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ASSESSMENT OF OUTDOOR THERMAL HUMAN COMFORT OVER HOUCHE AL-OUMARA, NORTH LEBANON

Ali Adnan Shaar
Directorate General of Civil Aviaiton, ali.shaar@hotmail.com

Mahmoud Ahmed Hewehy
Ain Shams University Faculty of Graduate Studies & Environmental Research, prof.mahmoud.hewehy@iesr.asu.edu.eg

Ismail Ibrahim Abbas
Faculty of Science - Lebanese University, ismail.abbas@ul.edu.lb

El-Sayed Mohamed Abdel-Hamid Robaa
Faculty of Science - Cairo University, robaa@sci.cu.edu.eg

Mohammed Salah El-din Mostafa
Faculty of Graduate Studies and Childhood - Ain Shams University, salahmost42@gmail.com

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ASSESSMENT OF OUTDOOR THERMAL HUMAN COMFORT OVER HOUCHE AL-OUMARA, NORTH LEBANON

Abstract

This study examined thermal discomfort in Houche Al-Oumara between 1994 and 2021 using several discomfort indices and analyzing temperature, relative humidity, and rainfall data. The results showed that July and August recorded markedly higher mean temperatures than all other months, with July having the highest temperature overall. In contrast, January was identified as the coldest month. The study found a steady rise in mean air temperature from January to July, followed by a steady decline from July to December. Relative humidity showed the same pattern but in the opposite direction. Fewer than half of the residents experienced thermal discomfort during July and August. The research highlighted the need to understand long-term thermal discomfort trends in light of global warming, urbanization, and population growth. Alongside thermal discomfort, the study also assessed the occurrence of heat waves in Houche Al-Oumara between 1994 and 2021. The analysis showed that heat waves were a recurring feature in the area, appearing almost every year. The analysis of rainfall data showed considerable year-to-year variation in annual averages, with no consistent long-term trend. The study identified periods marked by several consecutive years of above-average or below-average rainfall. These findings offer useful guidance for policymakers working to improve human thermal comfort in rural areas, as they highlight the roles of air temperature, relative humidity, and rainfall. The results can support the development of strategies to reduce heat-related health risks and inform sustainable development planning in North Lebanon.

Keywords

Air temperature, Relative Humidity, Temperature-Humidity Index (THI), Discomfort Index (DI)

1. INTRODUCTION

Human thermal comfort signifies the level of contentment people experience with the thermal conditions around them. It is influenced by several factors, including temperature, humidity, air circulation, and radiant heat, and can differ significantly depending on individual preferences, activity levels, and attire. Even though each climatic factor has a distinct effect, yet the thermal reaction of the human body represents the collective influence of all these variables. (Kerslakje, 1972; VDI 1998; Matzarakis and Mayer (1996); Thorsson et al. 2014 and Thom 1959). Hot (high temperatures) and humid weather (high relative humidity) deliver uncomfortable feelings, and from time-to-time heat stress is expected (ANSI/ASHRAE Standard 55 2004). Thermal discomfort can origin various health issues, such as: fatigue, headaches, dehydration, and in severe cases, heatstroke. It may also weaken productivity and general comfort, adversely disturbing quality of life. Thus, comprehending thermal discomfort and the elements that lead to it is crucial for tackling the problem and enhancing human welfare.

Human thermal comfort circumstances can disclose temporal and spatial differences depending on the ambient seasonal differences, meteorological conditions, land-use types, and topography. Subsequently the state-of-the-art study of Haldane (Haldane 1905), the quantity and quality of studies in related works have increased. Human thermal comfort under outdoor and indoor conditions such as: suburban, corporate, commercial, equipped buildings conditions and public facilities has been widely discussed in numerous reports (Olgay 1973; Van der Linden et al. 2002; Givoni et al. 2003; and Zacharias et al. 2004). Understanding and managing human thermal comfort is serious not only for maximizing people's well-being and efficiency, but also for diminishing energy consumption and environmental impact in buildings and other indoor spaces. To address this, researchers have created several models and standards to evaluate and improve thermal comfort, often presented as numerical formulas or graphical tools. Among the most widely used indices are Thom's Discomfort Index (DI), the Kibler Temperature-Humidity Index (THI1), and the National Oceanic and Atmospheric Administration (NOAA) Temperature-Humidity Index (THI2). (Matzarakis and Mayer (1996); Kibler 1964; Thom 1959). In addition, there are many other human thermal comfort calculation indices like Standard Effective Temperature (SET), Physiological Equivalent Temperature (PET), Predicted Mean Vote (PMV) and Universal Thermal Climate Index (UTCI 2009) that have been used for assessment of thermal comfort and heat stress as well (Höppe 1999; ANSI/ASHRAE Standard 55 2004; Deb and Ramachandraiah (2010); and Matzarakis et al. 2006).

The assessment of human thermal comfort is crucial, particularly in urbanized areas, where environmental changes are increasing due to urbanization and population growth (Chu and Ren 2005; Ren et al. 2008 and Xu et al. 2013). According to United Nations' projections, there could be an additional 2.5 billion people living in urban areas by 2050 due to rapid urbanization and nearly 90% of this increase is expected to occur in Asia and Africa (UN 2018). Moreover, the Intergovernmental Panel on Climate Change (IPCC) found that each of the last four decades has been successively warmer than any decade that preceded it since 1850. The 21st century (2001-2020) will be 0.99 °C warmer than the 1850-1900 period. It also found that the Earth's surface temperature was 1.09 °C warmer between 2011 and 2020 than it was between 1850 and 1900 (IPCC (AR6) Masson-Delmotte et al. 2021). Additionally, the effects of rising temperatures and extreme heat were apparent across the Northern Hemisphere, where snow-cover extent by June 2022 was the third smallest in the 56-year record, and the seasonal duration of lake ice cover was the fourth shortest since 1980. More frequent and intense heatwaves contributed to the second-greatest average mass balance loss for Alpine glaciers around the world since the start of the record in 1970 **(**Blunden *et al.* 2023).

Climate change and its impact on socio-economics and tourism reinforce the need for assessing thermal discomfort in tourist areas (Sauter, C. *et al.* 2023, İsmail C. et al. 2022 and De Freitas et al. 2008; Sofronov 2018). Lebanon's tourism industry has historically been important to the local economy and will remain as an important source of revenue for the country (Moussawi 2013). In 2020, Lebanon generated around 2.37 billion US dollars in the tourism sector alone (worlddata.info 2023). Meanwhile, due to the strong competition between the tourism destinations, analyzing present and future climate conditions using real-time monitored data, indices, scenarios, and thermal discomfort values to reveal their (dis)advantages for companies, visitors and investors is very important and significant (Shaar et al. 2023; Demiroğlu et al. 2020; Şensoy S. 2020).

Upon investigation of literature, it was found that most of the research conducted in Lebanon concerning human comfort in outdoor environments has been inadequate in evaluating factors like heat stress potential. Instead, previous studies have primarily focused on indoor comfort conditions in coastal areas. For example, Kaloustain and Diab (2015) found a significant correlation between population growth and increasing temperature levels over the past 100 years, as well as a connection between high temperatures and mortality rates in Beirut (Habib C., 2021). However, the comfort conditions in Lebanon's high-altitude rural areas (such as the village of Houche Al-Oumara) and the impact of climate on outdoor human comfort have not been thoroughly studied. Therefore, there is an urgent need to evaluate human thermal discomfort in rural area, Houche Al-Oumara, to provide necessary comparisons with Beirut, which is the most urbanized city in Lebanon (Shaar et al. 2023). Thus, this study aims to evaluate human thermal discomfort in Houche Al-Oumara using various indices and to compare the results with Beirut, the most urbanized city in Lebanon. The results provide a useful benchmark for comparisons and help evaluate risks associated with heat stress.

