HEAT-RELATED PUBLIC HEALTH IMPACTS BASED ON THE WBGT INDEX IN COLOMBO, SRI LANKA

Srimalee Nanayakkara[1] and Lalith Chandrasiri[2]

[1] Institute of Eco-environmental Sciences, University of Chinese Academy of Sciences (UCAS), Chaina
[2] Department of Anesthesiology, Teaching Hospital Rathnapura, Sri Lanka

srimaleenw@gmail.com

ABSTRACT: *Human health, energy and comfort are determined by climate remained in the physical environment. All living beings are sensitive to the environment in physical and psychological terms. Climate change, urbanization, and an aging population create a perfect storm of risks to global health, particularly from the urban heat. Heat exhaustion, heat pyrexia, heat syncope, and heat cramps were found to be the most common effects of heat stress. Colombo is selected as the study area of the research and it is the commercial capital and largest city of Sri Lanka by population with the process of urbanization. This study tried to analyze heat stress and public health effects in Colombo, based on the secondary data (Temperature and Relative Humidity (RH%)) acquired from the Department of Meteorology in Colombo from 2008 to 2018. Then calculated the Wet-Bulb Globe Temperature (WBGT) index which has been introduced by the Australian Bureau of Meteorology (ABM) to examine heat waves and their impacts on public health. That requires only water vapour pressure (ρ), air temperature (Ta), and RH% as input. Throughout the year Colombo has not come under the "Comfortable" category (WBGT: ≤ 27.7) of the thermal sensation. Because the whole year's temperature is not below 27°C and RH% also fluctuates between 75% and 84%. As a result of that, for the whole year, the WBGT index value is 30.0 ≤. Therefore, throughout the year "Heat cramps and heat exhaustion are possible". Especially in the period of the First Inter Monsoon (FIM) and Second Inter Monsoon (SWM), the city belongs to the "Very severe stress" (WBGT: ≥32.2) category with "Heatstroke highly likely". When concluding the all facts, Colombo is a stressful city with several possible heat hazards. It is imperative to assess these risks and respond effectively.*

Keywords: Heat Stress, Public Health, Human Comfort, Urban Heat, WBGT

1. INTRODUCTION

Human behavior and the environment have always been closely related going back to the ancient time of the earth. The climate is one of the physical factors that significantly impact how people think, behave, and engage in their other activities (Howard, 1995). Significant, protracted changes in the world's climate are referred to as climate change. That Condition directly affects the increase of the global warming process. It is anticipated to have an impact on human health adversely, by raising the number of excess deaths and hospital admissions globally (Yanjun et al., 2019). Climate change, urbanization, and population aging combine to create a perfect disaster of global health risks (Milica and Jelena, 2020). Today Sri Lanka also faced a highly stressful situation in heat stress. The trend of mean annual temperatures has been increasing in all meteorological stations in Sri Lanka. Out of 15 stations, 13 displayed statistically significant ($P<0.0001$) increasing trends (Meegahakotuwa,

2018). Not only that the temperature is rising while the amount of rain and humidity are decreasing. During the previous few decades, annual mean, maximum, and minimum air temperatures have all increased significantly (Rekha. 2003). Not only that, there have been a large number of admissions because of heat stroke, heat rash (skin), and dehydration (Sathyamoorthy, 2016).

This study mainly focused on heat stress and public health in the Colombo Metropolitan area in Sri Lanka. The commercial capital and most populous city in Sri Lanka is Colombo. Moreover, it functions as both the district capital of the Colombo District and the administrative capital of the Western Province. As a result, the city is busy with a variety of business ventures, trading, and construction projects. (Manjula et al., 2021). Colombo port has a long history in South Asia and is one of the most well-known due to its strategic location in the Indian Ocean. Owing to the fast rate of urbanization, the amount of vegetation is gradually decreasing and being replaced by structures like buildings, roads, parking lots, pavements, and other things. In addition, the town's high car density contributes to waste heat and polluting gas emissions. Therefore, Colombo is the island's most polluted city, according to earlier studies (Senanayake, 2013). As a result of these factors, there is a significant potential for the formation of UHIs within the urban core of Colombo (Shen, 2008). Emmanuel (2004) primarily focused on the Thermal Heat Index (THI) in Colombo city and found that THI has steadily grown both during the day and at night in the city center.

