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DETERMINING THERMAL COMFORT ZONES FOR OUTDOOR RECREATION PLANNING: A CASE STUDY OF ERBIL – IRAQ

Twana ABDULRAHMAN HAMAD[1], Hakan OGUZ[2,*]

[1]Department of Soil Science and Plant Nutrition, Harran University, Sanliurfa
[2]Department of Landscape Architecture, Kahramanmaras Sutcu Imam University, Kahramanmaras

*Corresponding author: hakan@ksu.edu.tr

Twana ABDULRAHMAN HAMAD: https://orcid.org/0000-0002-2227-2977
Hakan OGUZ: https://orcid.org/0000-0002-0855-2032

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ABSTRACT: This study finds out thermal comfort zones for outdoor recreation planning in Erbil. Therefore, spatial distribution of Physiologically Equivalent Temperature (PET), which is a measure of thermal comfort, was obtained for the City of Erbil using meteorological data collected from 6 different weather stations located in the study area. Air temperature, relative humidity, radiation and wind speed are required for the calculation of PET. Data obtained from 6 meteorological stations, 15:00 over the period from 1992 to 2015 were used to calculate monthly PET values with RayMan 1.2 software. PET was spatially interpolated using IDW tool in ArcGIS 10.2 to convert the point-data consisting of PET-values for individual meteorological station into a continuous surface so that maps of spatial distribution of PET values could be created. The most comfortable months and areas for outdoor recreation activities were determined by analyzing these maps. The results reveal fundamental information which is of particular relevance to recreation authorities. The lowest PET determined was around 7.2 ºC in Masif Slahaddin area during the month of January. And the highest PET determined was 56.4 ºC in Makhmoor during the month of July. In Erbil governorate, we have concluded that both March and November can be the best months comfortable during the year. September, January and February are coldest. During May to September are the hottest months especially in July.

Keywords: Bioclimatic Conditions, Meteorological Data, PET, RayMan Model

REKREASYON ALANI PLANLAMASI İÇİN TERMAL KONFOR ZONLARININ BELİRLENMESİ: ERBİL-IRAK ÖRNEĞİ

ÖZET: Bu çalışma, Erbil'de rekreasyon alanı planlaması için termal konfor zonlarının belirlenmesi için yapılmıştır. Bu nedenle, çalışma alanında bulunan 6 farklı hava istasyonundan toplanan meteorolojik veriler kullanılarak Erbil şehri için termal konforun bir ölçüsü olan Fizyolojik Eşdeğer Sıcaklığın (PET) mekansal dağılımı elde edilmiştir. PET'in hesaplanması için hava sıcaklığı, bağıl nem, radyasyon ve rüzgar hızı gereklidir. RayMan 1.2 yazılımı ile aylık PET değerlerini hesaplamak için 1992'den 2015 yılları arasında ve saat 15:00 te 6 meteoroloji istasyonundan elde edilen veriler kullanılmıştır. PET, bireysel meteoroloji istasyonu için PET değerlerinden oluşan nokta verilerini sürekli bir yüzeye dönüştürmek için ArcGIS programındaki IDW aracı kullanılarak bir enterpolasyona tabi tutuldu. Böylece PET değerlerinin mekansal dağılım haritaları oluşturulmuştur. Rekreasyon alanı aktiviteleri için en konforlu aylar ve alanlar bu haritaların analiz edilmesi sonucunda belirlenmiştir. Sonuçlar, rekreasyon alanı yetkilileri ile özellikle ilgili olan temel bilgileri ortaya koymaktadır. Belirlenen en düşük PET, Ocak ayı boyunca Masif slahaddin Bölgesi'nde 7,2 ºC civarındadır vee belirlenen en yüksek PET, Temmuz ayı boyunca Makhmoor'da 56.4 ºC olarak kaydedilmiştir. Erbil valiliğinde, hem Mart hem de Kasım aylarının yıl boyunca rahat edilebileceği en iyi aylar olarak tespit edilmiştir. Eylül, Ocak ve Şubat en soğuk aylar olarak bulunmuştur. Mayıs-Eylül ayları arasında özellikle Temmuz ayı en sıcak aylar olarak bulunmuştur.

Anahtar kelimeler: Biyoklimatik Koşullar, Meteorolojik Veriler, PET, Rayman Modeli

INTRODUCTION

Recreation areas and parks are quite important in three ways; economic value, health and environmental benefits, and social importance. Parks and recreation areas increase property values and generate money for the local economy. These places play an important role for people to meet and stay fit. Parks and recreation areas improve air quality and protect ground water. Parks and recreation areas provide gathering places for people and social groups, as well as for individuals of all ages and economic status (EKU, 2020).

Several indices have been developed over the last four decades and used in many studies to assess the thermal conditions of outdoor activities (Mieczkowski, 1985; Hoppe, 1999; Matzarakis, et al., 1999; Morgan et al., 2000; Toy et al., 2005; Matzarakis, 2006; Matzarakis et al., 2007; Matzarakis et al., 2010; Zengin et al., 2010; Lin and Matzarakis, 2011; Farajzadeh and Matzarakis, 2012; Daneshvar et al., 2013; Topay, 2013; Yilmaz et al., 2013; Matallah et al., 2020). Common indices for thermal comfort analysis are Predicted Mean Vote (PMV), Physiologically Equivalent Temperature (PET), Standard Effective Temperature (SET) and Perceived Temperature (PT) (Matzarakis, 2006). The most widely known and applied index in thermal comfort analysis is the PET developed by Matzarakis et al., 2007 and 2010, which requires at least three meteorological parameters of air temperature, relative humidiy and wind speed. The advantage of PET index compared to other thermal indices is that PET uses the advantage of a widely known temperature unit (degrees Celsius), which makes results easily understandable for local planners, who may not be quite familiar with human bio–meteorological terminology (Matzarakis et al., 1999; Daneshvar et al., 2013).

