one day variables calculation that used in evapotranspiration determination for baghdad in (1- January- 1987).

T_{max}	T_{min}	R_a	R_s	R_{so}	R_{ns}	R_{nl}	R_n	e_a	e_s	U_2	P
18.6	2.6	18.04	11.54	13.545	8.893	4.130	4.762	0.736	2.880	2.169	100.96

Where:

T_{max} is the maximum temperature (Cº).

T_{min} is the minimum temperature (Cº).

R_a is the extraterrestrial radiation(MJ $m^{-2}day^{-1}$)

R_s is measured or calculated solar or short-wave radiation received at the earth's surface (MJ $m^{-2}day^{-1}$)

R_{so} is calculated clear-sky radiation (MJ m-2 day-1).

R_{ns} is net solar or short-wave radiation (MJ $m^{-2}day^{-1}$)

R_{nl} is net long-wave radiation leaving the earth's surface (MJ $m^{-2}day^{-1}$)

R_n is the solar net radiation at crop surface(MJ $m^{-2}day^{-1}$)

P is the mean atmospheric pressure in(KPa) at weather station

Table2. Annual ET_r values of the studied station due (1987, 1997, 2007, and 2017)

administrative	longitude (dec. deg.)	latitude (dec. deg.)	Altitude m (A.S.L)	1987's annual ET_r (mm)	1997's annual ET_r (mm)	2007's annual ET_r (mm)	2017's annual ET_r (mm)
Nasiriya	46.317	31.001	5	5228.069	4105.969	3785.941	3673.958
Hai	46.0763	32.1267	17	4405.341	4369.893	3969.281	3677.417
Karkuk	44.366	35.41	331	2215.628	1824.695	2304.33	1979.43
Baghdad	44.352	33.273	31	3812.661	3566.767	3561.144	4125.27
Mosul	43.154	36.287	223	2334.218	2219.019	1924.61	2000
Rutba	40.273	33.056	630	3127.302	2211.459	2436.048	2609.81
Basra	47.47	30.31	2	4442.049	4324.703	4553.619	3756.738
Emara	47.204	31.81	9	4149.285	4497.547	3714.948	3876.025
Dewaniya	44.57	31.57	20	3555.861	2594.363	2737.343	3082.151

Then each assigned year annual evapotranspiration values of the nine stations converted to point shapefile in Arc GIS 10.5 software environment and IDW (Inverse Distance Weighting) spatial interpolation scheme utilized to estimate the annual evapotranspiration for all Iraq region. As can be seen in figure 4.