2. MATERIALS AND METHODS

2.1 Study Area

Houche Al-Oumara located in Lebanon's Zahleh's Caza and a part of Beqaa's Mohafazah, is a rural area with an area of about 1.132 km^2. It has a latitude of 33° 49′ 5.9" North and a longitude of 35° 54′ 8.02" East, and an elevation of 983 meters (Fig. 1SI). The area has a population of 5,735 people out of a total population of 78,145 in Zahle City (worldometers.info 2023). The climate in Houche Al-Oumara is Mediterranean, with warm and arid summers and cold and rainy winters. The average annual temperature is 17.4°C, and the average annual precipitation is 627mm (LMD 2023).

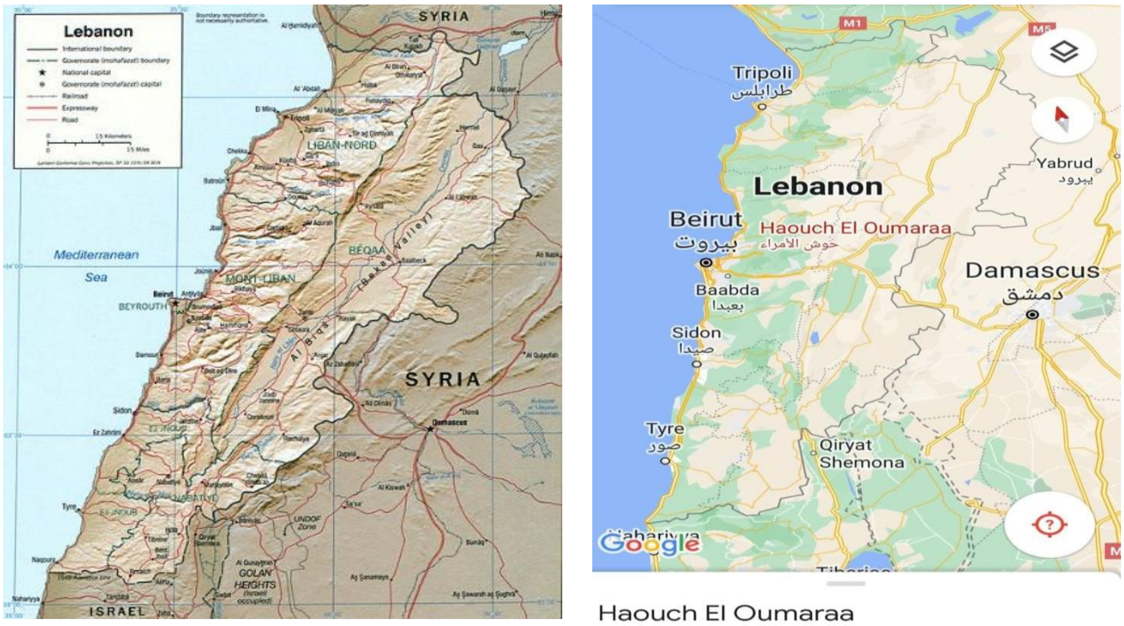

Fig. 1SI. Map of Houche Al-Oumara and its position in Lebanon (www.worldatlas.com)

The study area and the observational climatic data collection were conducted outdoors using Houche Al-Oumara's Synoptic Station (WMO station identifier 40101), which has been renewed at the beginning of 1990's, and is operating under the supervision of the Climatological Office at the Lebanese Meteorological Department (LMD) through the Automated Weather Observation System (AWOS) and located in the central region of Beqaa's Mohafazah, Lebanon (Shaar et al. 2010), at 920 m (3018 feet) above sea level (Fig. 2SI).

Fig. 2SI. Meteorological Station at Houche Al-Oumara (WMO identifier: 40101).

The meteorological data for the coastal weather station (Beirut) and one rural mountain station (Houche Al-Oumara) were collected. The data included air temperature (°C), relative humidity (%), and rainfall precipitation (mm) during the period from 1994 to 2021. Hourly-data provided by the Lebanese Meteorological Department (LMD) were collected, processed and calculated as monthly average. The two stations had sensor probes sheltered with louvered screen (Standard Stevenson Screen) from direct solar radiation at a height of 2 m above ground level with Vaisala-Milos 500/Airport and Degreane dataloger types for measuring ambient temperature (Ta) and relative humidity (RH), at an accuracy of ±0.1°C and ±1% respectively. The precipitation was measured using the calibrated pluviometer at the same synoptic stations (Fig 2SI). Calibration of the instruments and sensors was controlled periodically by the maintenance team, which has visited the stations every month and calibrated, maintained the instruments in a professional manner and in compliance with standards (WMO/TD-No. 1543; 2010) adopted by the World Meteorological Organization (WMO). The Kolmogoroff-Smirnoff homogeneity test was carried out and adjustments were made to filter out the inhomogeneities due to instruments and observational errors (Robaa, 2018).

It is a mountain station that situated nearby to the village Ksara, and about 49 km away from Beirut and it is surrounded on the north by Mount Sannine; on the south by the Bekaa Valley; the Ferzol Heights and Bahin from the east; and the church from the west. Houche Al-Oumara has experienced a slight rise in urbanization and industrialization, especially in the latter half of the 20th century. Within and around the village, there are several agricultural areas, the Zahle industrial area, which is 1.4 km away, Beqaa Valley, the Lebanese Eastern Mountain Chain, recent buildings, the main asphalt network roads (e.g., Zahle-Baalbek highway 10 km away), and the associated congestion to connect it to the neighboring regions.

2.2 Methods

For a duration of 27 years (1994-2021), the Meteorological station at Houche Al-Oumara (Zahle, North Lebanon) recorded hourly data, which was utilized to determine daily temperature and relative humidity information. The observational climatic data utilized by the National Oceanic Atmospheric Administration were provided by the Lebanese Meteorological Department (LMD) and the National Center for Environment Information (NOAA). Temperature (Ta) and Relative Humidity (RH) were measured at a height of 2 meters as recommended by the World Meteorological Organization (WMO 2008), and data were processed using Excel Microsoft Office Professional Plus 2019.

In the current investigation, Thom's DI was determined using the following formula:

$$DI = T_a - (0.55 - 0.0055RH)(T_a - 14.5) \quad (1)$$

Where DI = Discomfort Index, T = Mean air temperature in ° C., and RH = Average relative humidity (%). Table 1 depicts the classes of (DI), and it demonstrates that as the (DI) levels grow, so does human discomfort. (DI) is defined by a simple formula that accounts for the proportionate impacts of relative humidity and air temperature on a person's thermal comfort. This DI has already been used as an indication for the influence of heat stress on humans in numerous research (Anderson et al. 2013; Roghanchi and Kocsis (2018); Yasmeen and Liu (2019); Giles et al. 1990).

Table 1. Classification of Human Thermal related to the Discomfort Index (DI)

Class Number	DI range (°C)	Discomfort Conditions
1	DI < 21	No discomfort
2	21 ≤ DI <24	< 50% feels discomfort
3	24 ≤ DI <27	> 50% feels discomfort
4	27 ≤ DI < 29	Most of the population feels discomfort
5	29 ≤ DI < 32	Everyone feels severe stress
6	DI ≥ 32	State of medical emergency

In this study, the Kibler discomfort index (THI_1) was calculated by means of the following formula (Kibler 1964):

$$THI_1 = 1.8 \times T_a - (1 - RH)(T_a - 14.3) + 32 \quad (2)$$

Where: Ta = average ambient temperature in °C.
RH = average relative humidity as a fraction of the unit.

The NOAA-established formula was used to calculate the Temperature-Humidity Index (THI2) for each month (NOAA 1976).

$$THI_2 = (1.8 \times T_a + 32) - (0.55 - 0.55 \times RH) \times [(1.8 \times T_a + 32) - 58] \quad (3)$$

Where: Ta = average ambient temperature in °C. RH = average relative humidity.

The fundamental significance of the temperature-humidity index (THI) is shown in Table 2.

Table 2. Temperature-Humidity Index (THI) developed by Kibler

Class Number	THI_1	Human / Animal and Plant feeling
1	> 80	100% are not comfortable
2	75 - 80	50% are not comfortable due to hot and humid weather.
3	65 - 75	100% are quite comfortable
4	60 - 65	50% are partially comfortable.
5	< 60	Almost 100% are comfortable due to cold and dry weather

The Discomfort Index (DI) and Temperature-Humidity Indices (THI) were chosen due to their ability to quantitatively assess the impact of both air temperature and humidity on human perception of thermal conditions. Other indices were not taken into account for this study as the necessary parameters for calculating those indices are not accessible.

