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The Influence of Lake Tana Wind Breeze on the Thermal Comfort of Bahir Dar City: A Contribution to Urban Planning

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Abstract

In this study, the effect of Lake Tana wind breeze on the thermal comfort of Bahir Dar city was analyzed using four biomethrological thermal comfort indices such as Thom's Discomfort Index (DI), Relative Stain Index (RSI), Environmental Stress Index (ESI) and apparent environmental temperature (T_{app}). Data were collected by setting different metrological monitoring locations in the city canyons around Lake Tana to investigate how far the wind breeze went and affected the thermal comfort of the city inhabitants. The results showed that during the hottest seasons, the maximum mean wind speed, temperature, and RH were 2.53 m/s 32.6 °C and 55% respectively in the city. The maximum value of DI, RSI, ESI, and T_{app} were 27, 0.32, 28, and 27.9 °C respectively. It can be concluded that people living near the coastline felt slightly more comfortable than people living far from the coastline in the hot season. This was due to the dense construction around the Lake, which prevented the wind breeze to the city. This study showed that the urban planner could reconsider the current urban planning to maximize the wind breeze of Lake Tana to circulate cold air throughout the city for societal well-being and tourism attraction.

Keywords: *Thermal comfort, Lake tana wind breeze, Bahir dar city, Urban planning*

1. Introduction

Thermal comfort is the psychological state of mind that expresses the satisfaction of people with the thermal environments and is usually expressed in terms of weather in which someone is feeling too hot or too cold within the environment (Freiburg, 2014). The human thermal status is therefore balanced by thermal surroundings and metabolic processes in the human body (Szokolay and Auliciems, 2010). Climatic conditions became more significant after 1960 based on four main climatic parameters such as: (1) radiant (i.e., wall) temperature; (2) ambient air temperature; (3) air humidity; and (4) airstream velocity on the human thermal comfort (Shooshtarian, 2019). They enabled researchers to perform a wide range of studies to create indices for indoor thermal comfort conditions.

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Different reports indicated that urban design highly influenced the thermal comfort conditions of cities. For instance, Alcoforado *et al.* were studied the thermal comfort of Funchal (Madeira Island), Lisbon and they stated that sea breezes were an important wind system to ameliorate urban environment and thermal comfort conditions (Alcoforado *et al.*, 2009). In Lisbon, it was found that even if the breezes did not travel very far into the city, it had a significant effect in cooling the urban air near the riverbank, where the air temperature gradient was up to 4 °C as compared to the temperature in the city center (Eliasson, 2000). Outdoor studies have been investigated the relative influence of wind and temperature on inhabitant comfort, but these studies examined parameters of tolerance rather than measuring the degree of comfort and this has led to a call to measure users' comfort (Zacharias and Stathopoulos, 2001). Most people actively adapt to microclimatic conditions in outdoor environments than the indoor environment (Walton *et al.*, 2007). A detailed review of most of the thermal comfort and discomfort indices was reported by different researchers since 1905 (Papanastasiou and Melas, 2010). The influence of temperature on an individual thermal comfort depends on humans (metabolic rate, sex, age, tolerance, etc), environmental (air temperature wind, humidity, etc.), and other (e.g. clothing) factors (Papanastasiou and Melas, 2010).

Moreover, reports indicated that people adapt to the outdoor environment by adjusting their clothing styles, relocating themselves to place where there is more comfortable, limiting their exposure time, and assessing their conditions accurately (Johansson *et al.*, 2009). The Sun, temperature, and wind, can be distinctly evaluated to adjust the thermal conditions. It is found that maximum wind gust is the most important factor in predicting adaptively (Fang *et al.*, 2019). Vertical orientation and profile of the canyon in the urban has an impact on the thermal comfort and sensation of the human body (Ali-toudert and Mayer, 2007). The physical structure of the cities near the water body as well as the city center has a significant impact on the climate of the cities (Karakounos *et al.*, 2018). The outdoor thermal comfort and urban climate at the city street level are significantly influenced by urban forms. The connection between outdoor thermal comfort and urban design and in hot and humid climates should be understood for developing appropriate climate-oriented urban design guidelines (Johansson *et al.*, 2014).

Among the coastal city, Bahir Dar city is one of the most beautiful cities and is located in the Northwest region of Ethiopia. The city is located approximately 578 km north-northwest of Addis Ababa, having a latitude and longitude of 11°362 N 37°232 E and an elevation of about 1,800 m (5,906 feet) above sea level. Specifically, Bahir Dar city is found on the south of Lake Tana, (source of the Blue Nile). Bahir Dar city is the main city of Amhara regional state and one of the fast-developing cities in Ethiopia through tourism attractions (Asrese *et al.*, 2014). The living habitat in the city has shown an increasing trend for the last two decades. Bahir Dar is one of the leading tourist destinations in Ethiopia, with a variety of attractions in the nearby Lake Tana and Blue Nile River. The city is known for its wide avenues lined with palm trees and a variety of colorful flowers (Getahun, 2016). Bahir Dar city was awarded the Peace Cities Prize from UNESCO in 2002 for addressing the issues of rapid urbanization as well as for being rich in biodiversity in Lake Tana. Lake Tana, the source of the Blue Nile, is located in the northwestern part of Ethiopia and the largest Lake in Ethiopia with a surface area of 3156 km^2. Lake Tana has a huge impact in thermal confort, ecology, aesthetics, recreation, and different human interaction in Bahir Dar City.