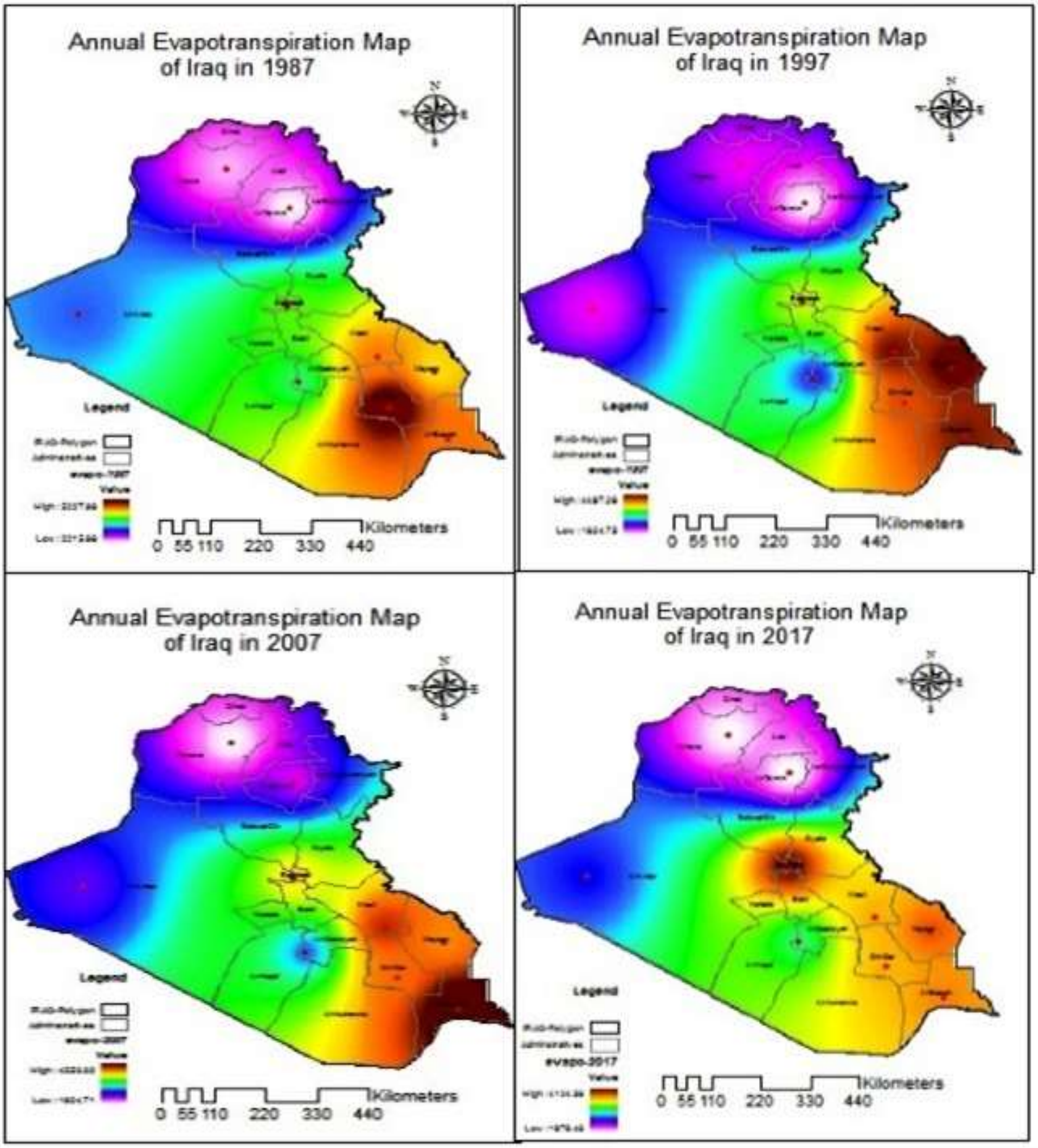


Figure 4. A. Annual evapotranspiration map of Iraq in 1987, B. Annual evapotranspiration map of Iraq in 1997, C. Annual evapotranspiration map of Iraq in 2007, and D. Annual evapotranspiration map of Iraq in 2017

RESULTS AND DESCUSION

The climate of Iraq is a result of two different climates interaction; the Arabian desert subtropical aridity climate and Arabian gulf subtropical humidity, so that with the topographical factor influence the middle and southern parts of Iraq evapotranspiration values are typically greater than the northern parts values. In the studied interval it was obvious from Table 2 that the eighties decade of the last century had generally climax (**ET_r**) values, then after (**ET_r**) value rates rapidly decreased in whole Iraq except some anomalies for each decade such as the capital (baghdad), which suffered an increment in (**ET_r**) values rate at 2017. These evapotranspiration variations explained in Table 3.

Table 3. Percentage variation of ET_r values for some Iraqi administratives from 1987

administrative	(1997-1987) percentage variation	(2007-1987) percentage variation	(2017-1987) percentage variation
Nasiriya	-21.463	-27.5843	-29.7263
Hai	-0.80466	-9.89844	-16.5237
Karkuk	-17.6443	4.00347	-10.6605
Baghdad	-6.44941	-6.59689	8.199234
Mosul	-4.93523	-17.548	-14.3182
Rutba	-29.2854	-22.1038	-16.5476
Basra	-2.64171	2.511679	-15.4278
Emara	8.393301	-10.4678	-6.58571
Dewaniya	-27.0398	-23.0188	-13.3219

In AL-Nasiriya and AL-Hai, the main reason beyond evapotranspiration values continues descending is wind speed rates continues decrement. In Emara, Karkuk, Basra, and Baghdad, there was positive anomaly in 1997, 2007, and 2017 respectively because of high decreasing in Rh and high increasing in wind speed. While interaction of wind speed decrement (which was the dominated reason beyond ETr rates decrement) and Rh occasionally increment in the three later decades after 1987 was the cause of ETr behavior for AL-Mosul, Rutba, and Dewaniya administratives. These factor variation explained in Figures (5, 6, 7).

