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GUEST EDITORIAL

The existential threat posed by humid heat waves due to global warming

In 2010, Sherwood and Huber (*Proc. Nat. Acad. Sci.*, **107**, 9552–9555) showed that there is a limit to how far human beings can adapt to humid heat waves that will occur in the future. The amount of water vapour in the atmosphere increases by 7% for every one-degree Celsius rise in temperature. Hence humid heat waves will be more severe in the future because of an increase in both temperature and humidity. The number of heat waves and forest fires has increased dramatically in the past few decades due to global warming. The heat waves that are widely reported are those with temperatures above 40°C. These are dry heat waves, and they occur in the pre-monsoon season and hence the relative humidity during these periods is not high. Several methods are available to adapt to such heat waves. The India Meteorological Department has been able to predict heat waves about a week in advance and various 'heat action plans' have been developed to reduce morbidity and mortality during dry heat waves. When the ambient relative humidity is low, evaporative cooling is the best way to adapt to these heat waves.

The heat waves that occur after the onset of the monsoon are 'humid heat waves' and these pose a greater threat to the mammalian life because they reduce the amount of evaporation from the body. The humid heat waves occur when the wet-bulb temperature approaches 35°C. The wet-bulb temperature is the temperature recorded by a thermometer whose bulb is kept moist. In India, most states (except Gujarat and Rajasthan) are influenced more by humid heat waves than dry heat waves. For outdoor work or work near furnaces in the industry, the additional heat load must be considered. This is incorporated by introducing the concept of global wet-bulb temperature. The global wet-bulb temperature is a weighted average of the dry-bulb, wet-bulb and black-bulb temperatures. The black bulb measures the impact of radiant heat (from the sun or a furnace).

Human beings must maintain a core body temperature close to 37°C to avoid heat stress. They maintain their core body temperature close to 37°C by rejecting heat through the skin. The temperature of the skin is usually around 35°C. If the ambient dry-bulb temperature is above 35°C, we cannot lose heat by convection and hence we begin to sweat. This enables us to lose heat by evaporation. This method will not work if the wet-bulb temperature is equal to 35°C. At present, there are few locations in the world where the ambient wet-blub temperature exceeds 35°C for a few hours every year. The stress on the human cardiovascular system increases rapidly as the wet-bulb temperature approaches 35°C. The increase in stress is on account of the attempt by the heart to pump more blood to the surface of the skin. Studies have been conducted by the United States army to understand how soldiers acquire tolerance to humid heat during training. They have shown that there is a rapid increase in the core body temperature if the outdoor wet-bulb temperature exceeds 30°C. They have also shown that considerable inter-individual variability exists in the ability to tolerate high core temperatures. If any human being is unable to lose heat by convection and evaporation, the core body temperature will increase by 1°C every hour and hence within a few hours the situation will become untenable. Death due to a combination of heat and humidity has been reported in some sports. During the period from 1980 to 2009, 58 young and healthy adults died in the USA due to a combination of large exertion, high temperature and humidity during football practice (Grundstein, A. J. *et al.*, *Int. J. Biometeorol.*, 2012, **56**, 11–20). In 2007, the Chicago marathon was cancelled after more than 300 people suffered from heat exhaustion. If young and healthy adults can die due to heat and humidity, then we should be concerned about a much larger population that is neither young nor healthy. In a recent paper in *Nature Communications*, Parsons *et al*. (doi:org/10.1038/s41467-021-27328-y) have argued that if the global mean temperature increases by 1°C above the value during 2001–2020, the number of hours of heavy labour lost will be around 400 billion. The International Labour Organization has warned that heat stress can reduce the global gross domestic product in 2030 by US$ 4200 billion. It estimates that around 60% of the reduction in working hours is projected to occur worldwide in 2030 because of heat stress in the agricultural sector. Wolf *et al*. (*Am. J. Physiol*., 2021, **321**, R295–R302) conducted trials on 36 young and healthy adults at Pennsylvania State University under controlled temperature and humidity to determine the conditions under which the core body temperature rises rapidly. They showed that a dry-bulb temperature of 38°C and relative humidity

of 40% represent an upper threshold. Many coastal cities in India have temperatures above 38°C and humidity above 40% during some days of the year. Hence the threat of high heat stress is already present in India, which will worsen during the next 80 years. This will increase the demand for air conditioners, which may lead to further increase in emission of carbon dioxide. One can cool air using solar photovoltaic panels and hence avoid carbon dioxide emissions. Air conditioning is not an option for those who need to work outdoors (e.g. agriculture and construction industry).

Some researchers have estimated that extreme humid heat wave events can increase by 100 times in the next 60 years and lead to 500 million people being exposed to such events by 2080. The Indo-Gangetic plains will experience at least 3 days with wet-bulb temperatures above 32°C by the end of this century. The humidity in the Indo-Gangetic plains will be higher on account of irrigation. This will impact the productivity of workers in factories and in agriculture fields. In India, about 55% of the population works in agriculture or the construction industry. These workers will bear the maximum impact of the increased heat stress due to global warming. A detailed analysis of exposure to heat stress among workers in south India has been undertaken recently (Krishnamurthy, M. *et al*., *Safety and Health at Work*, 2016, doi:10.1016/j.shaw.2016.08.005; Venugopal, V. *et al*., *J. Expos. Sci. Environ. Epidemiol*., February 2021, https://doi.org/10.1038/s41370-020-00261-w). They have shown that workers in the steel and auto-parts industry are subjected to the highest global wet-bulb temperature, which impacts the function of their kidneys.

The global mean temperature of the earth was higher than the present during Eocene (about 50 million years ago). How did mammals survive under those conditions? The ability of the mammals to maintain core body temperature depends upon the heat generation in the body (which depends upon volume) and the ability to dissipate this heat (which depends upon the surface area). During cold climates mammals tend to be larger. This decreases the surface area to volume ratio of the body. In the Eocene most mammals were small (weighing less than one kilogram). During this period the global mean temperature changed by around 3°C in 10,000 years. This change was slow and hence mammals had time to evolve to adapt over many generations to the changes in climate. Currently, the global mean temperature is increasing at the rate of 2°C in 100 years and hence mammals cannot thrive unless they move to higher elevations or latitudes. Hence large mammals like elephants, lions and tigers will not be able to survive during a prolonged humid heat wave. Most mammals have fewer sweat glands than human beings and hence will be subject to greater heat stress during humid heat waves. This threat to the survival of large mammals posed by high temperature and humidity has not been highlighted in India.

The Paris Agreement in 2015 was hailed as an outstanding achievement but since then there has not been sufficient progress in reducing the emission of carbon dioxide. Some countries have been arguing that we need to adapt to climate change. There is however an upper limit to how far we can adapt to global warming. There is a need to highlight the fact that mammals cannot adapt to higher global temperature and humidity and hence global warming poses an existential threat to most large mammals (including human beings). People in developed countries may be able to survive humid heat waves through air-conditioning but this luxury will not be available to most poor people in the developing countries. The area of the world that will be rendered unhabitable by heat stress will be much larger than the area that will be affected by sea level rise. Therefore, the threat of heat stress from high temperature and humidity should be taken seriously. This issue must receive more attention from policy makers during international negotiations.

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