The rapid growth of population and expansion of urban areas toward the suburban and rural sides address the number of risk cases that are directly and indirectly combined with urban heat island effects and human health. Although different climatic classifications and research can be seen to identify the various climatic patterns in the city, attempts of measuring heat stress by combining heat-related health illnesses are rare and limited to a certain framework. It seems to be a big shortcoming in the meteorological and urban analysis in the country. The main objective of this research is to analyze heat-related public health impacts based on the WBGT index in the Colombo Metropolitan area in Sri Lanka. This indicator is useful for measuring how the human body feels under heat stress when the atmospheric Relative Humidity (RH) and Air Temperature (AT) are combined. Identifying the population at risk is crucial to planning and implementing relevant public health intervention programs. At the same time, this research would be very useful for future studies, and it will also be helpful for planning and making policies for developing Colombo as a comfortable city.

2. METHODOLOGY

Colombo Metropolitan Area (CMA) in Sri Lanka has been selected as the study area of the research (Fig. 1). The climate of Colombo could be categorized as tropical because the island is located in the tropics between 5° 55' and 9° 51' North latitude and between 79° 42' and 81° 53' East longitude. The city experiences warm, humid weather without any discernible seasonal changes in temperature and humidity (Senanayake et al., 2013). Due to contemporary urban planning and development

initiatives, the city has significantly increased its urbanization level in the South Asian region. The Colombo Metropolitan Area is the only city in South Asia that has experienced rapid urban growth and rapid changes in surface cover during the past twenty years (Subasinghe, 2016). These significant changes to the urban environment directly impact urban heat island risk and heat-related health issues. Due to the city's poor planning, buildings with huge footprints and roofs made of low-albedo materials like asbestos or concrete are one of the leading causes of the UHI effect in the city (Manjula, 2021). By considering all these issues, this research tried to analyze the heat stress and public health issues in CMA in Sri Lanka monthly and seasonally.

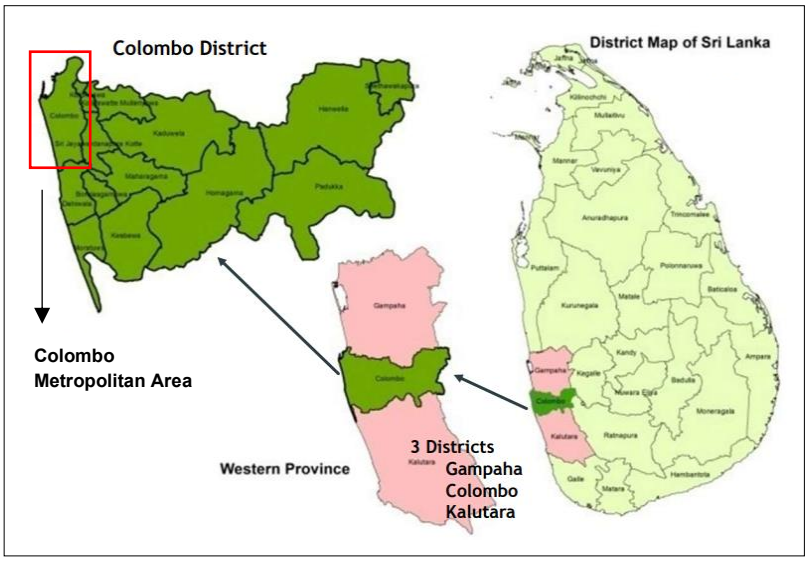

Figure 1. Study Area of the Research

Heat-related illnesses based on the WBGT index

In this study, one of the main objectives is to examine heat waves and their impacts on public health by using Wet Bulb Globe Temperature (WBGT) index from 2008 to 2018. The Australian Bureau of Meteorology (ABM) has developed a standard formula that only needs two inputs to calculate the WBGT index: water vapour pressure (ρ) and air temperature (Ta) (Equation 01). The website (http://www.bom.gov.au) gives a standard physical science formula to calculate ρ from RH and Ta. Whole the analysis was based on secondary data sources, collected from the Meteorology Department in Colombo, Sri Lanka. Using the WBGT index values, thermal sensitivity and heat-related health effects in people have been categorized from "Comfortable" to "Very severe stress" levels (Md Motakabber, 2018). The classification was used to identify the population at risk both monthly and seasonally in the city of Colombo.