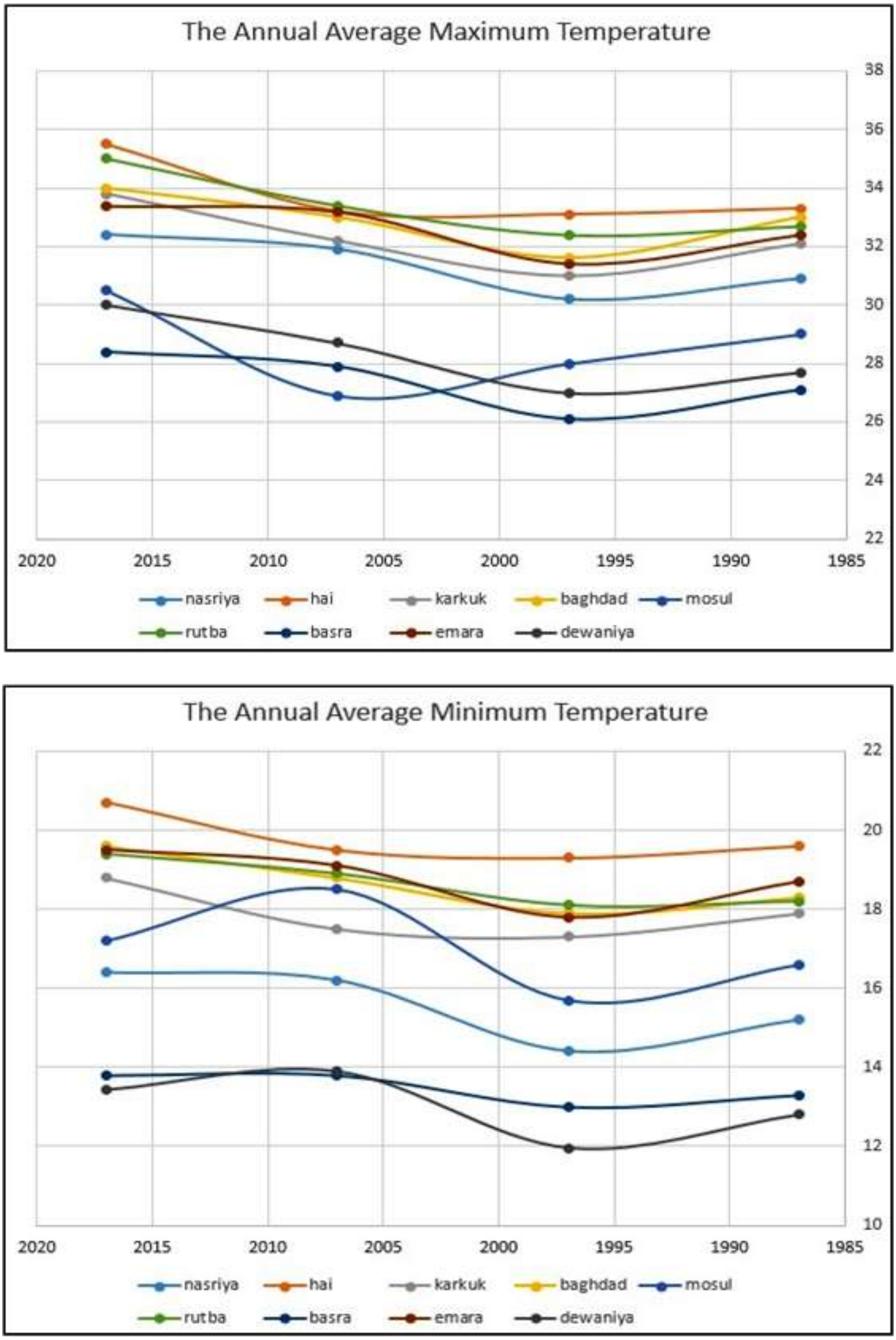


Figure 5. a. Annual average maximum temperature , b. Annual average minimum temperature