Despite the beautifulness of Bahir Dar city, little attention is given to one of the attractive potential factors of the thermal comfort coming from the Lake Tana wind breeze system. Sea and lake wind breezes are important to the wind system to ameliorate the urban environment and thermal comfort conditions of cities in the coastal area (Krelling *et al.*, 2023). However, money huge apartments and dense constructions were built around Lake Tana, which prevented the Lake Tana wind breeze from entering the downtown. The city also has not enough canyons around the lake in which wind gust goes through it for the thermal comfort of the city center. Recently, the people of the city are feeling discomfort during the summertime, which may be due to the blockage of Lake Tana wind by the upcoming huge construction. Even though there are extensive studies about thermal comfort due to the coastal wind system throughout the world, there is limited information in the open literature about the effect of the Lake Tana wind breeze system on the thermal comfort of Bahir Dar City. Therefore, the objective of this study was to analyze the effect of the Lake Tana wind breeze system on the thermal comfort of Bahir Dar city during the hottest season and to show the impact of long buildings and dense constructions around Lake Tana on the thermal comfort of Bahir Dar city. This study also brought critical information for urban planners to take action for future planning of Bahir Dar city expansion.

2. Materials and Methods

2.1. Materials

Different instruments were used to monitor the environmental conditions of the city. The solar radiation was measured with a Pyranometer (Apogee; Model: SP-110) with a reading accuracy of ± 5 W/m^2. The hobo ware data logger (UX 100-011 Temp/RH, Onset HOBO Data Loggers) was used to record the temperature and relative humidity of the flowing air mass at different locations in the city. The velocities of ambient air were measured by velocity meter with the specification of (Model: TESTO-490, range 0-25 m s^{-1}). An accuracy of ± 0.5 m s^{-1} was taken in the velocity measurements.

2.2. Location of the Study Area and Data Measurement Procedures

An urban coastal site and an urban inland site were selected to analyze the effect of Lake Tana wind breeze on the thermal comfort of Bahir Dar city as shown in Figure 1. Measurements were taken at two monitoring sites (Figure 1). For each site, four places were taken at a distance of 500 m for the record of the solar, wind, air temperature, and relative humidity data. The first monitoring site was selected near the Lake Tana, West to East across the city and denoted as location one and it has four measurement places such as lakeshore hotel site (LS), mango recreation site (MR), *Gion* hotel recreation site (GH) and *Dipo* canyon site (DS). The second site was also selected far from the Lake Tana (inside the city, *beg tera* to *kidane mihiret* canyon) which was located 700 m from the coastline and it has four measurement places: Blue Nile hotel site (BS), *Wawi* hotel site (WS), Mulualem hotel site (MS) and *kidanemihiret* church site (KS) as shown in Figure 1. Data were recorded during the hottest season of the year from February to April in 2017. Measurements were taken three times per week and four times per day at 9 AM, 12 AM, 3 PM, and 5 PM for the three consecutive months. The locations were denoted as L1 for location one and L2 for location two. Moreover, the study months were denoted by M1, M2, and M3 for February, March, and April respectively. The mean values of the recorded data were taken for each month at the two locations.

Figure 1: Location of the Study Area and Data Collection Sites

2.3. Characterization of Thermal Comfort and Discomfort Conditions

To calculate the thermal comfort and discomfort conditions of Bahir Dar city, different types of human biometeorological indices were analyzed. To determine the thermal comfort and discomfort of Bahir Dar city, Thom's Discomfort Index (DI), Relative Stain Index (RSI), Environmental Stress Index (ESI), and apparent environmental temperature were analyzed in detail and thermal comfort assessments were carried out using critical criteria as shown in Table 1. These environmental variables were determined based on direct measurements of environmental conditions such as air temperature, solar radiation, wind speed, relative humidity, and vapor pressure in the city as follows:

2.3.1. Thom's Discomfort Index (DI)

It was used to determine the percentages of the population suffering from discomfort or not. Thom's DI analyzed the

Table 1: Effect of Human Health on the Applied Bio-Meteorological Indices (Papanastasiou and Melas, 2010)

Index Range	Effect on Human Health Class
DI<21	No discomfort
21≤DI<24	Less than 50% of the population feels discomfort
24≤DI<27	More than 50% of the population feels discomfort
27 ≤ DI < 29	Most of the population suffers discomfort
29 ≤ DI< 32	Everyone feels severe stress
32 ≤ DI	State of a medical emergency
RSI< 0.2	Comfortable satisfaction conditions (general satisfaction)
0.3< RSI <0.5	Discomfort conditions (feeling of unease)
0.6 <RSI <1	Distress conditions (physical strain)
1<RSI	Failure conditions (loss of physiological equilibrium)
ESI<21	Safe conditions
21<ESI<25	Warning conditions
25<ESI<28	Alert conditions
28<ESI <31	Severe alert conditions
31<ESI	Danger conditions

thermal comfort of the societies based on relative humidity and temperature using Equation (1) (Thom, 1959; Giles *et al.*, 1990; Ohashi *et al.*, 2009).

$$DI = T - 0.55(1 - 0.01RH)(T - 14.5) \quad ...(1)$$

where: T – Air Temperature (°C) and RH – Relative Humidity (%).