This study assesses the thermal comfort zones for outdoor recreational areas in Erbil, Iraq based on the Physiologically Equivalent Temperature using the RayMan Pro Model. The final output of this study was a spatial map that shows thermal comfort zones in Erbil, Iraq.

MATERIALS AND METHODS

Study Area

In this study, Erbil-Iraq was selected as our study area since it is one of the oldest continuously inhabited cities in the world dating back to at least 6000 BC (UNESCO, 2010). Erbil is one of the governorates of the north Iraq. The geographic location of Erbil governorate is between latitudes 35° 30´ and 37° 15 N, and longitudes 43° 22´ and 45° 05´ E with elevation ranges from 136 m to 3609 m. The Erbil shares its border with Iran in the East and Turkey in the North. It is the third largest city in Iraq as illustrated in Figure 1 below, as well as it is the fastest growing city as shown in Figures 2 and 3 below. The plains in the south of the city are quite important in terms of agricultural production.

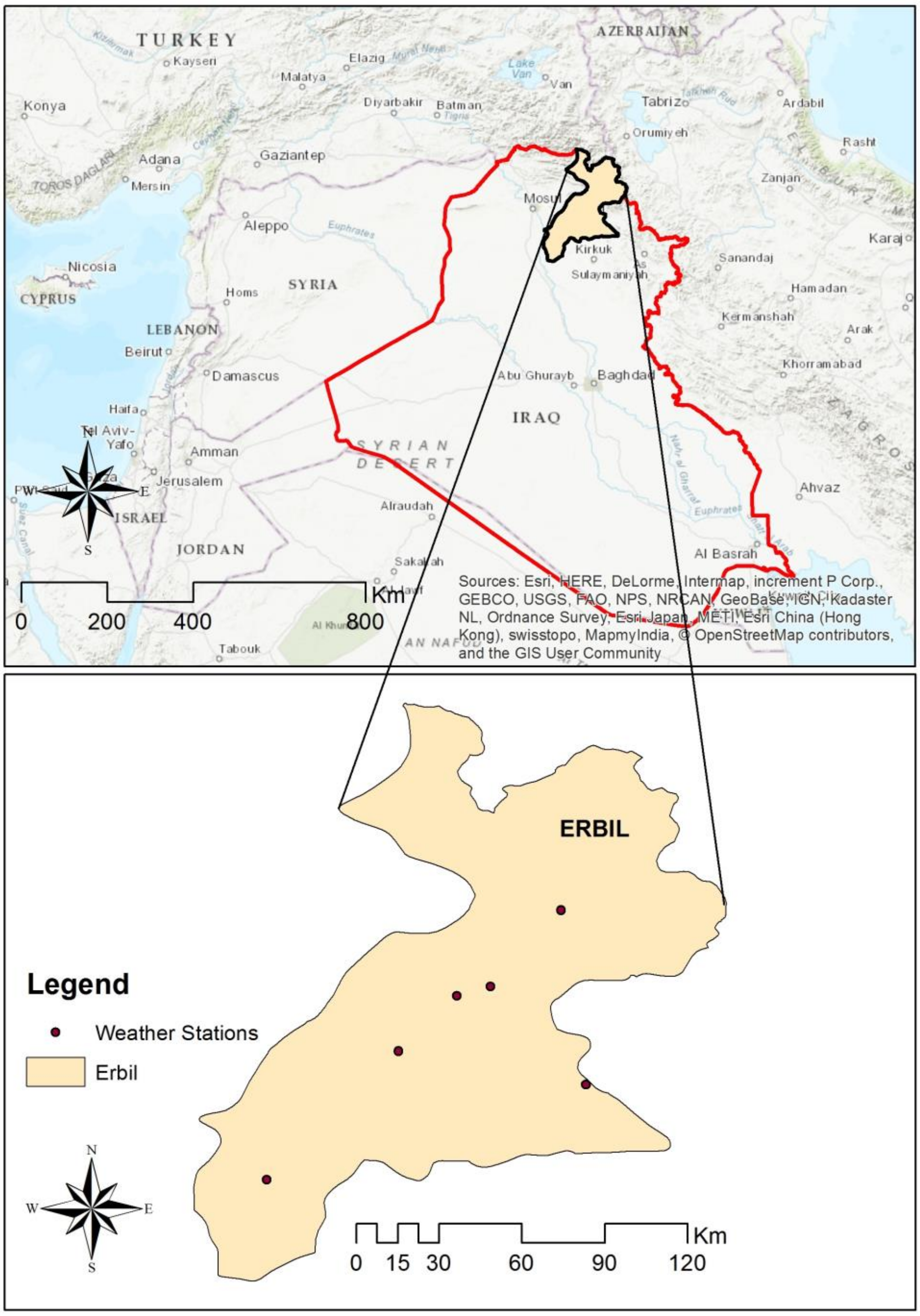

Figure 1. Location map of the study area.