Equation 1: Calculate the WBGT index
Source: (Bruno, 2012)

$$WBGT\ (°C) = 0.567\,Ta + 0.393\,\rho + 3.94$$

$$\rho\ (hPa) = RH/100 \times 6.105 exp(17.27Ta/\ (237.7 + Ta))$$

Where;

Ta *– air temperature*

ρ *– water vapour pressure*

RH *– Relative Humidity*

The United States Navy created the WBGT index in its initial version. It was created as a screening tool for evaluating heat stress in the workplace, in the military, during sports, and during occupational activities. The International Organization for Standardization (ISO) certification has suggested the index. In consideration of this, WBGT can be regarded as a user-friendly and trustworthy indicator of heat stress and an evaluation of its effects on health. For statistical analysis, the Mann Kendall test and SPSS software were used.

Table 1: Heat exposure and associated health effects by WBGT Index

WBGT	Thermal sensation	Health Effects
≤27.7	Comfortable	---
27.8-29.4	Partial discomfort	Fatigue
29.5-31.0	Discomfort	Heat cramps and heat exhaustion are possible
31.1-32.1	Severe stress	Heat cramps or heat exhaustion likely and heatstroke possible
≥32.2	Very severe stress	Heatstroke highly likely

Source: (Md Motakabber, 2018)

3. DISCUSSION AND RESULTS

The comfort of the human body is simultaneously being negatively impacted by rising temperatures and humidity levels. Hence, it is evident that temperature, humidity, and human bodily comfort are interrelated. In order to relationship can be identified between the thermal sense and the heat related diseases on the populace, based on the WBGT index. From January to December, the Minimum and Maximum temperatures of Colombo city is flowing as an equal line (Fig. 2). Throughout the year, the mean temperature of Colombo has varied from 27°C to 28°C (Table 2). Therefore the whole year, hot and humid climatic conditions can be observed in the atmosphere. It leads to making stressful conditions inside the city.

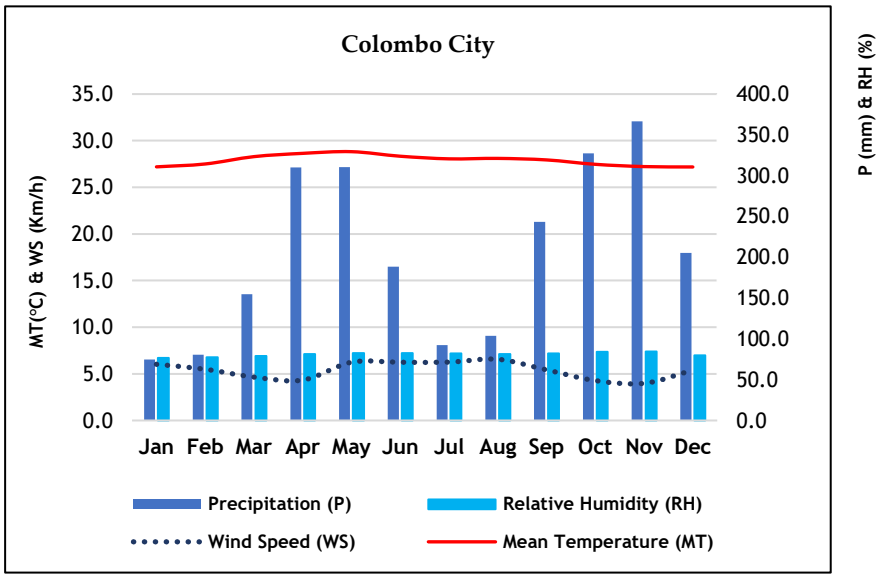

Figure 2. Fluctuation of Climatic variability in Colombo city

Table 2. Summary Statistic of Average Temperature (°C) and RH (%) in Colombo (2008-