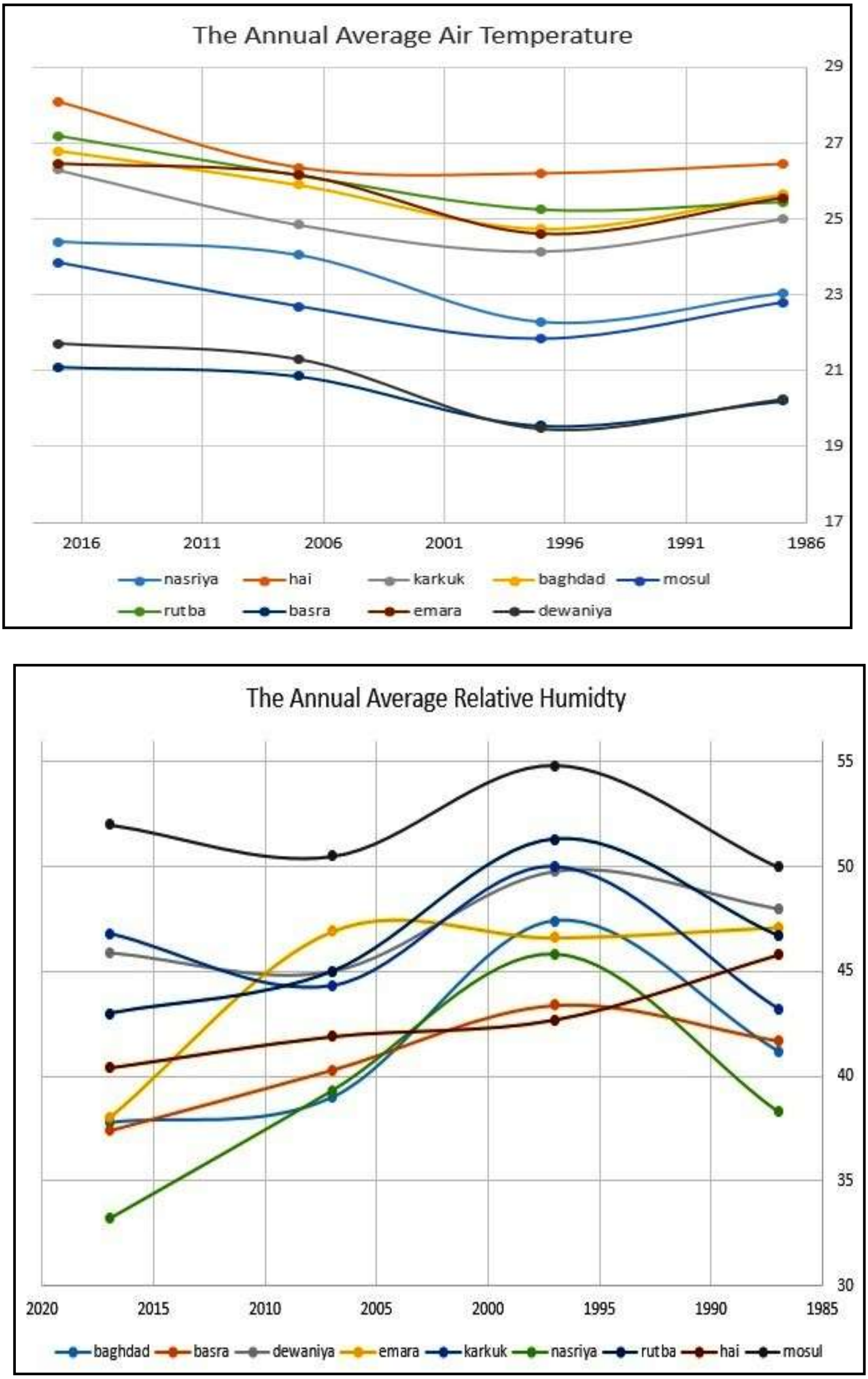