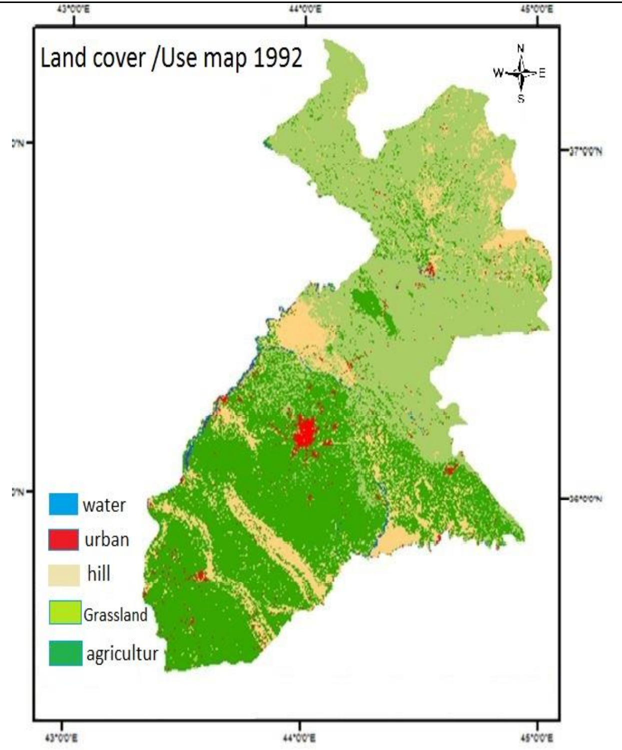

Figure 2. LULC map of Erbil in 1992

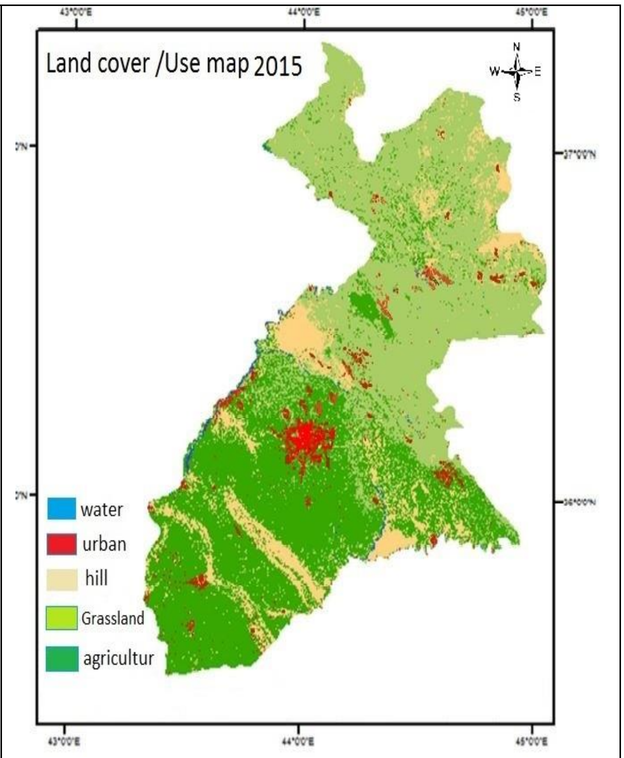

Figure 3. LULC map of Erbil in 2015

Erbil is located between the two rivers known as the Greater Zab in the west and the Lesser zab in the east. The study area covers approximately 15074 square kilometers. Erbil consists of seven districts (Erbil, Makhmur, koyea, Shaqlawa, Choman, Soran and Merqasur). 41% of the area in Erbil is arable land and 93% of agricultural crops depend on rainfall and unfortunately only 7% of the land is irrigated.

Erbil, according to Köppen’s climate classification system, is classified as a transitional climate zone between the Mediterranean climate (Csa) and the Arid climate (Bwh). The weather is comprised of cool snowy winters and warm dry summers. The plains in the south have semi-arid climate conditions. Usually precipitation starts in October and ends in May.

Input Data

In this study, the meteorological data of 6 weather stations over a 23-year time period (1992–2015) were obtained from the Ministry of Agriculture and Water Resources of Iraq. The three of these six stations have 23-year period records while the other three stations have only 13-year period records as illustrated in Tables 1 and 2 below. The values of air temperature, relative humidity, and wind speed were collected from each synoptic station to obtain the mean monthly values of Physiologically Equivalent Temperature (PET) in the RayMan Model. The station base results were extended to pixel base values by spatial analysis operations in Geographic Information System (GIS). GIS allows the production of spatial mapping of PET in Erbil.

Table 1. Coordinates, elevations and years for all weather stations used in this study

Meteorology Stations	Latitude	Longitude	Elevation (m)	Years
Erbil	36.19	44.01	425	1992-2015
Masif Salahaddin	36.37	44.2	1088	1992-2015
Makhmur	35.77	43.58	275	1992-2015
Koyea	36.08	44.62	631	2002-2015
Shaqlawa	36.4	44.31	980	2002-2015
Soran	36.65	44.54	680	2002-2015

Table 2. Monthly mean air temperatures, humidity and wind speed values for all stations

