DETECTION OF DISCOMFORT INDEX WITH REMOTE SENSING TECHNOLOGY: THE CASE OF ANTALYA PROVINCE

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ABSTRACT:

Thermal adaptation and thermal comfort indices are critical in determining the thermal comfort of the outdoor environment. They also play an essential role in research on heat stress, an environmental threat that can affect individuals' productivity, health and even survival. Urban growth and the resulting expansion of impervious surfaces affect the thermal characteristics of a landscape by raising Land Surface Temperatures (LST). The resulting warming can lead to thermal discomfort, the prevalence of heat-related health problems, air pollution, increased water use and energy demand for air conditioning, among others. Recently, efforts to understand the effects of urbanization and landscape changes on indoor and outdoor temperatures have increased significantly. Together with remote sensing technology, this study aims to understand human heat stress, and geographic information system (GIS) is a tool used in the research. In the estimation of heat stress, besides temperature, physiological status, environmental impact and relative humidity factors are also important. The discomfort index (DI) is a heat stress indicator proposed by Thom (1959), which expresses the contribution of air temperature and relative humidity to human thermal comfort. The discomfort index proposed by Thom (1959) was calculated as DI=0.5Ta+0.5Tw (Ta: dry bulb temperature, Tw: wet bulb temperature) modified by SOHAR, Adar and Laky (1963). In the study, the dry bulb temperature, assumed to be equal to the air temperature, was taken monthly from MODIS LST data at 1km resolution. Relative humidity was produced by interpolating 73 meteorological data in the study area at 1km resolution. Wet bulb temperature is difficult to measure, so it was calculated from dry bulb temperature and relative humidity data so that the discomfort index as a measure of heat stress in the study area was calculated with a resolution of 1 km. The discomfort index was calculated monthly and annually and classified according to Thom's 4 comfort classes. According to the calculation results, Antalya's average discomfort index value for the whole year is 24.9 0C, indicating that Antalya is a moderately comfortable place. This value varies monthly, especially in April and October when the heat stress is the highest.

1. INSTRUCTION

Houghton and Yaglou (1923) proposed effective temperature (ET), which is considered as the first direct heat stress index. It was established to provide a measurement of temperature and humidity on human comfort (Song and Wu, 2017). As the most widely utilized heat stress index, wet-bulb globe temperature (WBGT) was developed in US Navy as a part of a study associated with heat-related injuries during military training (Yaglou and Minaed, 1957, Song and Wu, 2017). Coefficients in WBGT were determined empirically and no physiological variables were needed to calculate the index. In spite of the simplicity of WBGT, its limitation lies in the applicability across a broad range of environments, due to the inconvenience of the measurement of black-bulb temperature (Song and Wu, 2017). Discomfort index (DI) is another heat stress indicator proposed by Thom (1959) and was adjusted by Sohar, Adar, and Kaly (1963) (Song and Wu, 2017). It requires only dry-bulb and wet-bulb temperature as the input and has been proved to be a reliable direct heat stress index due to its strong correlation with ET and its physiological significance (Tennenbaum et al., 1961; Song and Wu, 2017).

Different from heat stress indices, bioclimatic comfort employs multiple environmental and personal parameters to evaluate heat environment (Oliveira and Andrade 2007; Cetin 2015; Cetin et al., 2016; Song and Wu, 2017). Despite all the endeavors have been done to address heat stress, heat stress indicators are usually measured at specific sites where individuals could expose to extreme heat stress due to their occupations, such as construction workers and soldiers (Song and Wu, 2017). However, addressing heat stress only at scattered sites may not be sufficient since any citizens exposed to high temperature can be threatened by heat stress, and extreme hot weather has appeared more frequently within large areas such as a country or even across a whole continent (Meehl and Tebaldi 2004; Patz et al. 2005; Robine et al. 2008; Song and Wu, 2017). Spatial information is urged for addressing heat stress through continuous space (Song and Wu, 2017).

Therefore, the spatial details of the discomfort index values in Antalya province were revealed. A better understanding of the spatial details of heat stress is very important both in terms of urban planning and design and tourism planning. Antalya is a province of the Mediterranean region known for its popular tourist destinations and favorable climate. In terms of its impact on Antalya's tourism, heat stress and associated discomfort can significantly affect the experiences and behavior of tourists. High temperature and humidity levels can result in discomfort, tiredness and even health risks in tourists, which can negatively affect participation in outdoor activities or tourist attraction. The discomfort caused by extreme heat can affect the amount of time tourists spend outdoors and thus also affect their interactions and spending in the local tourism sector. In addition, heat stress can have negative impacts on local flora and fauna and alter the biodiversity and ecological dynamics of the region, which can harm tourism attraction.