3. RESULTS AND DISCUSSION

3.1 Effect of Urbanization on Air Temperature and Relative Humidity

First, we examined the monthly mean temperatures and monthly mean RH (Fig. 1) for Houche Al-Oumara from 1994 to 2021. July and August (7 and 8) had significantly higher monthly mean temperatures than the other months. Fig. 1 demonstrates how air temperature changes from winter to summer. Throughout the summer, high temperatures were recorded, with the greatest temperature being recorded in July (8) at 26.38 °C for the entire study period. The lowest temperature ever recorded was 6.58 °C in January. As a result, January is the coldest month, while July (7) is the warmest. Temperatures (> 20 ºC) were usually greater in May and September than in any other month. The temperature is normally between the range of 6.58 and 8.28 °C throughout winter (December – February). There are distinct seasonal cycles in the monthly mean air temperatures and relative humidity with the highest temperatures occurring in July and August and the lowest in January while the relative humidity peaks in the winter.

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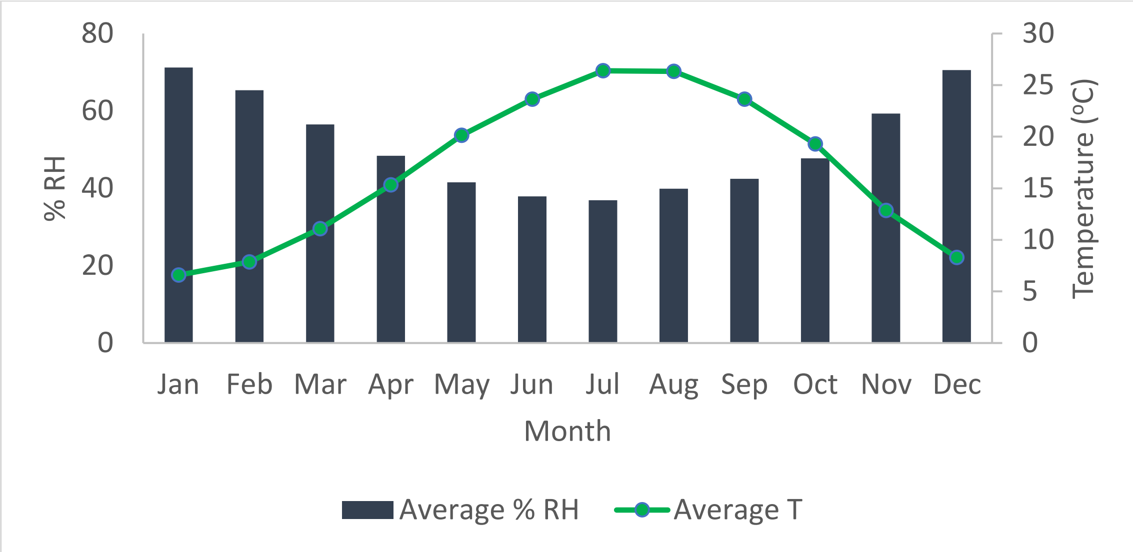

Fig. 1. The variations of mean air temperature and average relative humidity (1994-2021).

In July and January, the average relative humidity was found to be 36.88% at its lowest and 71.23% at its maximum. The relative humidity of the air changed noticeably throughout the year, with the highest measurements (> 55%) occurring in January, February, March, November, and December. The mean air temperature increased linearly (R^2 = 0.98) from January to July and then decreased linearly (R^2 = 0.93) from July to December. The average relative humidity, on the other hand, declined linearly (R^2 = 0.96) from January to July and then increased linearly (R^2 = 0.91) from July to December. The highest mean air temperature (ºC) and lowest average relative humidity were recorded in July in Houche Al-Oumara. High temperatures and humidity can exacerbate heat stress, which can have detrimental effects on one's health. According to research, prolonged exposure to heat makes people more vulnerable to a number of health issues, such as kidney illness (Luo et al. 2014), cardiovascular ailments (Vangelova et al. 2006), and psychological distress (Smith et al. 1997 and Tawatsupa et al. 2010). Studying the long-term thermal discomfort index, its fluctuations, and trends while accounting for urbanization, population increase, and global warming is therefore essential.

Houche Al-Oumara's population growth was examined, showing a significant increase of approximately 100% between 1975 and 2000, and 62.9% between 2000 and 2015 (Fig. 3SI), with an average population density of 4,928/km² (City-facts 2023). The surge in population has accelerated urbanization (Robaa 2018 and Carroll 2007).

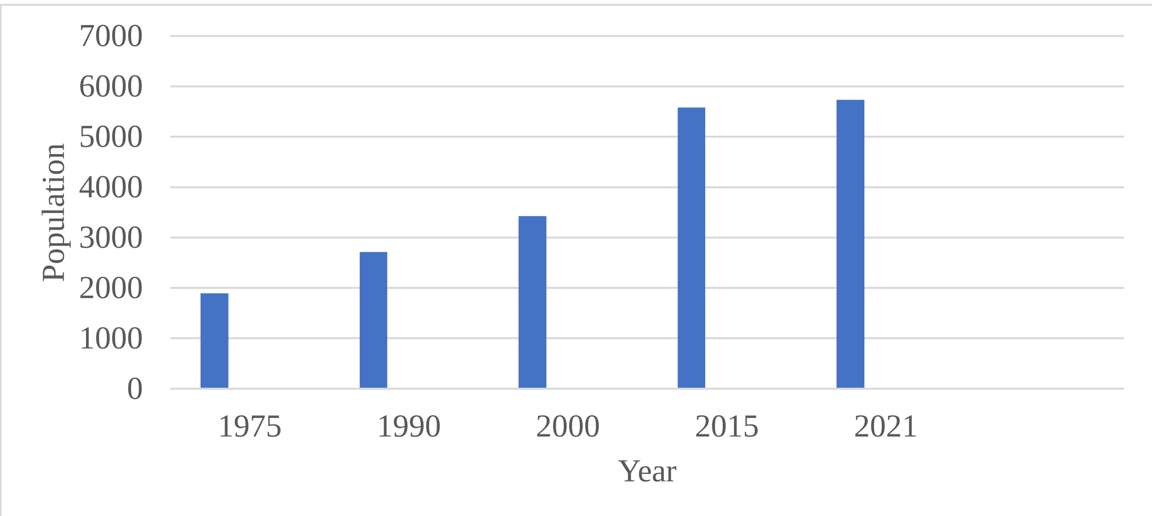

Fig. 3SI. Population of Haouch Al-Oumara from the years 1975 to 2021(city-facts.com).

Figs. 2-4 show the monthly changes in DI, THI1, and THI2 for Houche Al-Oumara. THI1 and THI2 discomfort indices were examined in this study and found to be almost identical. Heat indices (DI, THI1 and THI2) have a distinct annual cycle, with peak values in the summer and minimum values in the winter. DI values of ≥ 24 and THI values > 75 are not seen in Houche Al-Oumara's DI and THI time series (Figs 2-4). Table 3 also includes the Houche Al-Oumara's discomfort index (DI) values from 1994 to 2021. DI levels have shown seasonal fluctuations. From October to May, DI values were frequently less than 21 and within the comfort range. As a result, no one should have been affected during these times because the temperature was mostly lower than it was during other months. However, the DI range was found to be between 21 and 24 in the months of June (1994-97, 2016, and 2019), July, August and September (1994-96, 2007, 2010, 2015 and 2020). Therefore, less than half of the population in Houche Al-Oumara encountered discomfort during these months (Table 1). August 2010 had the highest DI value (23.7) and June 2004 had the lowest DI value (16.1). These months had high average temperatures, which influenced the DI ranges for those months. The discomfort indices (DI, THI1 and THI2) show clear yearly cycles with summer peak values and winter minimum values suggesting patterns of seasonal thermal stress.