2.3.2. Relative Strain Index (RSI)

This was an index of feeling and statistics evaluating the response of individuals concerning a condition of heat stress and was used to assess the condition of heat stress due to the excess heat exchange between the human body and hot environment. It was determined using Equation (2) (De Garín and Bejarán, 2003; Moran *et al.*, 2003).

$$RSI = [10.7 + 0.74(T - 35)] / (44 - e) \quad ...(2)$$

where: T –Air Temperature (°C) and e- air vapor pressure (mm Hg) and given by Equation (3).

$$e = 0.254RH(0.00739T + 0.807)\hat{}\,8 \quad ...(3)$$

2.3.3. Environmental Stress Index (ESI)

This was an environmental stress index that was determined based on measurement of Solar Radiation (SR), Relative Humidity (RH), and air temperature (Ta) using Equation (4) (Ohashi *et al.*, 2009).

$$ESI = 0.63T - 0.03RH + 0.002SR + 0.0054(T * RH) - 0.073/(0.1 - SR) \quad ...(4)$$

where: T- Air temperature (°C), RH-Relative Humidity (%), and SR- Solar Radiation (W/m^2).

2.3.4. The Wind Chill Index (WCI)

It measured the effect of wind speed on the perception of temperature. In windy conditions, if the air is cool ($Ta < 25$ ºC) it feels cooler than it is (because of increased perspiration), but if the air is hot, the hot wind feels even hotter and WCI was determined using Equation (5) (Lamberts, 2015).

$$T_{WCI} = T_a - \sqrt{v}\,(25 - T_a)/15 \quad ...(5)$$

where: T_{WCI} and T_a in [ºC] and v in [m/s].

2.3.5. The Heat Index

It measured the effect of humidity on the perception of temperature. In humid conditions, the air feels hotter than it is, because of the reduction of perspiration, and the heat index was computed based on Equation (6).

$$T_{HI} = T_a + (RH - 50)\,(T_a - 10)/100 \quad ...(6)$$

2.3.6. Apparent Environmental Temperature

Apparent temperature was a wide-ranging term for the perceived outdoor temperature, caused by the combined effects of air temperature, radiative temperature, relative humidity, and wind speed. The combined effect of radiation, humidity, wind speed, and temperature, on the perception of temperature, was approximated using Equation (7) (Lamberts, 2015).

$$T_{App} = T_a + {q_{rad}}/{50} + {(RH - 50)(T_a - 10)}/{100} - {\sqrt{v(25 - T_a)}}/{15} \quad ...(7)$$

where the air temperatures and apparent, T_a, and T_{app} are in [ºC], the net radiation, q_{rad}, is in [W/m^2], wind speed, v, is in [m/s] and RH is in [%].

Hence, the apparent environmental temperature incorporated the effect of heat and wind chill indexes.

3. Results and Discussion

3.1. Lake Tana Wind Breeze Development

Lake Tana wind breeze is a phenomenon that develops frequently on the north coast of Bahir Dar city, especially during the summer season of the year. The daytime Lake Tana mean wind breeze speed trend in the hottest season is presented in Figure 2.

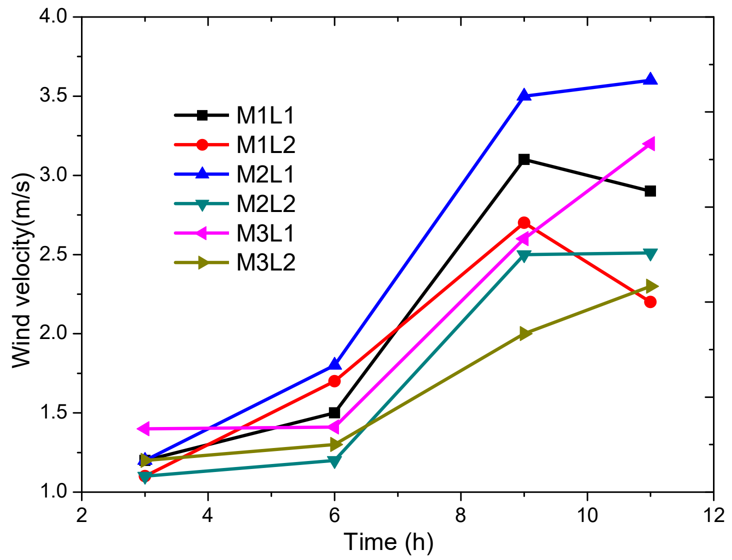

Figure 2: The Hottest Season Lake Tana Mean Wind Breezes

Note: Where M1-February, M2-March, M3- April, L1-location one, L2-location two.

The mean duration of Lake Tana wind breeze development in the hottest season was approximately 11 h, and it usually started at 9 AM and declined to cease at 5 PM. The fastest wind speeds were observed from 6 h up to 9 h for the three months. The maximum mean wind speed was observed in March at location one (M_2L_1, 2.53 m/s). On the contrary, the minimum mean wind speed was observed in April at location two (M_3L_2, 1.7 m/s). The canyon orientation is an important factor in many aspects of solar radiation, air temperature, and wind speed distribution. Bahir Dar city had a high building and dense construction near the shoreline and there were not enough canyons in the city. As a result of the absence of these canyons, the wind breeze was prevented to go far away from the lake and most parts of the city were located far away from the coastline, which was slightly hotter than the city near the Lake.