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2. MATERIAL

This study is aimed to reveal the heat stress situation using remotely sensed data. Heat stress is not only related to temperature but also to other factors such as physiological state, environmental impact and relative humidity. The discomfort index (DI) is one of the indices based on the basic environmental parameters air temperature and relative humidity, and expresses the contribution of air temperature and relative humidity to human thermal comfort together.

The discomfort index is a heat stress indicator proposed. Environmental factors, which are not sufficiently taken into account when determining the bioclimatic comfort status, can be used more effectively with remote sensing data that come into play when determining heat stress areas, taking into account the presence of permeable surface and impermeable surface. However, the discomfort index will also contribute to the improvement of tourism, which is an important source of income for Antalya.

This study was carried out in Antalya, which is located in southwestern Turkey between 29° 20'-32° 35' east longitude and 36° 07'-37° 29' north latitude. It is surrounded by the Mediterranean Sea to the south and the Taurus Mountains running parallel to the sea to the north, and is neighbored by Mersin, Konya and Karaman to the east, Isparta and Burdur to the north, and Muğla to the west. The surface area of the province is 20.177 km2. This corresponds to 2.6 per cent of Turkey's surface area. Located in the west of the Mediterranean Region, Antalya province constitutes 17.6 per cent of the region's surface area. On average, 77.8 per cent of the province's land is mountainous, 10.2 per cent is plain and 12 per cent is hilly. Many peaks of the Taurus Mountains, which cover 3/4 of the provincial area, exceed 2500-3000 meters. The geographical location of study area is illustrated in Figure 1.

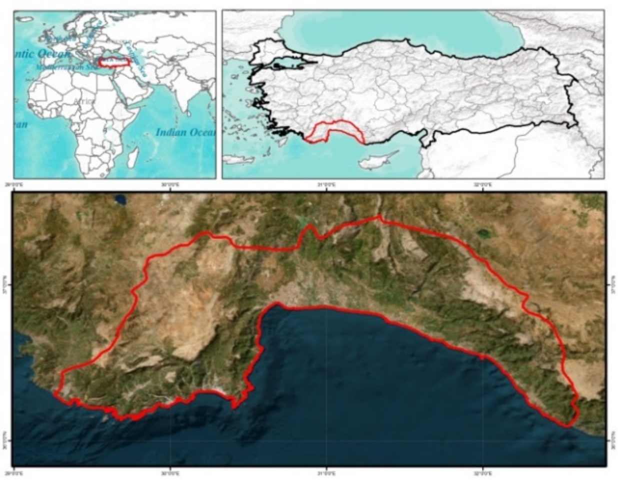

Figure 1. Geographic location of Antalya

3. METHOD

The discomfort index (DI) is one of the indices based on the basic environmental parameters air temperature and relative humidity, and expresses the contribution of air temperature and relative humidity to human thermal comfort together. The discomfort index is calculated by summing the land surface temperature data, which is considered as dry-bulb temperature and the wet bulb temperature data produced by the empirical method with equal coefficients (Figure 2).

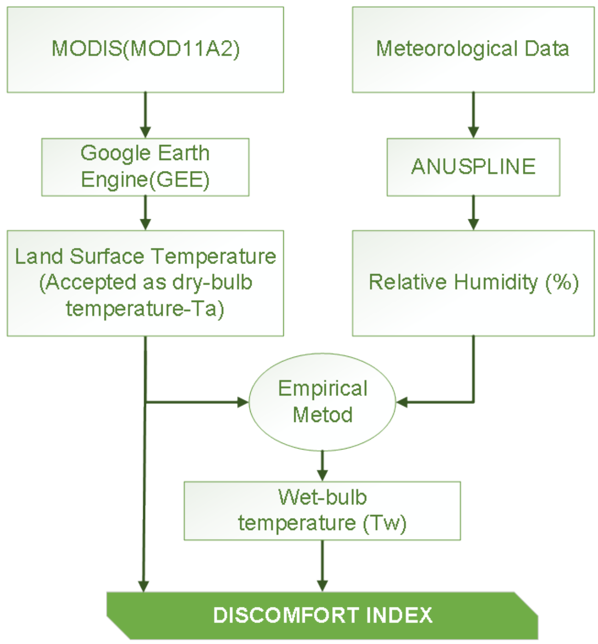

Figure 2. Method flowchart

The empirical method proposed by Thom (1959) and modified by SOHAR, Adar and Laky (1963) is based on the following formula (Song, 2018);