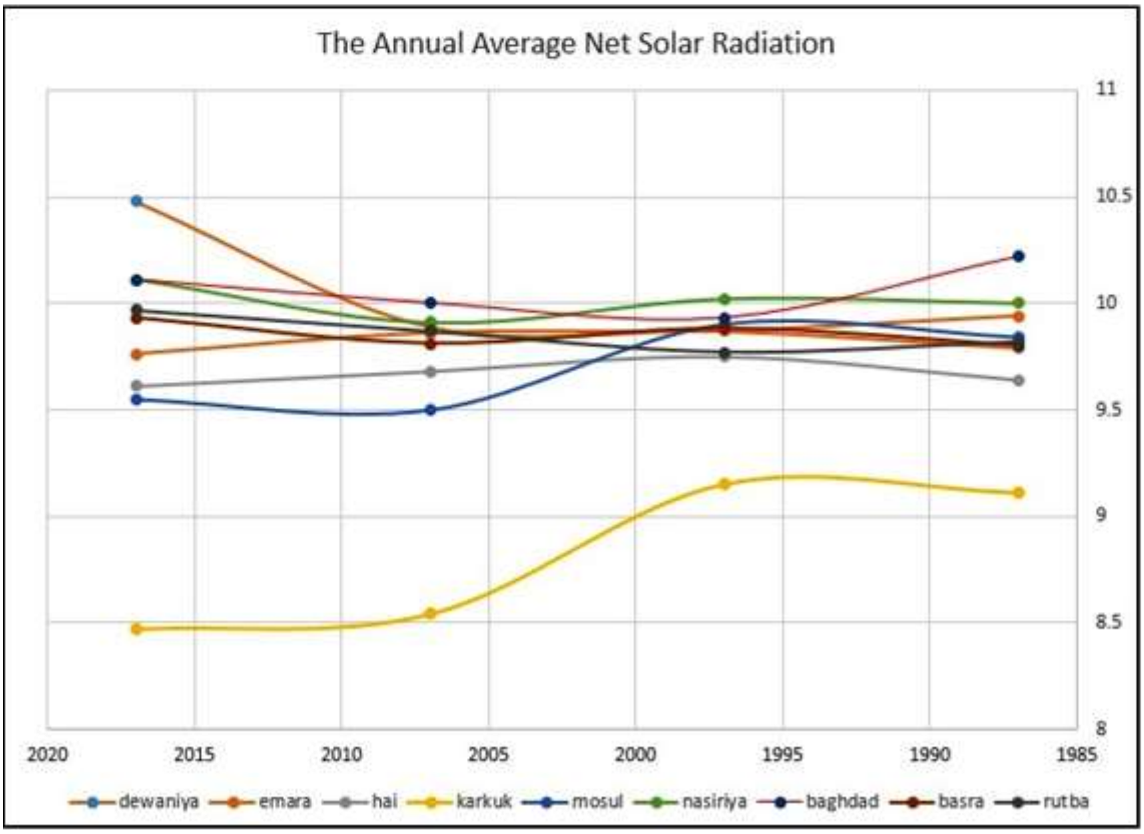