3.1.1. Temperature and Relative Humidity

The variation of mean temperature and relative humidity of Bahir Dar city at locations one and two in February, March, and April in 2017 are presented in Figure 3.

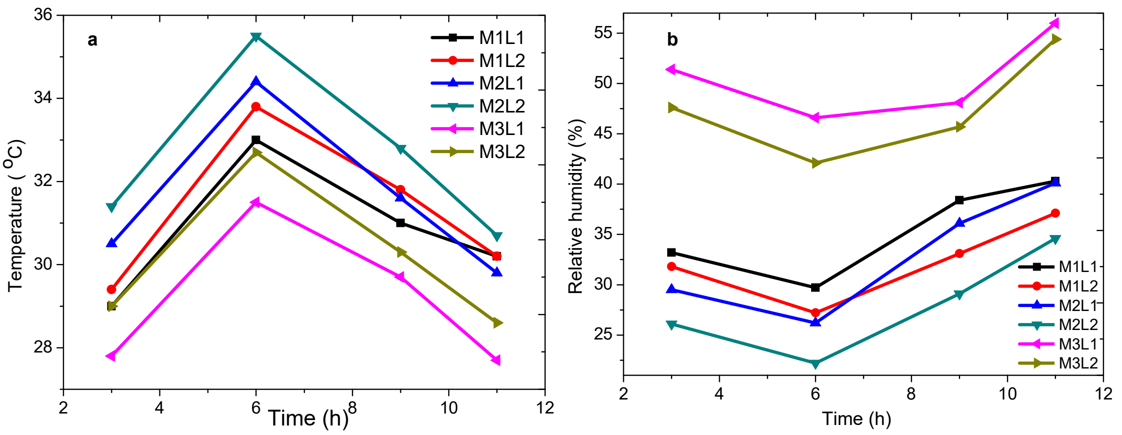

Figure 3: The Hottest Season Daily Mean Temperature (a) Relative Humidity; (b) Distribution

Note: Where M1-February, M2-March, M3- April, L1-location one, L2-location two.

The maximum and the minimum temperatures were observed in March at location two (far from the coastline, M_2L_2) and April at location one (near the coastline, M_3L_1) respectively. For those months, the mean temperatures were 32.6 °C for March and 29.2 °C for April. Moreover, for each month, location one (near the coastline) had a relatively low temperature than location two (city center). This was due to the advection of cool Lake Tana air over the land due to the lake breeze circulation that developed near the shoreline (location one), which affected the temperature levels enormously as it prevented the temperature rise, resulting in cooler temperatures near the coastline. On the contrary, location two was found far from the coastline, inside the city, and the Lake Tana wind breeze was restricted to reach the place due to dense construction. It was also noticeable that the weakening of the Lake Tana wind breeze coincided with an increment of temperature as compared to location one. Starting from the morning, the temperature gradually increased and reached a maximum at mid-day and then declined as the wind speed increased. In contrast, relative humidity followed the opposite trends of the temperature. Reports indicated that a temperature of 32 °C was the threshold above which impacts on mortality can already be observed (Nogueira and Paix, 2007). The thermal comfort temperature rises above 18 °C in summer conditions can become too warm for human comfort in Ireland and a temperature of 25 °C with a wind speed of 1 m s^{-1} and an average midday intensity of direct and diffuse radiation were regarded as unacceptably hot (Lai *et al.*, 2019). This study was also in agreement with these studies concerning the maximum temperature. However, the establishment of even a weak Lake Tana wind breeze circulation maintained the ambient temperature at relatively low levels during most of the hotter hours of the day.

3.2. Assessment of Comfort and Discomfort Conditions of Bahir Dar City

3.2.1. Heat Stress

Four biometeorological indices (DI, RSI, ESI, and T_{app}) were analyzed to assess the impact of Lake Tana wind breeze development on people's heat stress, and the results are shown as follows.

3.2.1.1. Thom's Discomfort Index (DI)

The hottest three months mean variations of DI are presented in Figure 4. It can be observed that the discomfort index gradually increased starting from 3 h, reached a maximum of 6 hours, and then declined after midday for the hottest months of February, March, and April. Among the three months, April had a maximum value of DI, especially at midday far away from the coastline, which was at a temperature index of 27. On the contrary, February had a minimum value of DI (mean 24.7) as compared to the other months near the coastline. The values of DI's in March were in between them for both locations.

Near the coastline (location one, L_1), the value of mean DI in February, March, and April were in the range 24.6-25.3 which were still above the lower limit. These were the reason that even though a Lake Tana wind circulation was established near the coastline, the cool air that was advected over the land was rich in moisture, so relative humidity increased near the shoreline. This showed that more than 50% of the inhabitant feel discomfort as indicated in Table 1. As DI is a function of relative humidity and temperature, the weakening in apparent temperature initiated by the temperature reduction was balanced by an increase in apparent temperature, which was induced by the rise in relative humidity revealing that some societies felt discomfort. This fact revealed that the effect of relative humidity on DI was more pronounced than the effect of temperature on the coastline of Lake Tana.