Meteorology stations		Erbil	Makhmur	Masif Slahaddin	Shaqlawa	Soran	Koyea
January	T (ºC)	12.8	13.9	8.7	9.7	9	10.8
	H (%)	70.81	74.9	73.66	67.6	75.4	71
	W (m/s)	2.3	3.3	1.9	2.2	1.5	3.2
February	T (ºC)	14.6	16.3	9.8	18.9	11.4	12.6
	H (%)	67.25	67.8	70.3	69.2	74.1	68.3
	W (m/s)	2.4	3.6	2.3	2.1	1.6	2
March	T (ºC)	26.6	21	14.5	15.6	16.4	17.4
	H (%)	60	58.4	61.27	61.3	68.4	63.1
	W (m/s)	2.5	3.8	2.6	1.7	1.7	2.2
April	T (ºC)	24.6	27.1	19.9	20.5	21.8	23.7
	H (%)	54.14	47.5	56.12	57.9	68.1	58.5
	W (m/s)	2.6	4	2.8	1.8	1.8	2.5
May	T (ºC)	33.9	34.5	26.4	27.3	28.2	30.8
	H (%)	39.41	33.8	43.1	48.3	61.7	46.8
	W (m/s)	2.7	4.3	2.5	1.8	2	2.6
June	T (ºC)	38.4	40.8	32.2	35.3	35.4	37.6
	H (%)	27.34	25.2	35.29	38.1	51.3	38.2
	W (m/s)	2.4	4.4	2.5	1.6	2.2	2.6
July	T (ºC)	41.8	44.3	36.4	39.1	39.2	41.6
	H (%)	25.18	23.1	35.7	30.4	49.2	35.9
	W (m/s)	2.3	4.3	2.2	1.8	2.1	2.7
August	T (ºC)	41.6	44	36.7	38.4	39.4	41.6
	H (%)	26.77	24.6	34.58	27.9	49.5	36.7
	W (m/s)	2	4.1	2.1	1.5	1.9	2.5
September	T (ºC)	36.6	38.5	31.9	34.1	34.5	36.7
	H (%)	31.14	28.3	39.83	29.1	50	40.3
	W (m/s)	2	3.7	2	1.3	1.7	2.4
October	T (ºC)	29.8	32.1	25.3	26.9	26.9	29.6
	H (%)	42.15	39.2	56.66	38.1	62.2	48.5
	W (m/s)	2	3.5	2	2.1	1.9	2.3
November	T (ºC)	20.6	22.4	16.6	17.1	17.6	19.3
	H (%)	59.41	57.8	62.76	55.8	69.4	60.3
	W (m/s)	1.9	3.2	2	1.6	1.6	2.2
December	T (ºC)	14.2	16	11.5	11.9	11.1	13.3
	H (%)	68.63	69.4	67.56	66.1	74.1	65.3
	W (m/s)	1.7	3.2	1.8	2	1.6	2.2

The PET was calculated using the computer program called RayMan (Matzarakis et al., 2007; Matzarakis at al., 2010) as illustrated in Figure 4. The RayMan model developed according to Guideline 3787 of the German Association of Engineers and calculates the radiation flux in simple and complex environments on the basis of various parameters (VDI, 1998; Matzarakis et al., 2007; Matzarakis et al., 2010). The model outputs the calculated mean radiant temperature required in the energy balance model for humanbeing. This is also required for the assessment of thermal indices such as Predicted Mean Vote (PMV), Physiologically Equivalent Temperature (PET), and Standard Effective Temperature (SET) (Matzarakis et al., 2007; Matzarakis et al., 2010; Daneshvar et al., 2013).