$$DI = 0.5Ta + 0.5Tw \quad (1)$$

where Ta= dry-bulb temperature,
Tw= wet-bulb temperature

Dry-bulb temperature (dry-bulb temperature) refers to the air temperature measured with a thermometer exposed to air but protected from moisture and radiation. In this study, the dry-bulb temperature, which is assumed to be equal to the air temperature, will be taken from MODIS LST data at a resolution of 1km (Song and Wu, 2017).

Wet-bulb temperature (wet-bulb temperature) is the temperature measured by a thermometer covered with a cloth soaked in water through which air passes. Since it is difficult to measure the wet-bulb temperature, the empirical method proposed by Stull (2011) will be used. This empirical method can be expressed by the following formula (Song and Wu, 2017).

$$\begin{aligned} Tw = Ta * \mathrm{atan}[0.151977\,(\mathrm{RH} + 8.313659)0.5\,] \\ + \mathrm{atan}(\mathrm{Ta} + \mathrm{RH}) \\ - \mathrm{atan}(\mathrm{RH} - 1.676331) \\ + 0.00391838 * \mathrm{RH}1.5 \\ * \mathrm{atan}(0.023101\mathrm{RH}) - 4.686035 \end{aligned} \quad (2)$$

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where Ta (°C)= dry bulb temperature,
RH (%)= relative humidity,
Tw= wet bulb temperature.

The applicability or valid range of this model is mainly influenced by three factors; relative humidity RH (%), air temperature (°C), and air pressure (kPa). Air pressure is another factor that affects the accuracy of the model. The ideal air pressure for this model is 101,325 kPa.

While obtaining the discomfort index, the monthly daily surface temperature data for 2020 covering the study area were obtained from MODIS satellite MODA11 images. The MODIS satellite used has a spatial resolution of 1km, daily temporal resolution, 8-bit radiometric resolution and a bandwidth of 2330km. MODIS images were obtained from MOD11A1.006 Terra Land Surface Temperature and Emissivity Daily Global 1km data in its own library with Google Earth Engine. Antalya's average annual land surface temperature is 22^{0}C. The most land surface temperature month of the year is July. The average land surface temperature in this month is 45^{0}C. The driest month of the year is January. The average land surface temperature in this month is -9 ^{0}C (Figure 3).

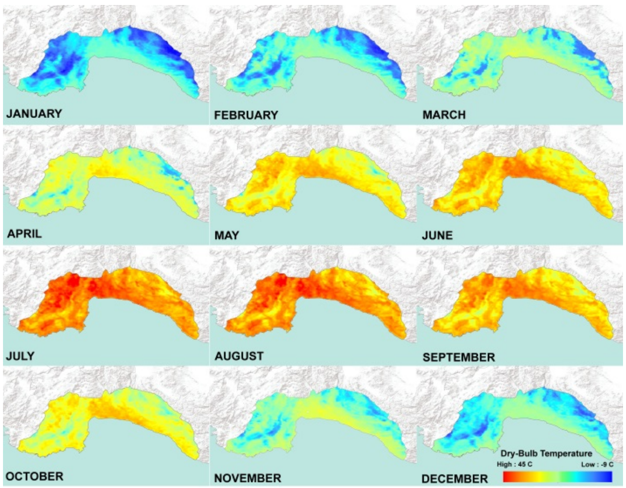

Figure 3. Monthly distribution of land surface temperature (dry-bulb temperature) values

Relative humidity data were obtained from 73 meteorological stations covering the study area (Figure 4).