Table 3. Discomfort index (DI) of Houche Al-Oumara from the years 1994-2021

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1994			12.39	17.55	19.07	21.77	22.56	23.14	22.47	20.36	12.68	7.32
1995	9.52	10.58	12.44	14.55	19.19	21.32	21.90	22.58	21.11	17.77	11.73	8.83
1996	7.66	10.03	10.39	14.00	19.76	21.32	23.70	22.97	21.13	17.27	14.33	11.15
1997	9.06	7.26	9.35	13.43	19.16	21.02	22.41	21.38	20.71	18.32	14.00	10.06
1998	8.10	9.17	10.32	16.17	18.67	20.74	22.19	22.80	20.68	18.40	15.43	10.63
1999	9.42	10.08	12.02	14.93	19.00	20.07	21.75	22.05	20.23	17.76	13.56	10.96
2000	6.43	8.15	10.38	15.55	17.60	20.91	23.05	22.57	20.20	16.74	13.96	9.09
2001	8.34	8.60	14.57	15.85	17.65	20.65	22.21	22.26	20.55	17.75	12.45	8.77
2002	5.57	11.05	12.56	13.78	17.39	20.14	22.18	21.44	20.31	18.60	13.41	7.87
2003	9.27	6.56	8.51	14.60	19.06	20.40	21.75	22.28	19.80	18.08	12.76	8.25
2004	6.66	8.14	11.77	14.73	17.26	16.14					11.79	7.52
2005	8.21	8.78	12.12	15.02	16.93	19.71	21.78	21.67	19.65	16.52	11.87	10.93
2006	7.12	9.29	11.81	14.20	18.01	20.79	21.18	22.29	20.37	16.66	11.56	8.33
2007	7.48	8.56	11.10	13.14	18.98	20.34	22.14	21.74	21.14		13.26	8.67
2008	4.93	7.04	15.49	16.87	17.27	20.93	21.79	22.71	20.66	17.17	13.55	10.04
2009	8.72	8.64	10.00	14.48	17.33	20.81	21.76	21.92	19.87	18.49	12.25	10.33
2010	9.93	10.51	13.83	15.78	18.63	20.91	22.67	23.71	21.38	18.70	15.55	10.97
2011	8.63	8.76	11.72	14.09	17.07	20.32	22.40	22.08	20.54	16.69	9.95	8.88
2012	6.51	7.65	9.95	16.12	18.04	21.52	22.72	22.24	20.65	18.36	13.88	9.48
2013	7.75	10.73	13.28	14.60	18.65	20.46	21.90	22.01	19.91	16.26	14.62	7.56
2014	9.43	10.47	13.36	16.33	17.98	20.72	22.03	22.81	20.13	17.07	12.19	10.69
2015	6.28	8.46	12.67	13.96	18.14	19.67	22.31	22.70	21.78	18.51	13.84	
2016	7.20	12.08	13.10	16.97	17.85	21.41	22.52	23.19	20.34	18.29	13.69	6.66
2017	7.08	9.10	11.77	15.69	18.31	20.53						
2018												9.50
2019	7.43	8.79	10.92	13.24	19.29	21.51	21.86	22.59	20.65	18.40	13.74	9.21
2020	6.88	8.46	12.43	14.56	17.94	20.04	22.91	22.29	22.62	19.46	12.94	10.36
2021	9.84	10.00	11.55	15.91	19.50	18.68						

The Temperature-Humidity Indices (THI1 and THI2) created by Kibler (Fig. 3) and NOAA (Fig. 4) indicates that discomfort is not expected for most individuals during the majority of the year (Table 2) from 1994 to 2021.

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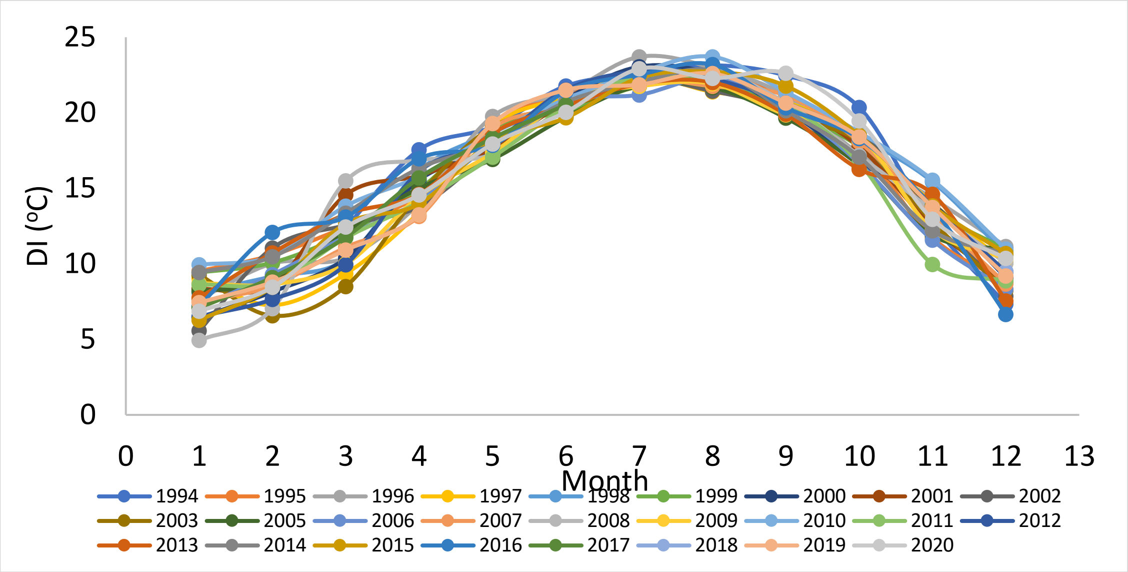

Fig. 2. Time series of monthly average (DI) values in Houche Al-Oumara from the years 1994-2021.

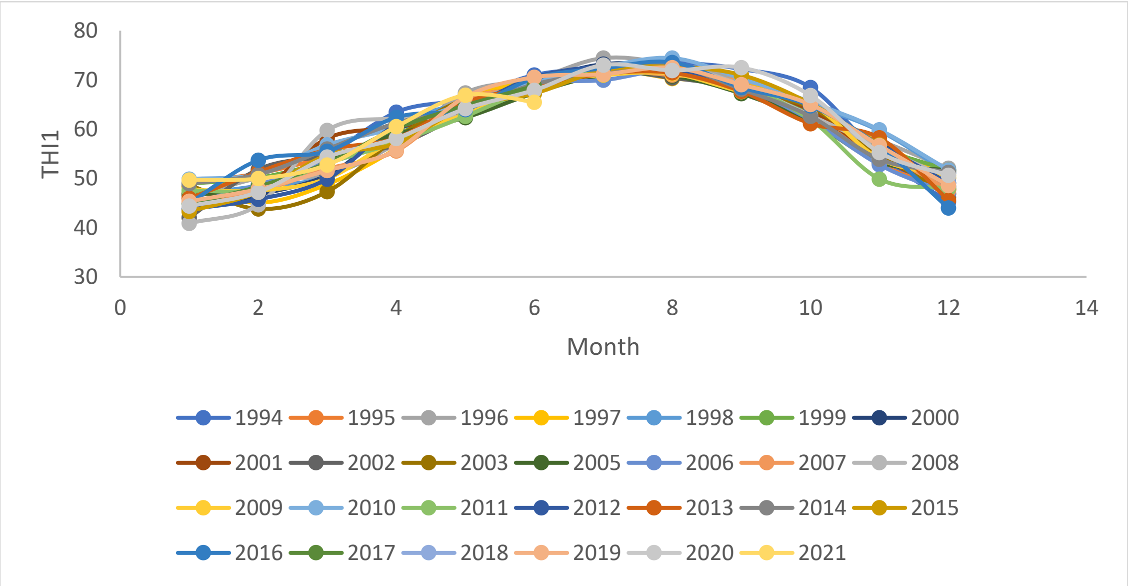

Fig. 3. Time series of monthly average THI1 values in Houche Al-Oumara from the years 1994-2021.