Figure 6. a. Annual average air temperature, b. Annual average relative humidity



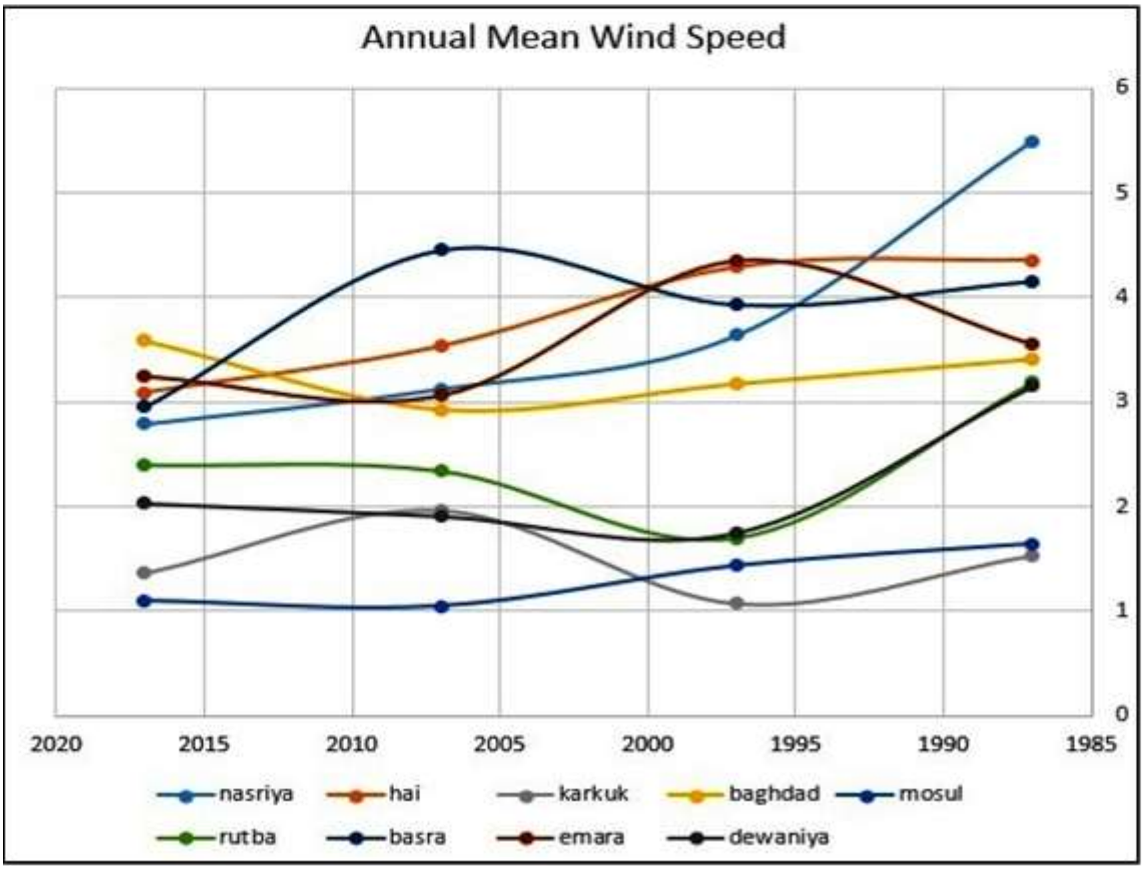


Figure 7. a. Annual average net solar radiation, b. Annual average wind speed.