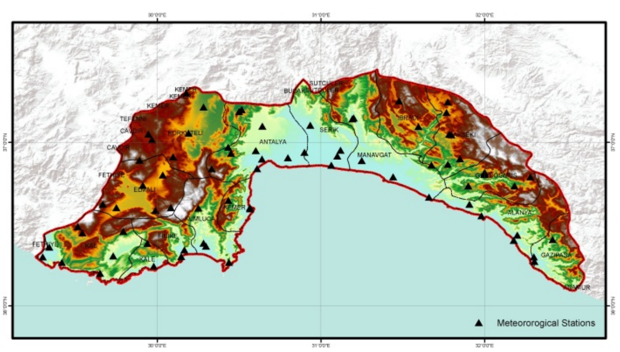

Figure 4. Distribution of meteorological stations

The relative humidity data obtained from these stations were extended to the surface at a local resolution of 1km to be the same as the MODIS satellite image by interpolation techniques. Antalya's average annual humidity is 65%. The most humid month of the year is January. The average humidity in this month is 91%. The driest month of the year is July. The average humidity in this month is 40% (Figure 5). Interpolation method is a method for estimating unknown surfaces according to a determined algorithm using known point data. ANUSPLIN software, which will be used in the interpolation method within the scope of this study, has proved to be suitable for processing various surfaces simultaneously, especially for climate data.

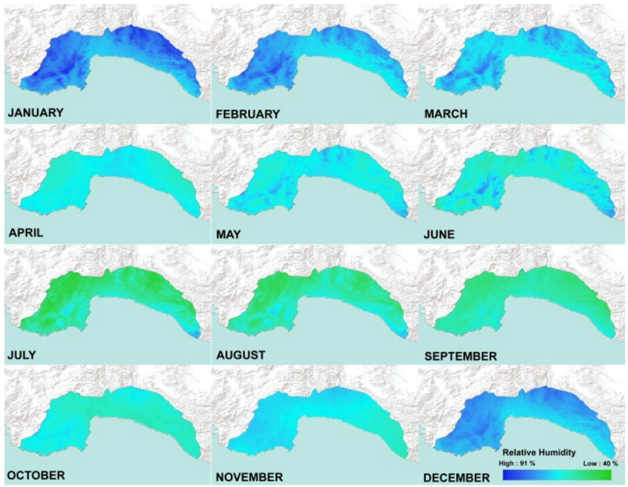

Figure 5. Monthly distribution of mean humidity values

The wet bulb temperature was calculated by using the humidity data obtained by interpolation method with the help of the Tw formula determined above. Antalya's average annual wet-bulb temperature is 26 ^{0}C. The most wet-bulb temperature month of the year is July. The average wet-bulb temperature in this month is 60 ^{0}C. The driest month of the year is January. The average wet-bulb temperature in this month is -21 ^{0}C (Figure 6).

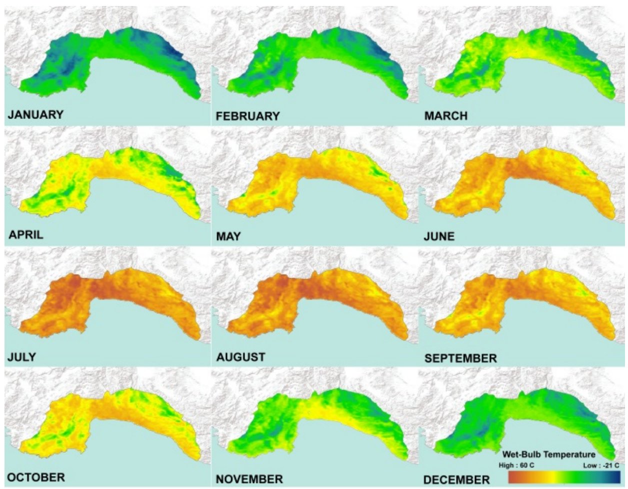

Figure 6. Monthly distribution of wet-bulb temperature values

In this context, a discomfort index was created based on the data obtained and classified according to Thom's discomfort index given in Table 1 and their spatial distributions were revealed.

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Discomfort Index (DI)	Heat Stress	Description
<22	Heat stress is not felt	A mild heat can be sensed by most people
22 - 24	Most people feel heat stress	Heat stress is moderate
24 - 28	Heat stress is moderate	People feel very hot within this range and difficulties may be found when physical work is performed
>28	Heat stress is severe	People who perform physical work are at high risk of heat-associated illness, such as heat exhaustion and heat stroke

Table 1. Classification of Thom's discomfort index (Song and Wu, 2017)

Detailed annual average values of the input data used in the calculation are presented in Figure 7 to facilitate a comprehensive analysis and to enable comparison of the average disturbance index across the year.