However, far from the coastline (Location two, L_2), the value of DI was higher as compared to location one (Near the shoreline, L_1). This was due to the existence of dense constructions and the limited canyon that prevented the Lake Tana wind breeze advection towards the city center. The monthly mean values of DI in February, March, and April were 24.9, 25.45, and 25.73 respectively. The values were significantly increased at midday of the hottest months and then declined in the late afternoon. To the extreme, it was raised to 27, especially in April, in which most of the people suffer from discomfort in that location. Consequently, it can be concluded that location two (far away coastline, L_2) showed a greater discomfort as compared to location one (coastline, L_1), which indicates that the effect of temperature on DI was

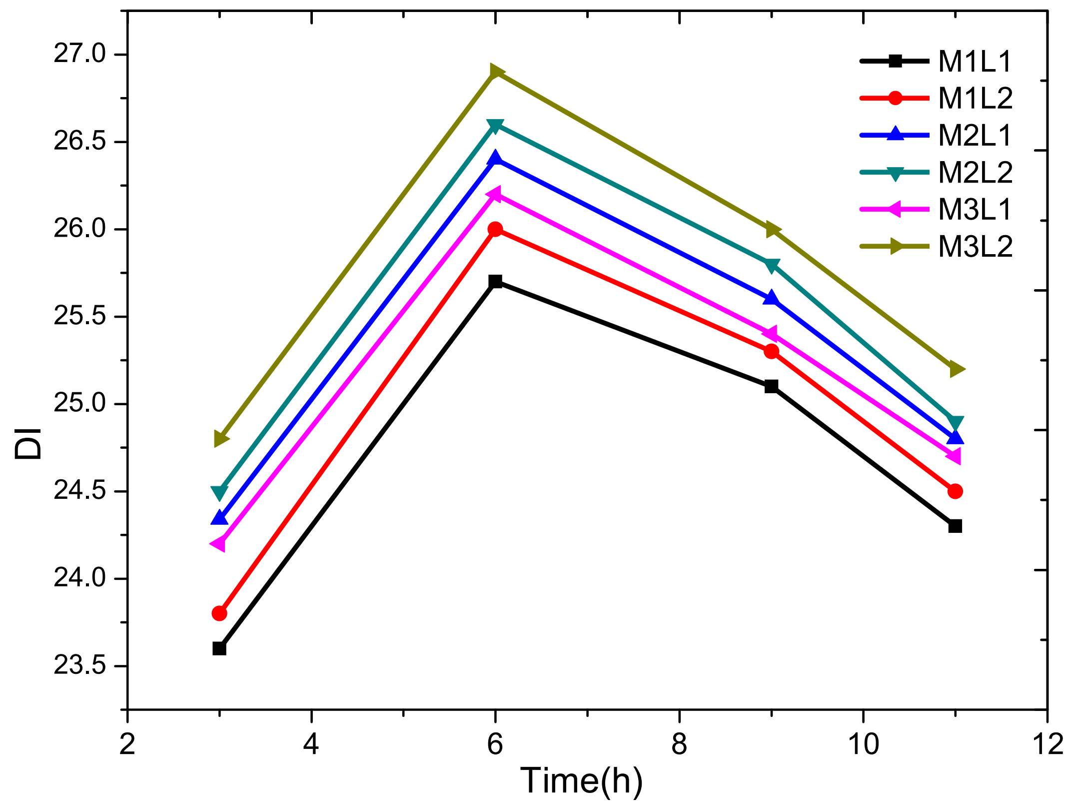

Figure 4: The Hottest Season Mean DI Variations

Note: Where M1-February, M2-March, M3- April, L1-location one, L2-location two.

more pronounced than the effect of relative humidity at the city center, which was located far away from the coastline. This indicated that more than 50% of the population feel discomfort (Table 1).

3.2.1.2. Relative Strain Index (RSI)

The hottest three months mean variations of RSI are presented in Figure 5. It was observed that at location one (near the coastline, L_1), the monthly mean values of RSI in February, March, and April were 0.22, 0.24, and 0.23 respectively.

Whereas, at location two, the monthly mean values of RSI in February, March, and April were 0.24, 0.26, and 0.25 respectively, which showed that location one (near the coastline) was slightly more comfortable than location two (far away from the coastline). Comparatively, March had higher RSI values in location two than the other months. On the contrary, April had a lower value of RSI in location one. According to the calculated RSI values, it can be concluded that there was no significant distress conditions were prevailing at the two locations, as the RSI value remained below 0.5 (Table 1) for all the hottest three months.