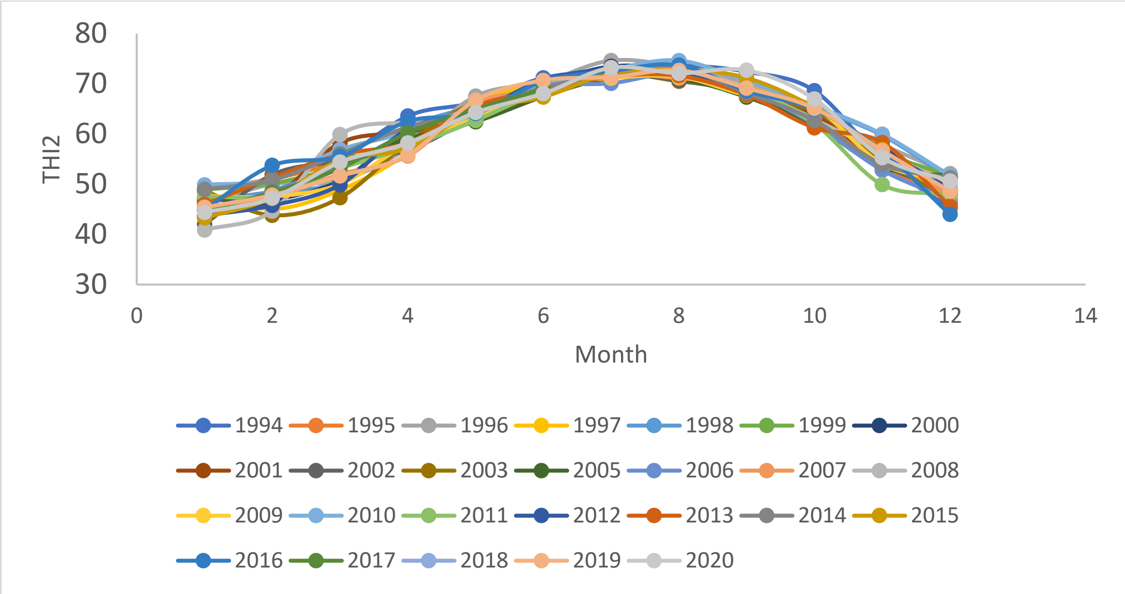

Fig. 4. Time series of monthly average THI2 values in Houche Al-Oumara from the years 1994-2021.

Percentage frequencies of monthly (DI) values from January to December in Houche Al-Oumara from 1994 to 2021 show that there are no records of 100% discomfort due to cold or dry weather (Table 4). According to Tables 3 and 4, the months of October through May are completely comfortable and enjoyable. June and September are characterized by moderate heat stress, with fewer than 50% of the population feeling uncomfortable, with percentage frequencies of 22 and 26%, respectively. In July and August, less than half of the population experiences thermal discomfort. According to Fig. 1 and Fig.3, the thermal discomfort during July and August is mostly controlled by the low relative humidity and high temperature throughout these months.

Table 4. Percentage Frequency of monthly mean (DI) values from January to December in Houche Al-Oumara from the years 1994 to 2021.

DI	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Discomfort Conditions
< 21	100	100	100	100	100	78	0	0	74	100	100	100	No discomfort
21≤DI<24	0	0	0	0	0	22	100	100	26	0	0	0	< 50% feels discomfort
24≤DI<27	0	0	0	0	0	0	0	0	0	0	0	0	> 50% feels discomfort
27≤DI<29	0	0	0	0	0	0	0	0	0	0	0	0	Most of population suffers discomfort
29≤DI<32	0	0	0	0	0	0	0	0	0	0	0	0	Everyone feels sever stress
≥ 32	0	0	0	0	0	0	0	0	0	0	0	0	State of medical emergency
Total	100	100	100	100	100	100	100	100	100	100	100	100	

From 1994 and 2021, a mean annual air temperature of 16.73 °C was recorded. Since 1994, there has been a statistically significant ($p = 0.039$) downward trend in the mean annual air temperature, declining at a rate of 0.03 °C per 27 years (Fig. 5). On the contrary, there has been a statistically significant ($p = 0.039$) increase trend in the mean monthly relative humidity, increasing at a rate of 0.186% per 27 years (Fig. 6).

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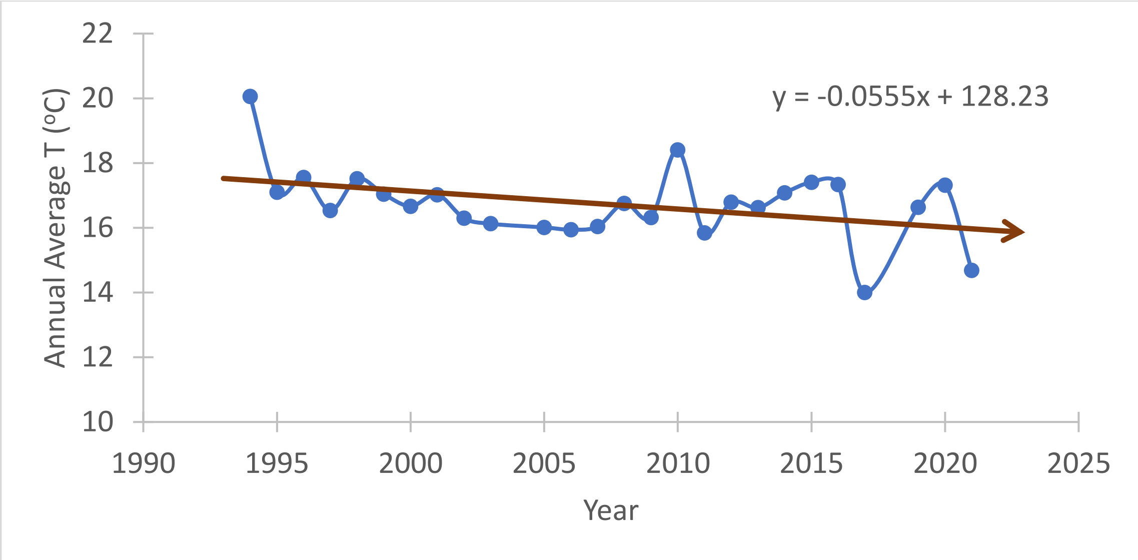

Fig. 5. Annual Average air temperature over the period 1994-2021.

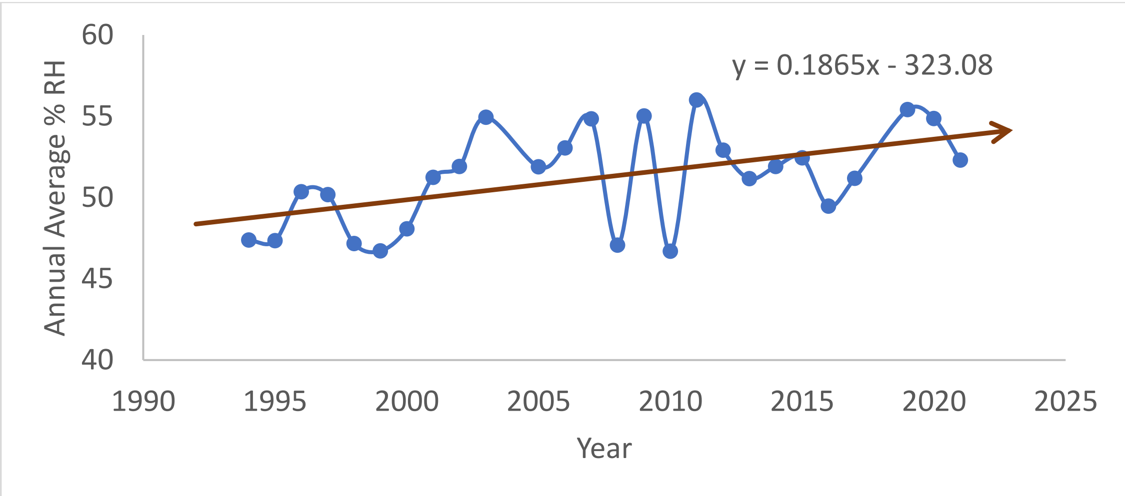

Fig. 6. Annual Average relative humidity over the period 1994-2021.