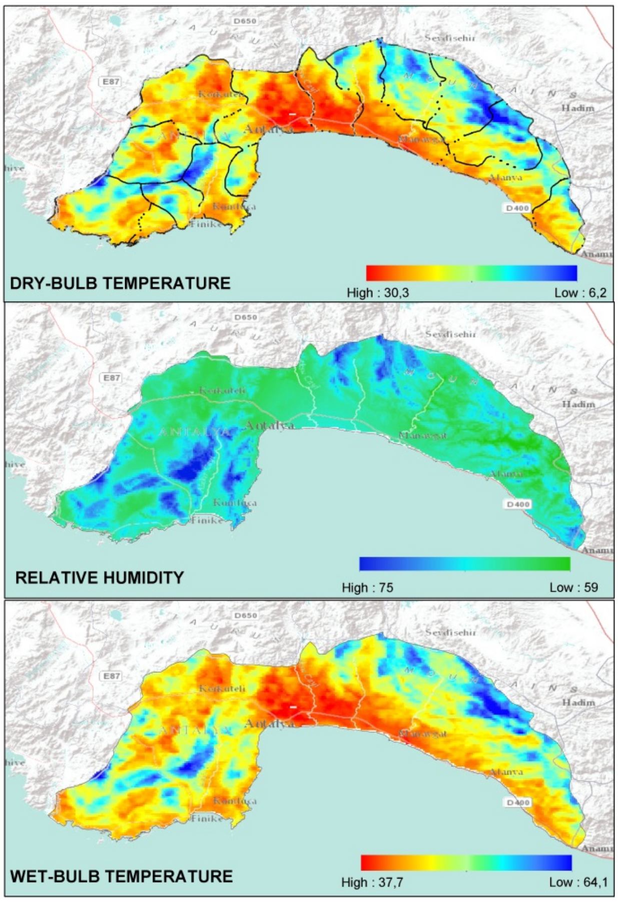

Figure 7. Annual discomfort index input data

4. RESULTS

Discomfort is an important issue for Antalya, one of the provinces with the highest temperatures in Turkey. The higher the discomfort index, the more difficult it is to live or travel in that place. According to study results, heat stress is observed between April and October when the maps, which are classified according to Thom's discomfort index and their spatial distributions are analysed monthly (Figure 8). Especially in areas where heat stress of 28 ^{0}C and above is felt, some difficulties can be seen in physical work. Antalya's discomfort index can be as high as 54 ^{0}C in summer and as low as 10 ^{0}C in winter.

This means the level of discomfort index in Antalya is high in summer and moderate in winter. This means that people living in Antalya need to take extra precautions to keep cool in summer and warm in winter. Especially in July, when discomfort index is high (heat stress is severe), people may have difficulty with physical work. They are also at high risk of heat-associated illnesses such as heat exhaustion and heat stroke.

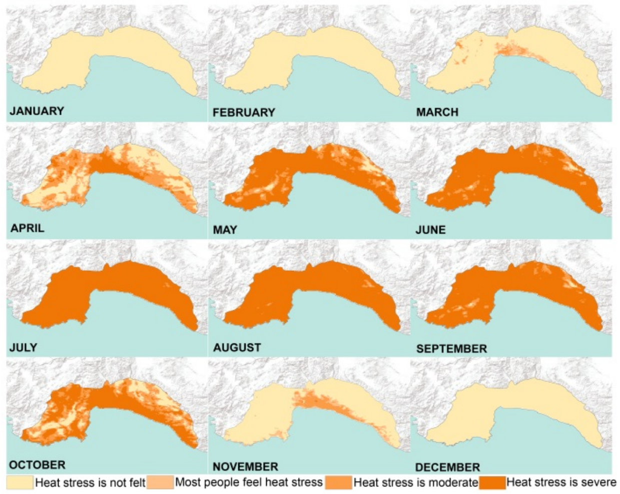

Figure 8. Monthly distribution of discomfort index

Antalya's discomfort index averages 24.9 ^{0}C throughout the year. This value is as high as 37 ^{0}C in the city center and as low as 4 ^{0}C in the mountainous areas (Figure 9). This indicates that Antalya is a moderately comfortable place. Therefore, people wishing to travel or live in Antalya should take into account the year-round discomfort index of the region. Antalya's status according to the discomfort index can also affect the tourism potential of the city. Antalya is one of the most popular tourist destinations in Turkey. Local and foreign tourists coming to Antalya, especially in the summer months, may feel uncomfortable due to the hot and humid weather and shorten their vacation.