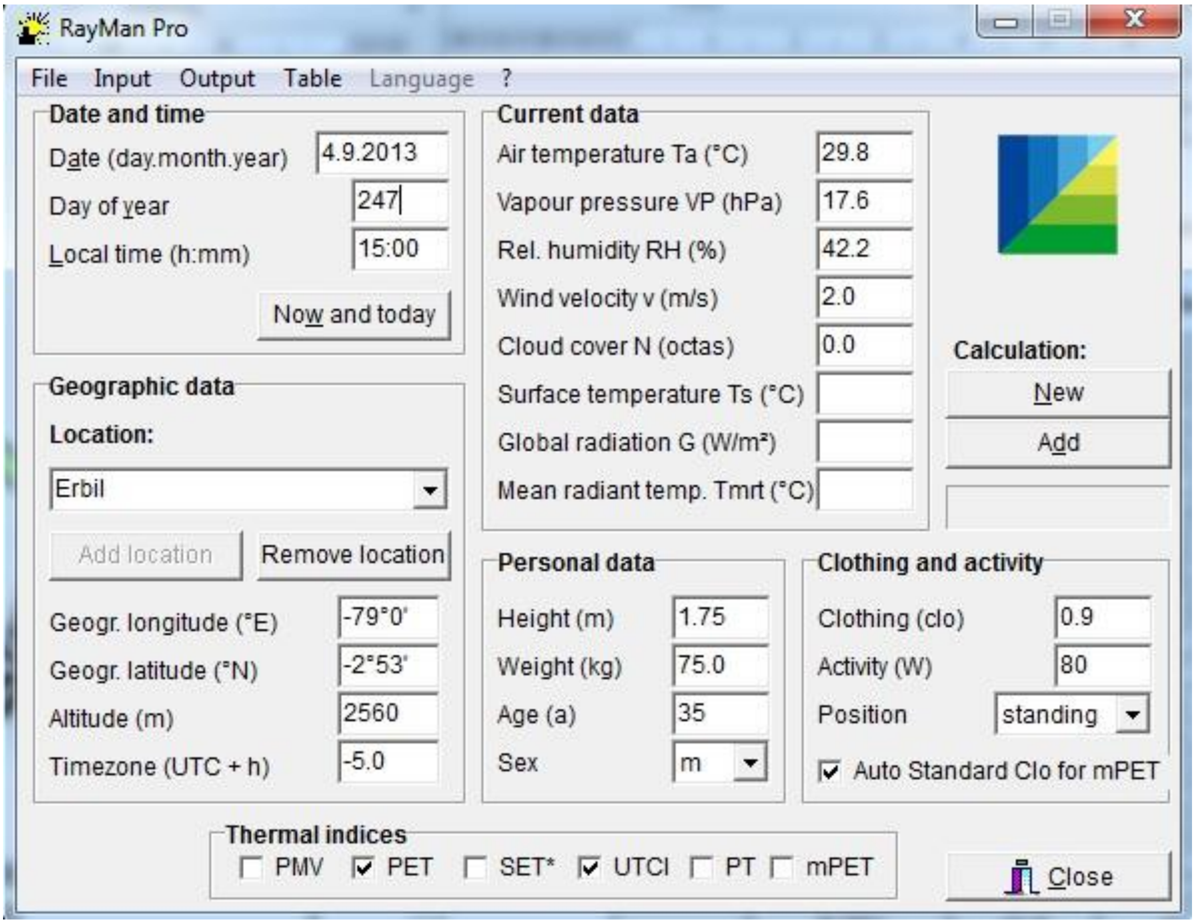

Figure 4. Graphical user interface of RayMan program

The PET is a thermal index that produces an estimation of the thermal component of a given environment. The PET not only provides an integrated index for thermal environments but also allows humans to predict their thermal perception of weather conditions. Thus, it is important to analyze the characteristics of thermal adaptation and comfort range of humans from different regions to adequately describe their perception (Lin and Matzarakis, 2008; Daneshvar et al., 2013). PET can be used for both the indoor and outdoor environment using the radiation and bioclimate model of RayMan. The program needs some parameters to calculate PET such as air temperature, vapor pressure, relative humidity, wind speed, mean cloud cover and mean radiant temperature. Human parameters such as activity, heat resistance of clothing, height and weight are usually standardized, since the focus is the climate conditions at different sites not on individual human characteristics.

Threshold values for PET have been developed for different levels of thermal stress to quantify the perception of the thermal environment by humans as illustrated in Table 3 below (Matzarakis and Mayer, 1996) . Threshold values of the PET are based on a standard human parameters such as 1.75 m, 75 kg, 35 years old standing male who stays in the sun and a metabolic rate of 80W (walking) with a heat transfer resistance of clothing of 0.9 clo (summer clothing) (Matzarakis and Mayer, 1996; VDI, 1998).

Table 3. The perception of the thermal environment by humans

PET (ºC)	Thermal Perception	Physiological Stress Level
<4	Very Cold	Extreme Cold Stress
4 – 8	Cold	Strong Cold Stress
8 – 13	Cool	Moderate Cold Stress
13 – 18	Slightly Cool	Slight Cold Stress
18 – 23	Comfortable	No Thermal Stress
23 – 29	Slightly Warm	Slight Heat Stress
29 – 35	Warm	Moderate Heat Stress
35 – 41	Hot	Strong Heat Stress
>41	Very Hot	Extreme Heat Stress

RESULTS AND DISCUSSION

Monthly PET values were calculated using RayMan program with the inputs of the mean monthly values of air temperature, relative humidity, and wind speed for each station as illustrated in Table 4 below as the PET values were color coded to reflect the thermal stress by months and weather station. The PET values were also mapped using the values in Table 4 with the inverse distance weighted (IDW) method, generally used as a simple local interpolation technique in ArcGIS (Lo and Yeung, 2002). As a result, the final mean monthly PET maps are illustrated in Figures 5 to 16 for the study area. The same map legend is used to allow for a better comparison of the months. The final PET values ranged from 7.2 °C to 56.37 °C in Erbil. The coldest PET values were observed in Masif Slahaddin area during the month of January with 7.2 °C while the highest PET values were observed in Makhmoor during the month of July with 56.4 °C.

The PET values for spring months ranged between 15.4 °C in the middle (Masif Salahaddin region) to 43.2°C in the south (Makhbour region) of the study area as illustrated in Figures 7 and 9 below. Temporary comfort conditions were experienced in the south of Erbil during the spring months. The PET values ranged from 40 to 56.4 °C in the summer months and dominantly represent a physiological level of strong heat stress. In the fall, it was observed that November experienced quite similar physiological stress level as March as illustrated in Figures 7 and 15. Slight cold stress and no thermal stress were observed in Erbil and Makhbur regions in November.

Table 4. The PET classification by color for all months

Weather Staions	Jan	Feb	Mar	Apr	May	Jun	Jul	Ogu	Seb	Oct	Nov	Dec
Erbil	10.9	14.0	21.0	30.2	43.2	49.8	54.1	53.6	46.6	34.9	21.4	13.1
Makhmur	11.38	14.9	21.5	31.1	41.9	51.4	56.4	55.7	47.2	36.7	21.6	13.6
Masif slahaddin	7.2	9.3	15.4	22.6	32.6	41.1	47.2	47.4	40.0	29.4	16.8	10.2
Shaqlawa	7.8	11.2	18.7	26.0	35.5	47.1	51.1	50.2	44.1	30.9	17.9	10.3
Soran	8.57	12.63	19.9	24.4	36.8	46.6	51.3	51.4	44.3	31.4	18.5	10.41
Koyea	9	12.8	19.7	28.8	38.9	48.5	53.4	53.2	46.0	34.0	19.1	11.2

> 4 : very cold	
4 - 8 : cold	
8 - 13 : cool	
13 - 18 : Slightly cool	
18 - 23 : Comfortable	