Mon	Minimum		Maximum		Mean		Std. deviation		*p*-value		Sen's slope	
	T	RH	T	RH	T	RH	T	RH	T	RH	T	RH
Jan	26.6	72.5	28.3	79.5	27.2	75.3	0.4	2.0	0.39	0.52	0.05	-0.18
Feb	25.7	73.0	28.7	80.0	27.4	76.8	0.8	2.1	0.43	0.26	0.05	-0.25
Mar	27.4	77.5	29.5	82.5	28.3	79.2	0.5	1.5	0.23	0.47	0.08	-0.16
Apr	27.5	77.5	29.9	84.0	28.6	81.5	0.7	2.1	0.13	0.04	0.14	-0.41
May	28.3	77.0	29.2	85.0	28.9	81.8	0.3	2.3	1.00	0.30	0.00	0.30
Jun	27.8	81.0	29.0	84.0	28.4	82.7	0.4	1.1	0.29	0.81	0.06	0.00
Jul	27.4	79.5	29.0	83.5	28.3	81.4	0.5	1.3	0.02	0.05	0.13	-0.31
Aug	27.5	78.5	29.1	83.5	28.2	81.3	0.4	1.4	0.58	0.33	0.05	-0.16
Sep	27.7	79.0	28.6	86.0	28.0	81.7	0.2	2.1	0.13	0.51	0.03	0.07
Oct	27.2	80.0	28.4	86.0	27.7	83.2	0.3	2.0	0.69	0.11	0.01	0.28
Nov	27.0	81.5	27.6	85.5	27.3	83.8	0.2	1.5	0.75	0.51	0.00	0.00
Dec	26.5	76.5	27.9	86.0	27.3	80.1	0.4	2.9	0.18	0.93	0.05	0.00

2018)

Note: $P < 0.05$ shows a significant trend of the distribution of data.

Increasing humidity and temperature are making a negative effect on human body comfort simultaneously. Normal air temperature between 25-26°C and atmospheric RH concentration in between 75% and 80% create a comfortable environment. But Throughout the year, Colombo does not come under the "Comfortable" category (WBGT: ≤27.7). Because during the whole year, the average temperature does not come down below 27°C and RH is also fluctuating between 75% and 84%. As a result of that, throughout the year, the value of WBGT index is ≤30.0.

Table 3. Relationship of Temperature, RH% and WBGT index

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Data
Colombo	30.0	30.5	32.0	32.8	33.1	32.7	32.3	32.2	32.0	31.9	31.4	30.8	WBGT
	27.2	27.5	28.4	28.7	28.9	28.5	28.3	28.2	28.1	27.8	27.4	27.3	MT
	75	77	79	82	82	83	81	81	82	83	84	80	RH

Note: RH: Relative Humidity, MT: Mean Temperature, WBGT: Wet Bulb Global Temperature

Especially in the period of First Inter Monsoon (FIM) and South West Monsoon (SWM), Colombo city remains under "Very severe stress" category with "Heatstroke highly likely". During the Second Inter Monsoon (SIM) period, "Severe stress" condition is recorded with a WBGT index score of 31.6, and health effects such as "Heat cramps or heat exhaustion likely and heatstroke are possible". North East Monsoon (NEM) is better than the other three monsoons in the year, but according to the classification, NEM comes under the "Discomfort" category with "Heat cramps and heat exhaustion are possible". But comparing with other seasons NEM is fairly more comfortable.

Table 4: Monthly and Seasonal Variation of WBGT Index

WBGT		Thermal Sensations	Health Effects	Colombo	
				Month	Monsoon
	≤27.7	Comfortable	….	….	….
	27.8-29.4	Partial discomfort	Fatigue	….	….
	29.5-31.0	Discomfort	Heat cramps and heat exhaustion are possible	January, February, December	NEM
	31.1-32.1	Severe Stress	Heat cramps or heat exhaustion likely and heatstroke possible	March, September, October, November	SIM
	≥32.2	Very severe stress	Heatstroke highly likely	April, May, June, July, August	FIM, SWM

Note: FIM: First Inter Monsoon, SWM: South West Monsoon, SIM: Second Inter Monsoon, NEM: North East Monsoon

When considering about the monthly pattern of the WBGT Index, Colombo city comes under “Very severe stress” with "Heatstroke highly likely" during the 5 months from April to August. “Comfortable” and “Partial discomfort” conditions can not be observed in the city of Colombo even in one month of the year. But January, February and December are somewhat better than the other months of the year. Generally, throughout the year, Colombo city is in discomfort and stressed. According to the summary statistic of the WBGT index (Fig. 3), three months (July, September and October) recorded a significant positive increasing trend of the WBGT index in Colombo city. The month of November is also very close to the significant level (P=0.05). Throughout the year all the mean values are recorded as WBGT ≥ 30.