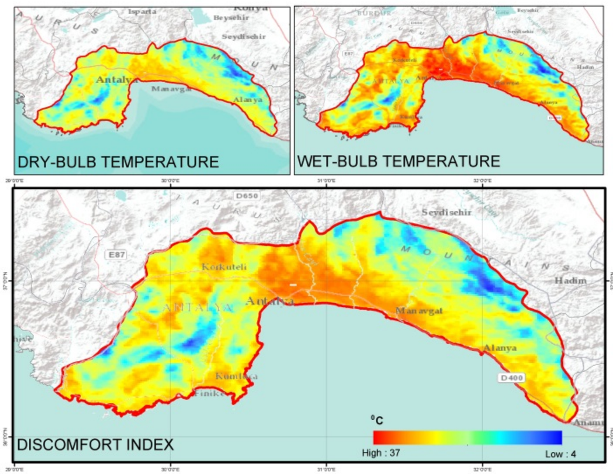

Figure 9. Annual average discomfort index values

When the spatial distribution of heat stress classified according to Thom's discomfort index classes is examined, it is seen more in urban center than in rural areas (Figure 10). The reason for this is factors such as construction, lack of green areas, vehicle traffic and industrial activities in the city center. These factors also create an urban heat island effect by increasing the air temperature and humidity in the city center. On the other hand, moderate and dangerous levels of heat stress in the coastal area will cause difficulties in the adaptation of local tourism infrastructure in Antalya.

Accommodation facilities, transportation services, and outdoor recreational amenities may need to invest in adaptive measures, such as improved cooling systems, shade provision, and alternative indoor activities, to mitigate the negative impact of heat stress on tourists' comfort and satisfaction.

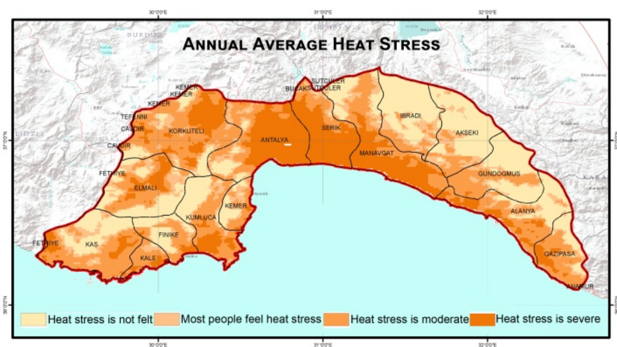

Figure 10. Annual average heat stress

When the heat stress situation in Antalya is analysed annually, heat stress is not felt in about 30% of the year, while heat stress is moderate in 33% of the year (Figure 11). Especially in the summer months, heat stress is felt severely in about 23% of Antalya, so people cannot regulate their body temperature and may experience health problems due to excessive heat.

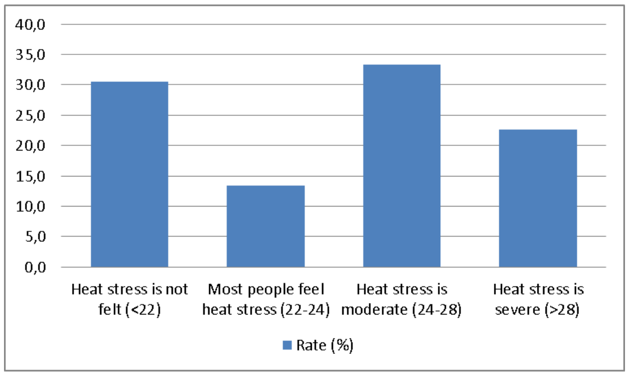

Figure 11. Annual distribution of heat stress

5. CONCLUSION

This research focuses on human heat stress from a continuous perspective and examines its impact on management response to heat waves. Thermal discomfort was mostly felt in the city center, which is characterized by built-up areas such as commercial, residential and industrial space. The spatial and temporal pattern of temperature is related to the discomfort index. In this context, in order to improve Antalya's situation according to the discomfort index, environmental measures such as sustainable planning, adaptation strategies, investments in resource management, increasing green areas in the city, making transportation and energy systems efficient, and insulating buildings should be taken. In this context, it is important to use the disturbance index more effectively in planning studies.

On the other hand, we are aware that the accuracy of the obtained DI is limited by the relatively complex data collection process and the accuracy of the LST, and due to limited resources, field measurements were not conducted to assess the reliability of the DI obtained by the method proposed in this study. Further research should be conducted in other areas at different scales to validate the results of this study.

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