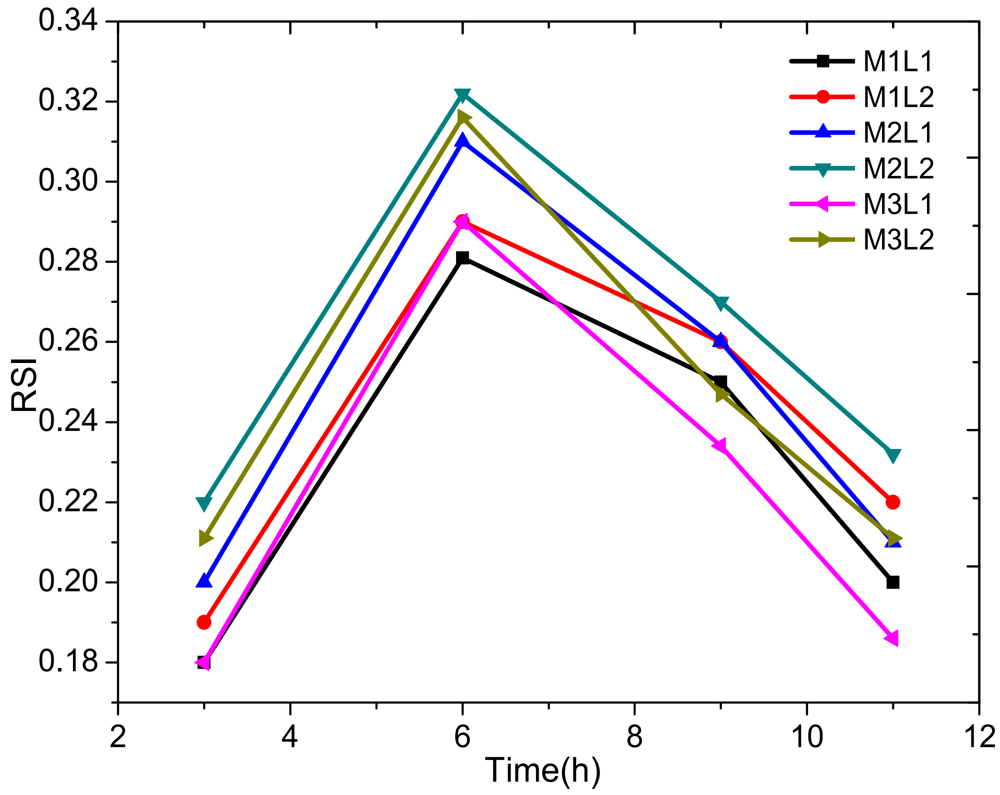

Figure 5: The Hottest Season Mean RSI Variations

Note: Where M1-February, M2-March, M3- April, L1-location one, L2-location two.

3.2.1.3. Environmental Stress Index (ESI)

The ESI values were measured from February to April and presented in Figure 6. The monthly mean values of ESI in February, March, and April were 23.5, 25.5, and 25.47 respectively at location one with warning thermal comfort. At location two, it was tabulated as 24.9, 25.7, and 26 for February, March, and April respectively. The lowest values of ESI were recorded in February at location one and the highest values were calculated in April at location two.

At midday in March and April, the ESI values were recorded as high as 27 and 28 at location two, which indicated that there might be an alarming condition for the thermal comfort of the societies. Even though the two locations were shown warning conditions in terms of thermal comfort regarding ESI values, location one was better than location two. This indicated that Lake Tana's wind breeze development could not trigger a significant reduction in thermal stress in location two (far away coastline) due to dense construction that prevents the speed of Lake Tana cooled air, but it indicated an alarming signal to take measures for urban planners of the city.

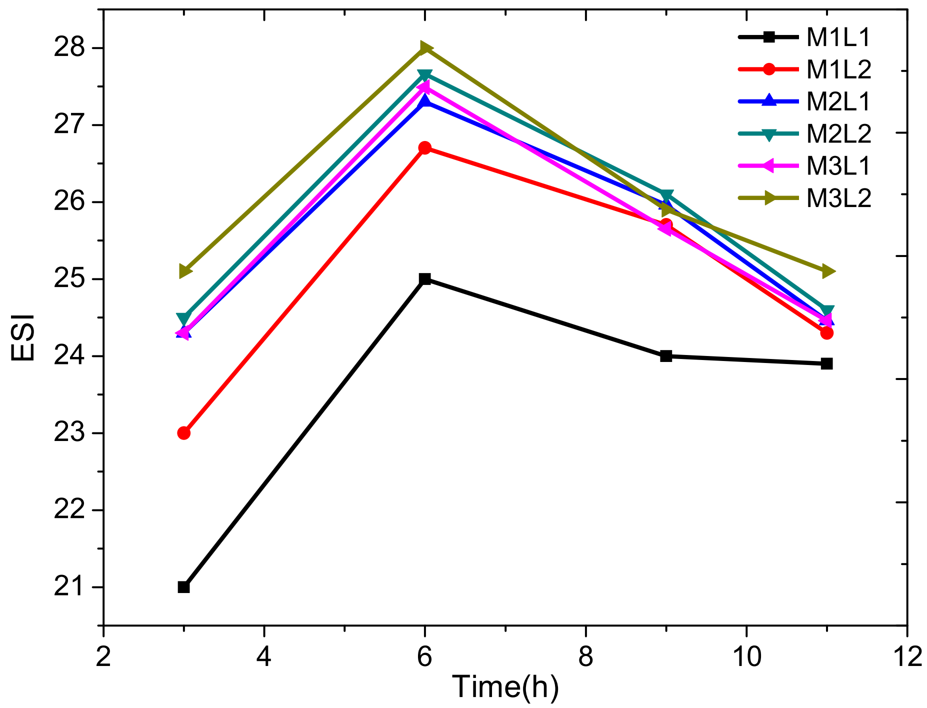

Figure 6: The Hottest Season Mean ESI Variations

Note: Where M1-February, M2-March, M3- April, L1-location one, L2-location two.

3.2.1.4. Apparent Temperature (T_{app})

The apparent temperatures in the hottest three months at the two locations are presented in Figure 7.