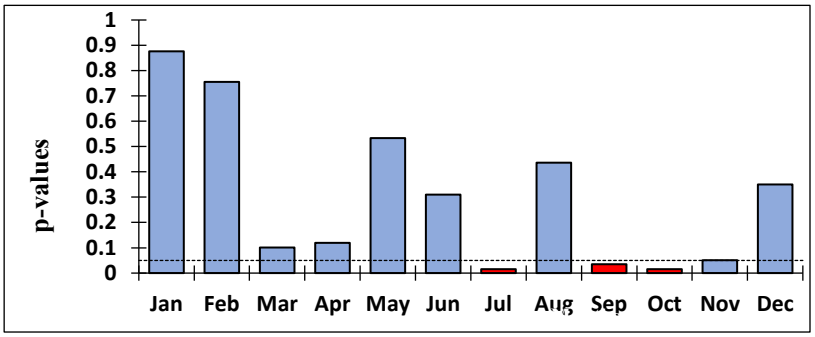

Figure 3. Monthly Significant Trend of WBGT from 2008 to 2018

A common threshold of the P-value is 0.05. It is a probability score that is used in the statistical test to identify the statistical significance of an observed effect.

- A low P-value (<0.05) means statistically significant
- A high P-value (>0.05) means statistically not significant

When considering the relationship between temperature – WBGT and RH – WBGT, a positive Co-relationship can be observed. A huge difference in values between temperature and WBGT can not be identified. All the Values of the two variables are reached up to 27°C in throughout the year. As a result of that, values of the upper level are gathered in one place when figure 04 is considered. The same pattern of positive co-relationship can be observed between RH and WBGT. RH values are always established in between 75≤ and ≤ 84 in the entire year. In the meantime, values of the WBGT index are also moved up to higher ranges of more than 30. As a result of this pattern, the positive co-relationship of RH and WBGT has been identified as indicated in figure 04. A higher number of Temperatures, RH and WBGT are created an uncomfortable environment for the human body. That leads to making a very stressful condition in the atmosphere and it directly and indirectly influences to have a number of heat-related health impacts in the human body. Both physically as well as mentally people suffer from heat stress in CMA.

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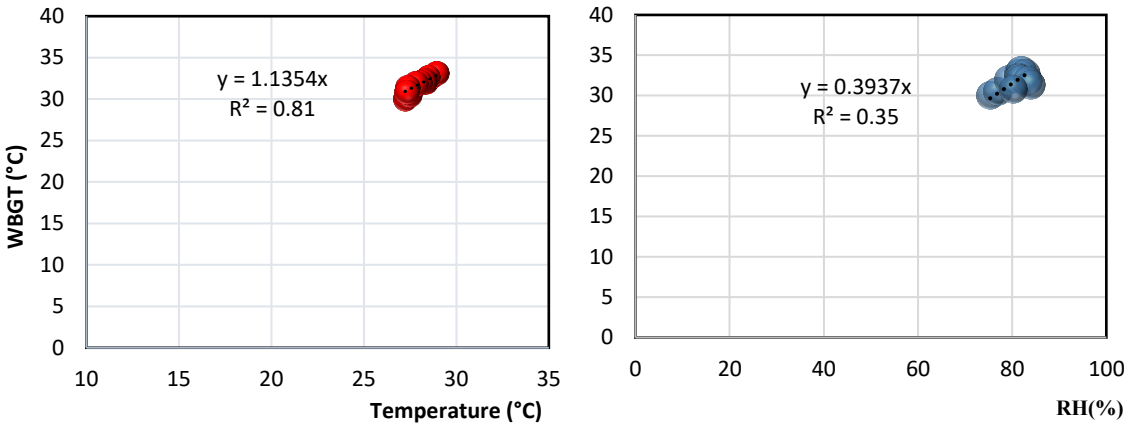

Figure 4: Co-relationship between Temperature-WBGT and RH%-WBGT

4. CONCLUSION

According to the WBGT index, heat stress and heat-related public health issues can be observed in Colombo throughout the year. With the fluctuation of air temperature and RH% in the atmosphere, WBGT index values are also fluctuating monthly and seasonally. Throughout the year, hot and humid climatic conditions can be observed in the city. As a result, Colombo has never been classified under the "Comfortable" category. Half of the year, the city belongs to the "Very severe stress" category with "Heatstroke highly likely". By comparison of all the factors, this research concludes that, Colombo city is a more stressful city with several types of heat-related health hazards. It became a big issue today. Not only that, but in near future, the continuously increasing trend of heat stress, and heat-related health issues will make several complications for all being in the city. It is necessary to assess these risks and respond effectively.

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