Comparison between the thermal discomfort indices of Beirut and Houche Al-Oumara

Beirut is Lebanon's capital and largest city. The latitude of Beirut is 33.888, and the longitude is 35.495. It has a subtropical climate that is moderate in the winter and hot and humid in the summer. It is situated on the Mediterranean coast, near the Lebanon Mountains. Greater Beirut has a population of 2.5 million people as of 2014, making it the third-largest metropolis in the Mediterranean region. The city is located on a peninsula on the Mediterranean coast of Lebanon. On the other hand, Houche Al-Oumara is a Lebanese local village in Zahleh's Caza (District), one of the administrative subdivisions of Beqaa's Mohafazah (Governorate). The latitude of Houche Al-Oumara is 33.817, and the longitude is 35.850. It has an elevation of 983 meters (Table 1SI).

Table 1 SI. Meteorological synoptic stations operated by the official Met. Office (LMD)

Station	Coordinates	WMO Id	Elevation (m)
Beirut (BRHIA)	33° 49' 15"N and 35° 29' 15"E	40100	15
Haouch Al- Oumara	33° 49' 0"N and 35° 51' 0"E	40101	920

Over the last two decades, the mean annual air temperature in Beirut increased (Shaar et al. 2023), whereas it decreased in Houche Al-Oumara (Fig. 5). In contrast, a decrease in annual relative humidity was reported in Beirut (Shaar et al. 2023), while an increase was observed in Houche Al-Oumara (Fig. 6). This may be attributed to the urbanization effect on Beirut, which has reduced long-term air humidity trend values due to both an increase in air temperature and changes to the land surface; these changes have also caused a quick runoff of precipitation (4 percent reduction in mean annual precipitation) and a decline in vegetation (Shaar et al. 2023).

Thermal conditions differed seasonally in both Beirut and Houche Al-Oumara. Yet, from May to September, discomfort values were between 25 and 27, signifying that more than half of Beirut's population experienced discomfort during these months. At the same time period, Houche Al-Oumara's discomfort values were less than 24, indicating that fewer than half of the population in this area experienced discomfort. From October to May, no thermal discomfort (DI < 21) was recorded in Houche Al-Oumara, while less than half of the people in Beirut encountered discomfort (21< DI< 24) between March and November (Table 5). These findings illustrate the effect of relative humidity on thermal discomfort of humans in different regions of the same country. The highest and lowest annual average relative humidity recorded in Beirut were 68.39 % in 2004 and 59.02 % in 2008 respectively (Shaar et al. 2023). While in Houche Al-Oumara, the highest and lowest values of annual relative humidity were 56.0 % in 2011 and 46.6 % in 2010. Accordingly, the higher humidity values in Beirut formed a negative result on the human’s thermal comfort (Table 5).

Table 5: Comparison at the Urban and Rural regions in Lebanon.

Parameters	**Temperature (°C)**		**Relative Humidity (%)**		**Rainfall (mm)**	**Wind Speed (m/s)**	
Values	**Min**	**Max**	**Min**	**Max**	**Average**	**Min**	**Max**
Beirut (Urban)	14.36 °C January	28.47 °C August	59.02 % 2008	68.39 % 2004	919.47	1.77 (m/s) 2010	4.74 (m/s) 2019
Haouch El Oumara (Rural)	6.58 °C January	26.38 °C July	46.6 % 2010	56.0 % 2011	873.78	0.43 (m/s) 2019	4.12 (m/s) 1994

Outdoor Thermal Human Discomfort (DI)

	DI < 21	**21< DI< 24**	**24< DI< 27**
Beirut (Urban)	November - April	May, June, & October	July, August & September
Haouch El Oumara (Rural)	October - May	July & August Partially in June & September	Not exist

The orographic features of the Lebanon Mountains near Beirut and the elevated topography of Houche Al-Oumara, in addition to the previously described topographical and climatic peculiarities, have a major influence on the local weather. Beirut is influenced by both the sea and the mountains due to its location on the Mediterranean coast and close to the Lebanon Mountains. As a barrier, the mountains cause orographic lifting, which results in cloud formation and affects the region's precipitation patterns. This can lead to increased rainfall and possibly higher humidity levels in Beirut during certain periods of the year. Unlikely, Houche Al-Oumara located in the Beqaa Valley has an elevation of 983 meters above sea level experiences diverse orographic influences. The nearby mountains produce a rain shadow effect, ensuring in lower precipitation than in coastal areas and consequently less humidity levels compared to Beirut. Consequently, beyond the influence of land-surface changes previously mentioned and urbanization, the orographic features of each location may benefit to explain the differences in temperature, humidity, and thermal discomfort between Beirut and Houche Al-Oumara. The interaction of elevation, urbanization, and local topography significantly shapes the microclimates and thermal conditions experienced by the populations in these two regions of Lebanon.

3.2 Effect of Urbanization on Rainfall

Table 2SI displays the average amount of the rainfall and the anomaly for the local village Houche Al-Oumara between the period years 1994 and 2021.

Table 2 SI. Average Rainfall over Houche Al-Oumara

Year	Average rain fall	Anomalies
1994	530.1	343.7
1995	501	372.8
1996	1045.1	-171.3
1997	1061	-187.2
1998	778.9	94.9
1999	364	509.8
2000	945.7	-71.9
2001	678.3	195.5
2002	1102.6	-228.8
2003	1252.8	-379.1
2004	933.3	-59.5
2005	795.9	77.9
2006	707.7	166.1
2007	789.8	83.9
2008	380.6	493.2
2009	1341.8	-468.1
2010	907.9	-34.1
2011	1248	-374.2
2012	1561.3	-687.5
2013	1057.4	-183.6
2014	595.8	277.9
2015	912.8	-39.1
2016	848.6	25.2
2017	388.2	485.6
2018	324	549.8
2019	1717.6	-843.8
2020	1191.4	-317.6
2021	504.2	369.6

The anomaly values, which specifies how much the rainfall amount in a given year varies from the overall average, is calculated by subtracting the average rainfall from the dataset's mean. Among the period of the years 1994-2021, the mean average rainfall was 856.04 mm, with a median of 848.6 mm. Houche Al-Oumara's rainfall values differ widely from year to year, as shown by the standard deviation of 344.44 mm. The rainfall statistics for Houche Al-Oumara station reveals important changeability across the years, with both above average and below-average values. The minimum-recorded rainfall was 324.0 mm in 2018, while the maximum was 1717.6 mm in 2019, resulting in a range of 1393.6 mm. The skewness value of 0.485 indicates a slight positive skewness, signifying that there are more years with below-average rainfall than above-average rainfall. To demonstrate the trends and patterns, we plotted the average rainfall from data from the years 1994 to 2021 (Fig. 7). The chart highlights the important fluctuations in average rainfall over the years selected, without a clear noticeable trend. However, there appears to be gathering of above-average and below-average rainfall in consecutive years.