23 - 29 : Slightly warm	
29 - 35 : warm	
35 - 41 : hot	
< 41 : very hot	

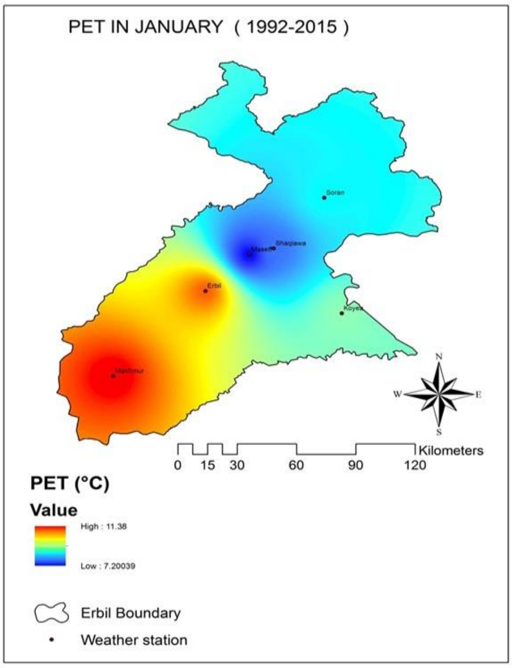

Figure 5. PET map of January

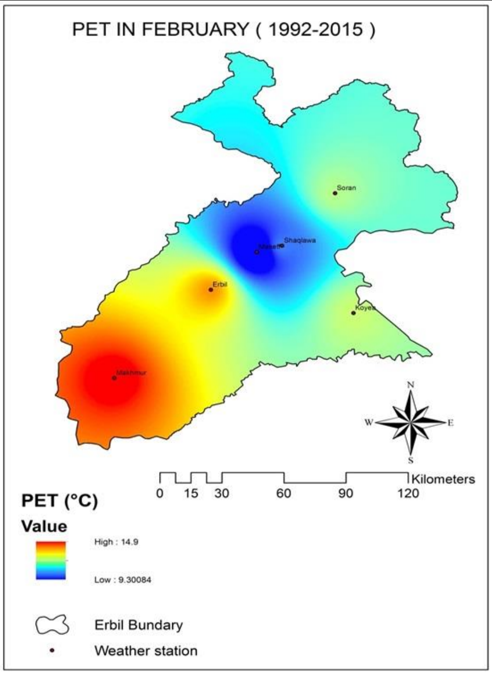

Figure 6. PET map of February

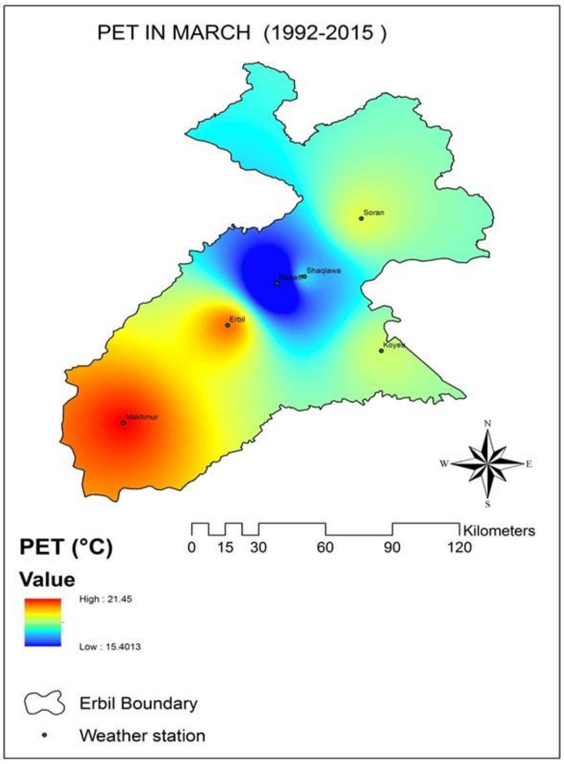

Figure 7. PET map of March

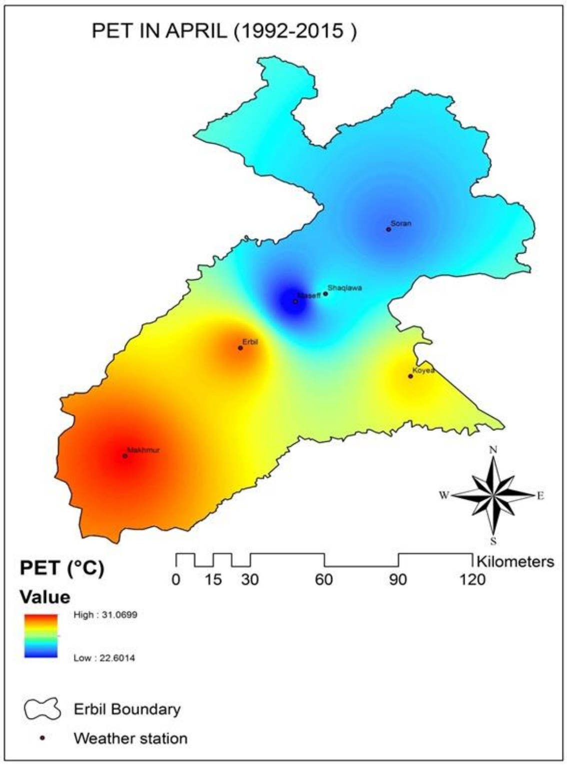

Figure 8. PET map of April

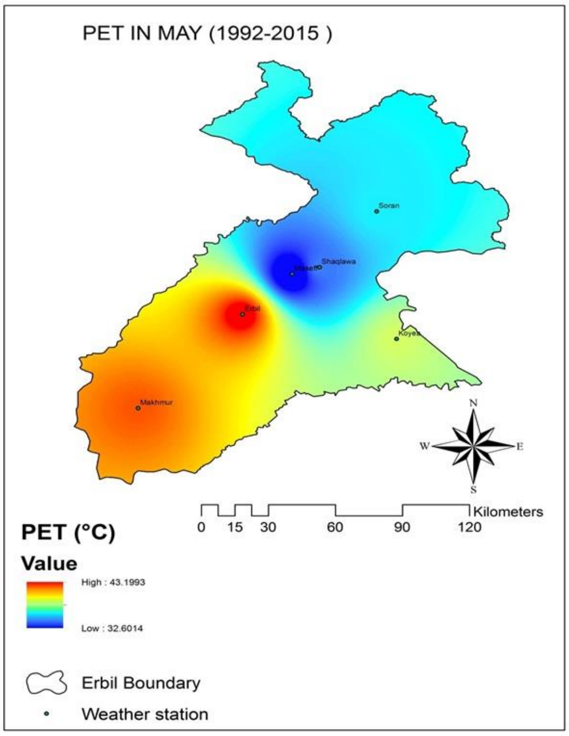

Figure 9. PET map of May

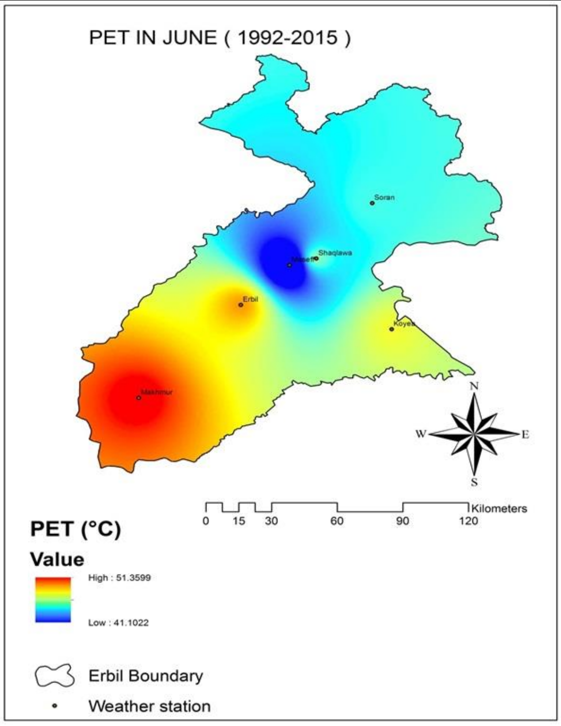

Figure 10. PET map of June

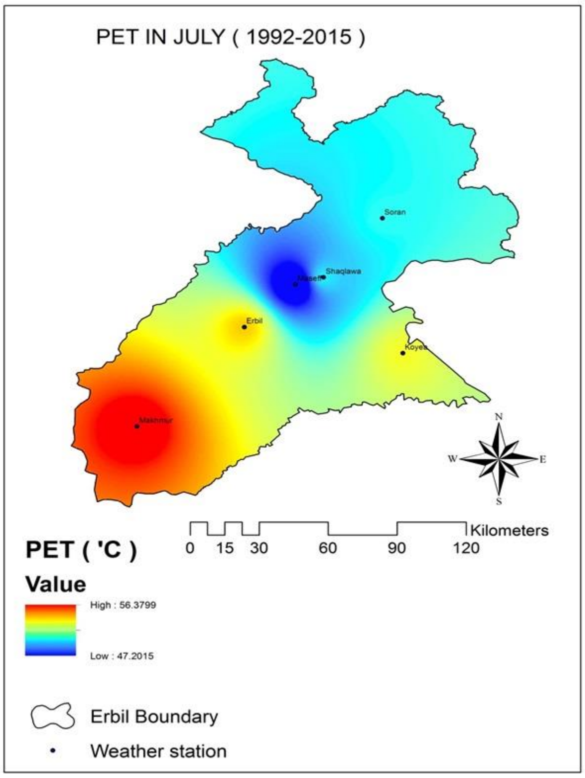

Figure 11. PET map of July

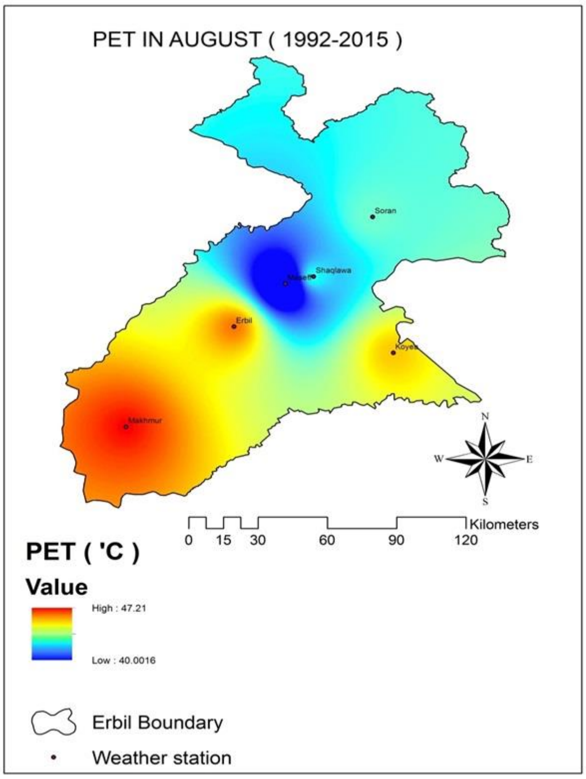

Figure 12. PET map of August

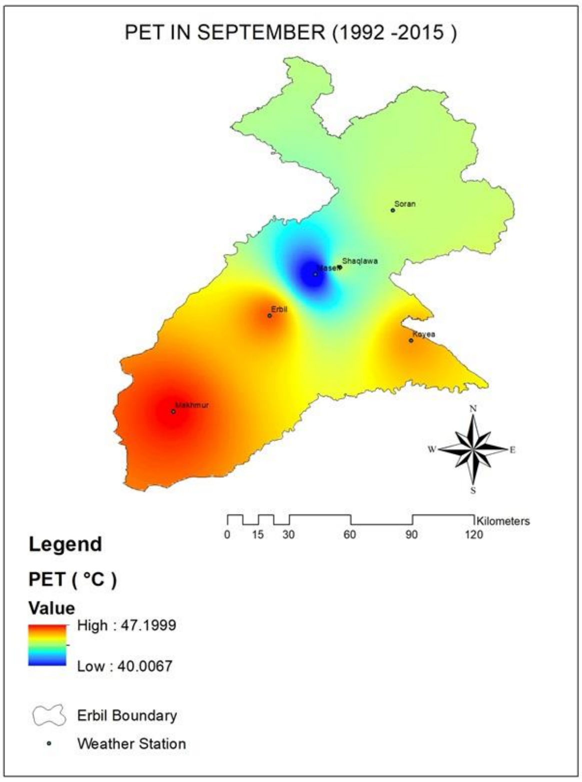

Figure 13. PET map of September