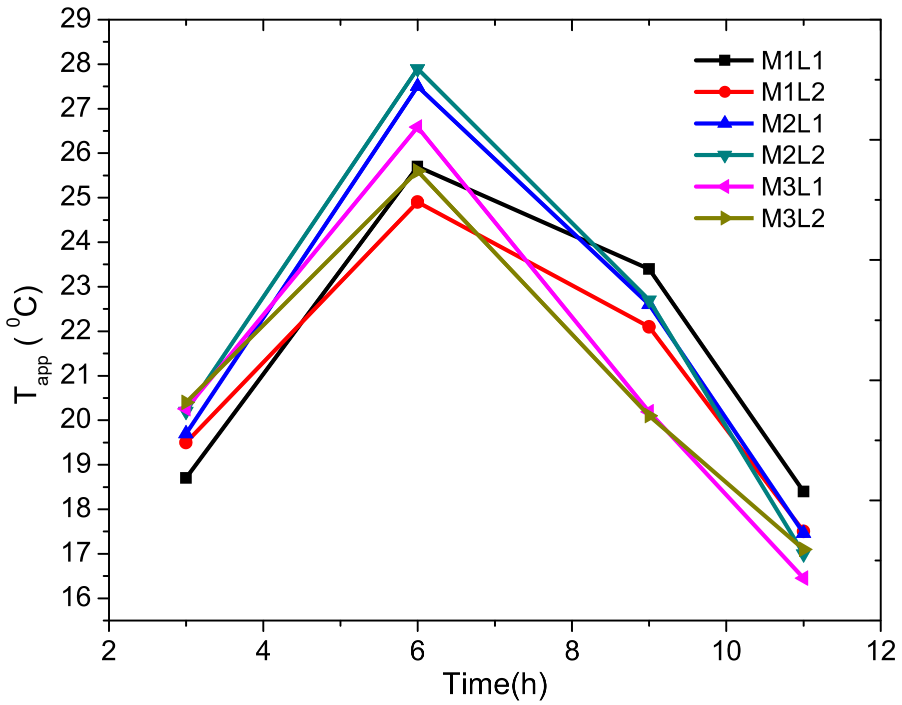

Figure 7: The Hottest Season Mean Apparent Temperature Variations

Note: Where M1-February, M2-March, M3- April, L1-location one, L2-location two.

As can be seen from this figure, the highest apparent temperatures were observed at midday. In contrast, in the morning and late afternoon, the apparent temperatures were recorded at a lower level at the two locations. Moreover, March had the highest apparent temperature in the midday at both locations as compared to the other months. In terms of magnitude, the highest apparent temperature was 27.9 °C at midday in March at location two whereas the lowest apparent temperature was 16.5 °C in the late afternoon in April at location one. Consequently, as the wind speed increased, the apparent temperature decreased which showed that there was a better thermal comfort in that location.

4. Conclusion

The influence of the Lake Tana wind breeze on the thermal comfort of Bahir Dar city has been studied. The effect of solar radiation, temperature, humidity caused by the Lake Tana wind breeze on the human comfort levels in Bahir Dar city during the hottest seasons has been analyzed. The assessment was based on collected data from the coastal city (Location one, near the coastline) and inland city (Location two, far away coastline) monitoring stations. The thermal comfort was determined using four biometeorological indices such as DI, RSI, ESI, and $T_{app,}$ which are directly determined from data collected in different monitoring sites within the city.

The result showed that Lake Tana wind breeze development mean duration in the hottest season was approximately 11 h. The highest mean wind speed was observed in March at location one. On the contrary, the lowest mean wind speed was observed in April at location two. The maximum and the minimum mean temperature variations were 32.6 °C for March and 29.2 °C for April. For each month, location one (near the shoreline) has a relatively minimum temperature than location two (city center). The assessment of four biometeorological indices (DI, RSI, ESI, and T_{app}) showed that during the hottest season, people living near the coastline felt more comfortable than those living in the city center did.

Finally, it could be concluded that Lake Tana's wind breeze development did not trigger a significant reduction in thermal stress in location two (far away coastline) due to a high building and dense construction that prevent the speed of cooled Lake Tana air mass. but it was found in the alarming stage in thermal comfort. Hence, the regional government should reconsider these high buildings and dense constructions near the coastline in urban planning. These high buildings prevent the movement of Lake Tana's cooled air into the central city, which reduces the attraction of tourists and increases the discomfort of the inhabitant of the city.

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Conflicts of Interests

The authors declare that there have no known competing interests that could have appeared to influence the work reported in this study.

References

Ali-toudert, F. and Mayer, H. (2007). *Effects of Asymmetry, Galleries, Overhanging Facades and Vegetation on Thermal Comfort in Urban Street Canyons*. 81, 742-754. doi: 10.1016/j.solener.2006.10.007.

Alcoforado, M., Andrade, H., Lopes, A. and Vasconcelos, J. (2009). *Landscape and Urban Planning Application of Climatic Guidelines to Urban Planning The Example of Lisbon (Portugal),* 90, 56-65. doi: 10.1016/j.landurbplan.2008.10.006.