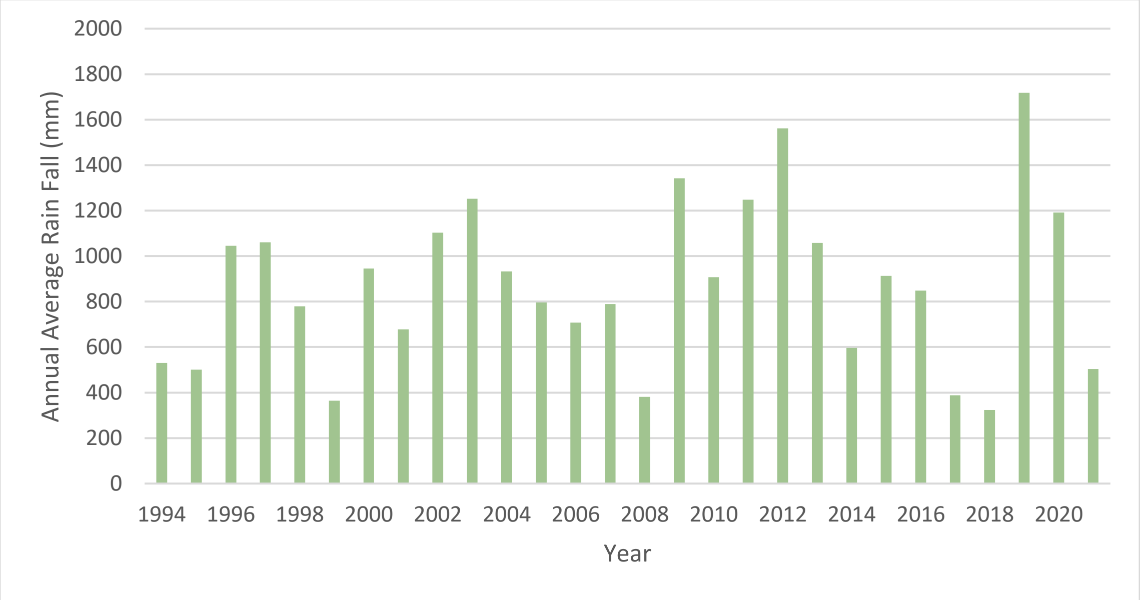

Fig. 7. Average annual rainfall in Houche El Oumara over the period 1994-2021.

After additional examining, distinguished negative and positive anomalies was observed (Fig. 8). Positive anomalies occurred in 1994, 1995, 1999, 2001, 2005, 2006, 2007, 2014, and 2021, indicating higher-than-expected rainfall. Conversely, negative anomalies were observed in 1996, 1997, 2000, 2002, 2003, 2004, 2009, 2010, 2011, 2012, 2013, 2015, 2016, 2018, 2019, and 2020, representing lower-than-expected rainfall. There is significant interannual variability in rainfall with positive and negative anomalies grouped in successive years indicating wetter and drier times.

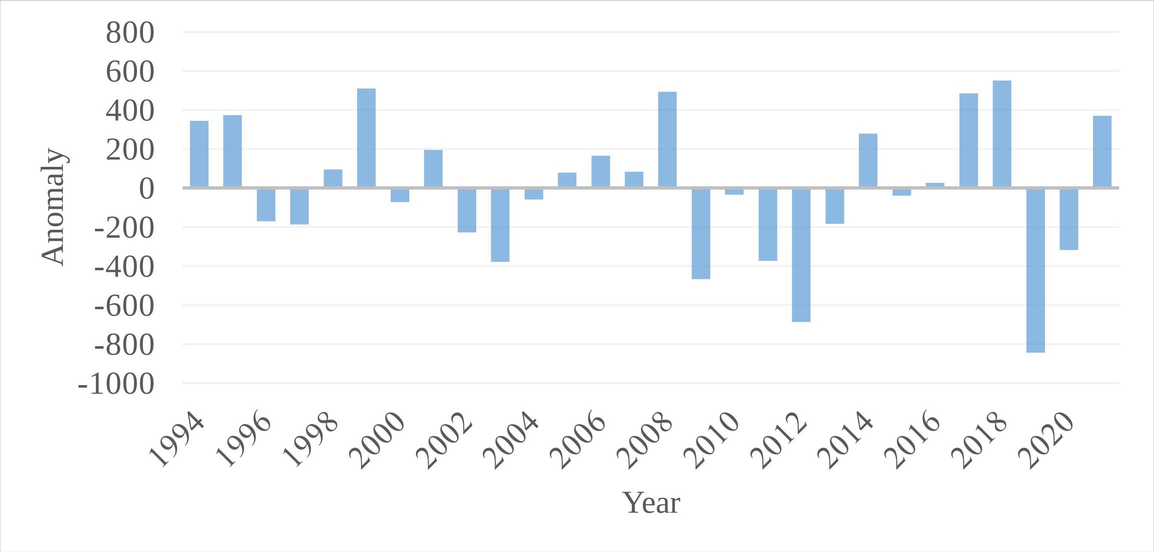

Fig. 8. Anomalies for rainfall in Houche El Oumara over the period 1994-2021

The existence of significant negative and positive anomalies suggests a deviation from the expectable rainfall patterns. The occurrence of successive years with negative or positive anomalies implies potential trends in the rainfall patterns. Generally, the evaluation unleashes considerable variability in rainfall from year to year in Houche Al-Oumara. These differences have consequences for the local environment, water resource management, and agriculture. Below-average rainfall may lead to drought, water resources, affecting agriculture productivity, and ecosystem stability. In contrast, above-average rainfall can cause flooding, soil erosion, and damage to infrastructure. Recognizing and responding to these rainfall patterns is crucial for sustainable planning and effective resource management in the region.

Examining and understanding these rainfall anomalies from a biometeorological viewpoint can profit in numerous ways. Firstly, it lets for the identification of latent climate-related risks and vulnerabilities in the discovered area. This evidence can support the Lebanese decision makers in developing national strategies for climate change adaptation and resilience-building measures. For example, agriculturalists can regulate their harvesting designs or implement water conservation methods based on the probable rainfall patterns. Furthermore, biometeorological examinations can contribute to the development of early warning systems for extreme weather events such as: floods or droughts. By monitoring meteorological parameters and their association with the anomalies, it becomes likely to provide timely information and guidance to the local authorities and the community, aiding in preparedness and response efforts.

3.3 Heat Waves in Houche Al-Oumara

The definition and classification of a heat wave can differ from one country to another depending on the climate conditions and district position. Generally, a heat wave is a continued period of excessively hot weather, often attended by high humidity (WMO and WHO; 2024). The temperature threshold that defines a heat wave can vary depending on the normal climate conditions of a specified region (Barriopedro et al. 2023). In Lebanon, a heat wave is commonly identified when the highest temperatures spread or exceed 32°C (90°F) continuously for a minimum of three successive days (Lelieveld et al. 2016). In Houche Al-Oumara village, the data shows that heat waves have occurred almost every year throughout this period (Table 6). Heat waves are a common occurrence in Houche Al-Oumara climate as evidenced by the majority of years with complete observational records experiencing at least one during the study period.

All years encounter multiple heat waves signifying that heat waves are a frequent phenomenon in Lebanon's climate. Throughout Houche Al-Oumara the heat waves are observed primarily during the summer months, especially in June, July, and August. However, there are many cases of heat waves occurring in other months as well, such as May, September, and October. This specifies that heat waves can spread beyond the typical summer season. It was observed that, the intensity and duration of the heat waves vary from year to year. Some heat waves lasted for just a few consecutive days, while others persisted for several weeks. The longest heat wave recorded in the data lasted for 31 consecutive days in July 1996 and August 2010. It is imperative to note that longer and more severe heat waves can have significant impacts on agriculture, human health, and the environment. There is an overall growing trend in the quantity of days with temperatures equal to or above 32 degrees Celsius over the years (Fig. 9). The data analysis showed some fluctuations, but there are clear periods of higher values, indicating an upward trend in heat extremes. Several years stand out with remarkably higher numbers of days above the temperature threshold (32 degrees Celsius). For example, in 1996, 1998, 2001, 2010, 2012, 2015, 2016, 2019, and 2020, the number of such days is relatively high compared to the surrounding years. These periods of higher values contribute to the overall increasing trend. The increasing trend in heat waves aligns with global climate change patterns, where rising temperatures are causing more frequent and intense heat waves worldwide. While it is challenging to attribute specific heat waves solely to climate change, the overall trend suggests a potential influence. Figure 9 shows an increase in the number of days with temperatures ≥32 °C despite Figure 5 showing a slight decrease in mean annual air temperature. This seeming discrepancy emphasizes how trends in mean temperature and temperature extremes do not always change in tandem. Even when average temperature changes are negligible or negative there may still be an increase in extremely hot days this is due to greater temperature variability rather than just variations in mean conditions. In addition to having an impact on human health and thermal comfort heat waves also have wider socioeconomic implications. Extended periods of intense heat can strain local water supplies lower worker productivity and increase energy consumption for cooling. Extreme heat can harm crops lower yields and interfere with planting and harvesting schedules in rural areas like Houche Al-Oumara which can have an impact on local income and food security. Planning adaptive strategies to reduce the economic and societal effects of heat waves requires an understanding of their frequency duration and intensity.