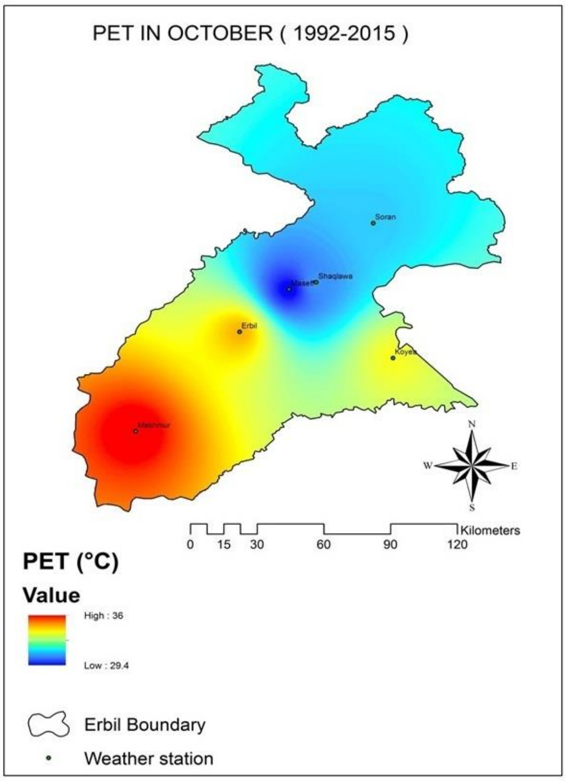

Figure 14. PET map of October

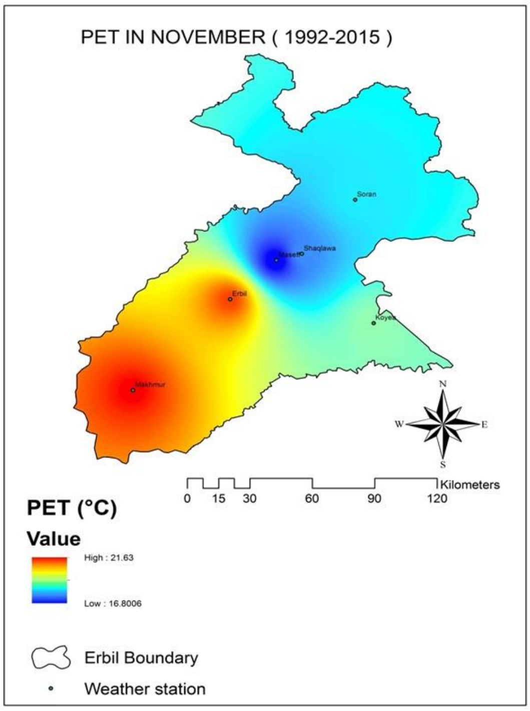	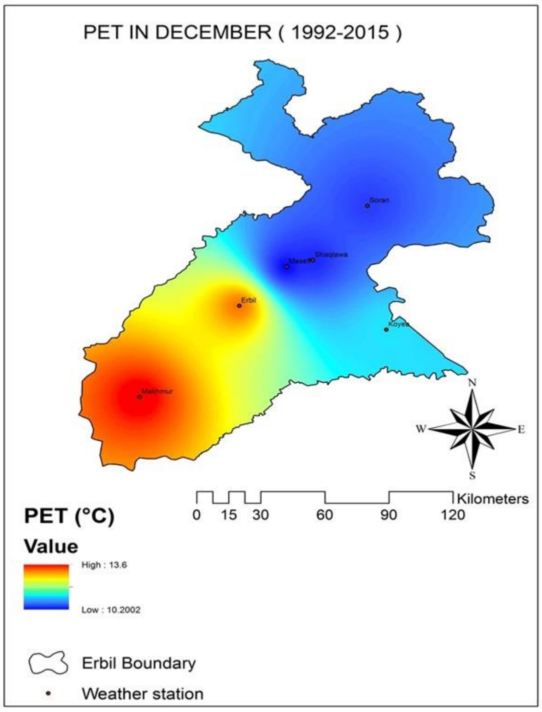
Figure 15. PET map of November	Figure 16. PET map of December

CONCLUSIONS

The PET is a popular method for the assessment of thermal comfort and thermal stress used by decision makers. The monthly PET values observed in Erbil ranged from 7.2 °C to 56.4 °C using RayMan program. The coldest PET values were observed in Masif Salahaddin region while the hottest PET values were found in Makhmur region during the summer months.

After working on Erbil central area for PET values calculated at 15:00 o'clock, we can conclude that topography is the main reason for the differences in the PET in Erbil. Urban expansion and urban sprawl are the second reason for PET differences. Water surfaces and green areas can be effective in cooling the city.

In Erbil, we can conclude that both March and November can be the best months for outdoor activity during the year. December, January and February are the coldest months. During May to September are the hottest months especially in July.

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AUTHOR CONTRIBUTIONS

Twana Abdulrahman Hamad: Organizing weather data, creating maps, help in manuscript writing. **Hakan Oguz**: Analyzing weather data using RayMan Pro and ArcGIS, writing, editing and reviewing the manuscript.

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