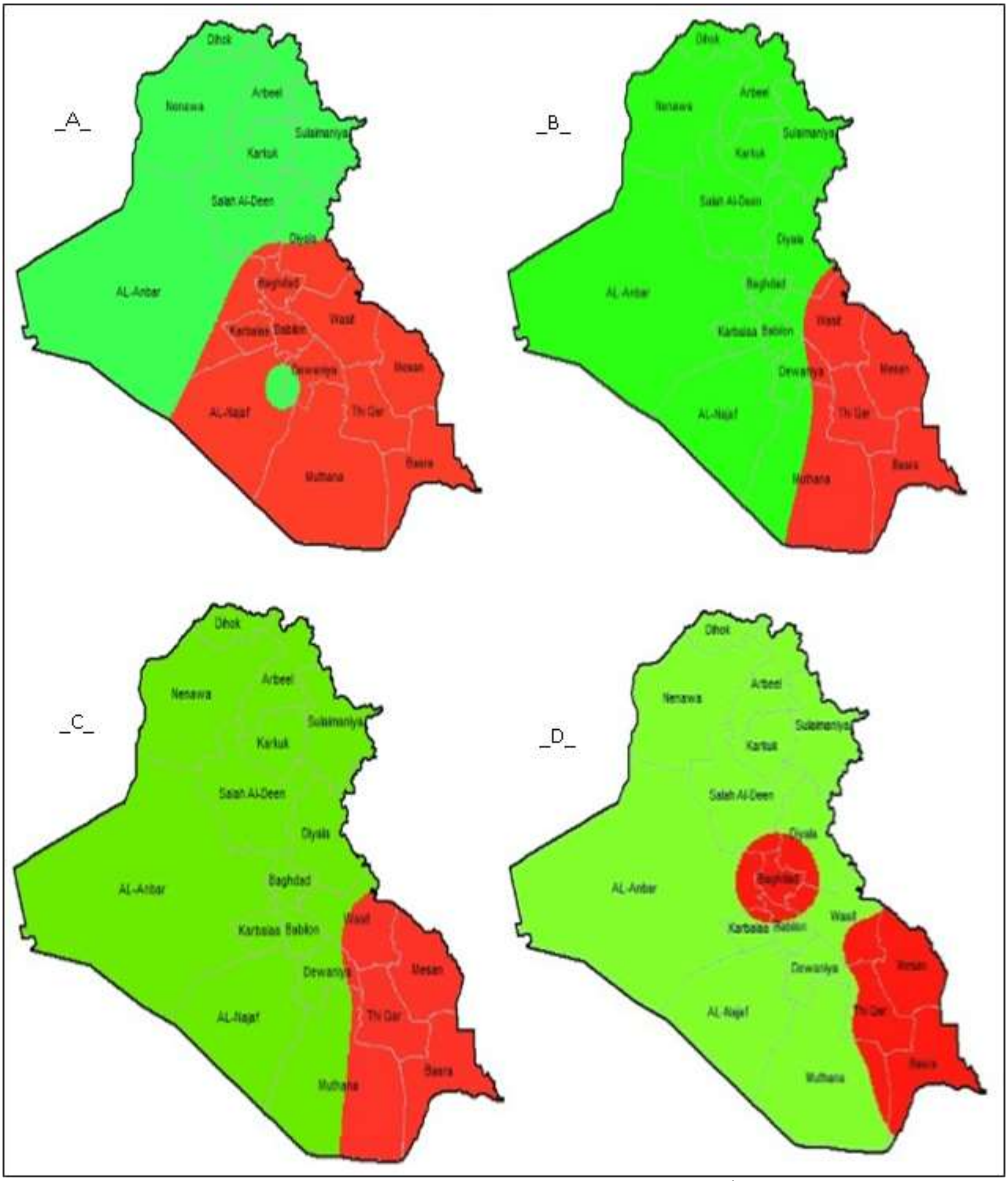


Figure 8. A. Regions of Iraq with ET_r more than 3650 mm. year $^{-1}$in red color at 1987, B. Regions of Iraq with ET_r more than 3650 mm. year $^{-1}$in red color at 1997, C. Regions of Iraq with ET_r more than 3650 mm. year $^{-1}$in red color at 2007, and D. Regions of Iraq with ET_r more than 3650 mm. year $^{-1}$in red color at 2017

The variation in reference evapotranspiration for any period is because of the change in all or some of the main factor values that determine it, these factors are included in Penman- Monteith equation which are (maximum temperature, minimum temperature, wind speed at 2 meter height, and net solar radiation). According to FAO (P_M) equation the rise in all the mentioned factors will rise the (ETr) value except minimum temperature.The rate of "Minimum temperature" ascending decrease the reference evapotranspiration value as it highly rising means the decrement in air temperature value which increase the relative humidity. the proportional of evapotranspiration and relative humidity is reversal, so any rising in RH will result ETr value falling In Iraq case for time range (1987-2017) the ETr declination reason was unexpected and it was the same for baghdad ETr value increasing in 2017. While maximum temperature and net solar radiation values increased in this interval, the minimum temperature increased too (i.e Rh rise), the wind speed decreased, but the dominate factor in this interaction process was the wind speed due its huge decrement rates in 2017, Baghdad area had the highest value of ETr, the reasons beyond that were (maximum temperature rise 3% and minimum temperature rise 7% due to air severely pollution with carbon dioxide. This increment resulted from cars and civil electrical generators value rising after 2003 war). Net solar radiation falling 1%, wind speed rise 15% comparing to 1987. The first phase in solving any problem is precise determination of its causes, so that precise determination of ETr and rainfall for long time is essential to state and treat the aridity and desertification in Iraq. In this work it was obvious that global warming effects on Iraq's climate lessen since eighty decade of last century. ETr rates had rapidly decrement in whole Iraq except some anomalies, two reasons were mainly responsible for this behavior. The 1st one was wind speed failing that considered as dominated factor in evapotranspiration values descending process, the 2nd reason was RH rates increment. The most interesting result of this work was Baghdad case, since Greenhouse Gases effect converted Baghdad weather to be the highest in ETr rates in 2017.

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