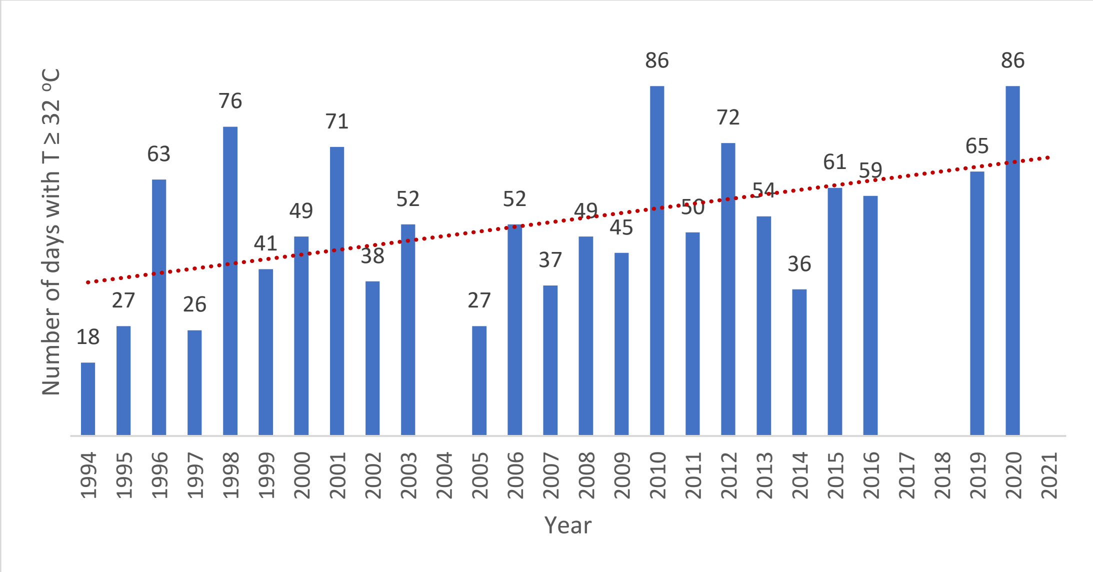

Fig. 9: Number of days with temperatures ≥ 32 ºC over the years 1994-2021.

Table 6: Frequency and Duration of Heat Waves in Houche Al-Oumara: An Analysis Across Years (1994-2021) and Months (May-October). NA: denotes years or months with incomplete or unavailable data.

Number of heat Waves (Duration in days)						
Year	May	June	July	August	September	October
1994	0	1(3)	1(6)	1 (9)	0	0
1995	1(6)	2(3; 5)	0	2(3; 4)	1(6)	0
1996	0	2(5; 5)	1(31)	2(6; 12)	1(4)	0
1997	0	1(4)	1(9)	1(3)	2(5; 5)	0
1998	0	2(7; 4)	3(5;10;8)	2(13;15)	3(3;6;5)	0
1999	1(3)	1(5)	1(12)	2(3;12)	1(3)	1(3)
2000	0	2(5;3)	2(17;10)	1(8)	1(6)	0
2001	1(3)	3(3;5;3)	1(20)	2(16;7)	3(4;3;7)	0
2002	0	2(4;4)	3(4;7;4)	1(5)	1(7)	1(3)
2003	0	1(6)	2(6;10)	4(13;6;4;3)	1(4)	0
2004	0	0	NA	NA	NA	NA
2005	0	0	3(3;5;3)	2(13;3)	0	0
2006	1(6)	3(6;5;3)	0	4(6;4;3;10)	1(6)	1(3)
2007	1(3)	2(3;5)	2(5;10)	1(6)	1(5)	0
2008	0	1(12)	3(3;5;5)	3(5;5;7)	2(3;4)	0
2009	0	3(3;4;4)	3(4;3;4)	2(4;10)	1(4)	1(5)
2010	0	3(5;4;3)	4(9;4;3;5)	1(31)	2(10;9)	1(3)
2011	0	1(5)	3(12;5;8)	4(5;3;4;4)	1(4)	0
2012	0	2(12;3)	1(22)	3(3;5;12)	3(5;4;6)	0
2013	0	1(8)	1(14)	3(6;12;6)	2(3;5)	0
2014	0	1(6)	3(3;5;4)	1(18)	0	0
2015	1(3)	0	2(3;16)	2(8;11)	1(20)	0
2016	0	1(10)	1(18)	2(15;11)	1(5)	0
2017	0	1(6)	NA	NA	NA	NA
2018	0	NA	NA	NA	NA	0
2019	3(4;4;5)	1(9)	4(4;3;5;3)	2(12;9)	2(4;3)	0
2020	1(7)	1(5)	2(4;24)	4(3;3;10;4)	2(22;4)	1(16)
2021	1(3)	0	NA	NA	NA	NA

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Generally, the data reveals that heat waves in Houche Al-Oumara village occur frequently, vary in intensity and duration, and may be showing an upward trend. This emphasizes the need from decision makers and experts in different related stakeholders and ministries especially the administrative of the Lebanese Meteorological Department to monitor and understand heat waves in order to implement effective measures that protect public health, strengthen resilience, and reduce the impacts of extreme heat waves events in Houche Al-Oumara.

4. CONCLUSION

The investigations of thermal discomfort in local village Houche Al-Oumara from 1994 to 2021 has produced important information on the local climate and how it disturbs human comfort. The investigation of monthly mean temperatures and relative humidity showed clear seasonal differences, with summer showing the greatest thermal discomfort and July and August having the highest temperatures. Conversely, there was comparatively less thermal stress in the winter. The outcomes and results highlighted how vital it is to understand human thermal comfort by considering environmental factors including air temperature, relative humidity, and rainfall. It was clear that prolonged exposure to high humidity and temperatures could exacerbate heat stress and have detrimental effects on one's health.

The comparison with Beirut, the country's capital, emphasized how relative humidity affects thermal discomfort in different parts of the same country. Human thermal comfort was found to be negatively impacted by Beirut's greater humidity levels, highlighting the importance of local climate variables in determining human well-being.

An analysis of rainfall data showed that Houche Al-Oumara's yearly average rainfall varied significantly over time. Clustering of above-average and below-average rainfall in consecutive years revealed potential cyclical changes in rainfall patterns, even though no clear trend or pattern was seen. This highlights how crucial it is for resource management and sustainable development to keep an eye on and adjust to shifting rainfall patterns.

The number of days with temperatures above 32 degrees Celsius has generally increased over time, according to the study. This tendency is consistent with patterns of global climate change, wherein increasing temperatures lead to an increase in the frequency and severity of heat waves globally. The study's findings regarding the regularity, varying intensity, and potential rising trend of heat waves in Houche Al-Oumara emphasize how important it is to monitor and understand these events.

The study has important ramifications for decision-makers. The information provided here can be used as a foundation for comprehending, simulating, and monitoring human thermal comfort and discomfort, allowing for improved planning and decision-making in North Lebanon's rural areas. In order to preserve human well-being and adjust to changing climate circumstances, it becomes increasingly significant to take these findings into account as population expansion and urbanization continue.

Generally, the study highlights how intricately urbanization, climate, and human comfort interact. Policymakers can establish strategies to support sustainable development and resilience in the face of climate change and take proactive and preventive steps to lessen the negative effects of heat stress on public health by looking at long-term patterns.

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6. Declarations

The Authors declare no conflict of interest.

7. Funding

This research received no external funding.

8. Data Availability Statement

The data that support the findings of this study are available from the Lebanese Meteorological Department and NOAA. Restrictions apply to the availability of these data, which were used under license for this study. Data are available at https://meteo.gov.lb/ or at https://www.ncei.noaa.gov/access/search/, with the permission of the Lebanese Meteorological Department and NOAA.

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