Asrese, K., Tilahun, T. and Mekonnen, A. (2014). Demographic and Socioeconomic Determinants of Women Begging in Bahir Dar, Ethiopia, 2007, 2(3), 75-80. doi: 10.11648/j.hss.20140203.14.

De Garín A. and Bejarán, R. (2003). Mortality Rate And Relative Strain Index in Buenos Aires City. *Int. J. Biometeorol.* doi: 10.1007/s00484-003-0175-1.

Eliasson, I. (2000). The Use of Climate Knowledge in Urban Planning. *Landsc. Urban Plan.* doi: 10.1016/S0169-2046(00)00034-7.

Fang, G., Zhao, L., Cao, S., Ge, Y. and Li, K. (2019). *Journal of Wind Engineering & Industrial Aerodynamics Gust Characteristics of Near-Ground Typhoon Winds,* 188(July), 323-337. doi: 10.1016/j.jweia.2019.03.008.

Freiburg, D.A.U. (2014).*Berichte des Meteorologischen Instituts,* Helmut Mayer (ed.) Celebrating the 50 Years of the Meteorological Institute, Albert-Ludwigs-University of Freiburg, Germany, January 2008.

Getahun, B.T. (2016). *Historical Survey of Tourism Industry in Ethiopia and its Potential for Economic Development: The Case of Lake Tana Region,* December.

Giles, B.D., Balafoutis, C. and Maheras, P. (1990). *Too Hot for Comfort: The Heatwaves in Greece in 1987 and 1988*, 74, 98-99.

Johansson, E., Ouahrani, D., Shaker Al-Asir, H., Awadallah, T., Blomsterberg, Å., Håkansson, H., Hellström, B. and Kvist, H. (2009). Climate Conscious Architecture and Urban Design in Jordan - Towards Energy Efficient Buildings and Improved Urban Microclimate. (Report; Vol. 12). Housing Development & Management, Lund University.

Johansson, E., Thorsson, S., Emmanuel, R. and Krüger, E. (2014). Urban Climate Instruments and Methods in Outdoor Thermal Comfort Studies – The Need for Standardization. *URBAN Clim.* doi: 10.1016/j.uclim.2013.12.002.

Karakounos, I., Dimoudi, A. and Zoras, S. (2018). The Influence of Bioclimatic Urban Redevelopment on Outdoor Thermal Comfort. *Energy Build.*, 158, 1266-1274. doi: 10.1016/j.enbuild.2017.11.035.

Krelling, A.F., Eli, L.G., Olinger, M.S., Machado, R.M.E.S., Melo, A.P. and Lamberts, R. (2023). A thermal performance standard for residential buildings in warm climates: Lessons learned in Brazil. *Energy Build*. https://doi.org/10.1016/j.enbuild.2022.112770

Lai, D., Liu, W., Gan, T., Liu, K. and Chen, Q. (2019). Science of the Total Environment A Review of Mitigating Strategies to Improve the Thermal Environment and Thermal Comfort in Urban Outdoor Spaces. *Sci. Total Environ.*, 661, 337-353. doi: 10.1016/j.scitotenv.2019.01.062.

Moran, D.S., Pandolf, K.B., Shapiro, Y., Laor, A., Heled, Y. and Gonzalez, R.R. (2003). Evaluation of the Environmental Stress Index for Physiological Variables, 28, 43-49.

Nogueira P. and Paix, E. (2008). *Models for Mortality Associated With Heatwaves/ : Update of the Portuguese Heat Health Warning System*, 562(2007), 545-562. doi: 10.1002/joc.

Ohashi, Y., Kawabe, T., Shigeta, Y. and Hirano, Y. (2009). *Evaluation of Urban Thermal Environments in Commercial and Residential Spaces in Okayama City, Japan, Using the Wet-bulb Globe Temperature Index,* 279-289. doi: 10.1007/s00704-008-0006-8.

Ohashi, Y., Kawabe, T. Shigeta, Y., Hirano, Y., Kusaka, H., Fudeyasu, H. and Fukao, K. (2009). Evaluation of Urban Thermal Environments in Commercial and Residential Spaces in Okayama City, Japan, Using the Wet-Bulb Globe Temperature Index. *Theor. Appl. Climatol*. doi: https://doi.org/10.1007/s00704-008-0006-8

Papanastasiou, D.K. and Melas, D. (2010). Temperature, Comfort and Pollution Levels During Heat Waves and the Role of Sea Breeze, July, 307-317. doi: 10.1007/s00484-009-0281-9.

Shooshtarian, S. (2019). Theoretical Dimension of Outdoor Thermal Comfort Research. *Sustain. Cities Soc.*, 101495. doi: 10.1016/j.scs.2019.101495.

Szokolay, S.V. and Auliciems, A. (2010). PLEA Note 3: Thermal Comfort, *Int. J. Biometeorol.*

Thom, E.C. (1959). The Discomfort Index. *Weatherwise*. doi: 10.1080/00431672.1959.9926960.

Walton, D., Dravitzki, V. and Donn, M. (2007). *The Relative Influence of Wind, Sunlight and Temperature on User Comfort in Urban Outdoor Spaces,* 42, 3166-3175. doi: 10.1016/j.buildenv.2006.08.004.

Zacharias, J. and Stathopoulos, T. (2001). Microclimate and Downtown Open Space Activity Downtown Open Space Activity, March. doi: 10.1177/0013916501332008.

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