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The Role of Ambient Temperature and Humidity in the Incidence and Spatiotemporal Distribution of Meningococcal Meningitis: A Review of Ecological Studies

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Abstract

Meningococcal meningitis remains a public health problem and threats to a number of populations associated with high mortality rates especially in Sub-Saharan Africa regions. Climate change and weather conditions are important factors influencing the occurrence, incidence, and transmission of meningitis. This review paper aims at evaluating the role of ambient temperature and humidity in the incidence and spatiotemporal distribution of meningococcal meningitis. The effects of temperature and humidity on the occurrence, incidence, and transmission of meningococcal meningitis were searched from the relevant literatures and documented. The relevant literatures were searched through ScienceDirect, PubMed, Web of Science, MDPI, Scopus, and Medline. It was found from the relevant literatures reviewed that temperature and humidity significantly influenced the occurrence, incidence, and transmission of meningococcal meningitis. High temperature and low humidity significantly increased the incidence and transmission of meningococcal meningitis. Thus, based on the available data and information in the literatures reviewed temperature and humidity are significantly associated with the incidence and spatiotemporal distribution of meningococcal meningitis.

Keywords: Climate variability, Humidity, Meningococcal meningitis, Temperature.

INTRODUCTION

Meningitis remains a major public health problem causing epidemics and is associated with climate change. Meningitis is an inflammation of the tissues surrounding the brain and spinal cord caused by bacterial, viral, fungal, or parasitic infection (Wright *et al.,* 2024; GBDM, 2016). Meningitis is associated with high mortality and morbidity rate, and has severe social, educational, and economic impacts on quality life of patients (Pickering *et al.,* 2018). The severity of meningitis is determined by the causative organism (Erdem *et al.,* 2017). Meningitis is commonly occurs in young children with high potential resulting to severe complications including high fever and mental retardation and leading to death if not treated (Kohil *et al.,* 2021). About 2.51 million people in the world have been affected by meningitis with incidence rate of 32.4 new cases per 100 k population worldwide (GBD, 2019). In sub-Saharan African countries, frequent meningitis outbreaks have been recorded in children between the ages 5–12 years with high incidence up to 1000 cases in 100,000 people (Mohammed *et al.,* 2017). In West African countries, about 400 million people are at risk to meningitis leading to 25,000 to 250,000 infected people every year (Ayanlade *et al.,* 2020).

Meningococcal meningitis has been an epidemic disease threatens the Sub-Saharan Africa public health. Meningococcal meningitis is an infectious disease caused by *Neisseria meningitidis* characterizes by the symptoms headache, fever, neck stiffness, vomiting and photophobia (Kim *et al.,* 2012). Meningococcus is a bacterium located in human nasopharynx causing infection when present in bloodstream (Asturias *et al.,* 2022). About 80– 85 % of all the bacterial meningitis cases were due to infection by meningococcal species (WHO, 2025). High incidence of meningococcal meningitis has been recorded in African meningitis belt comprising twenty six sub-Saharan African countries (WHO, 2025). It was estimated that 1.2 million people in the world are affected by meningococcal meningitis causing 135,000 deaths annually (Rouphael and Stephens, 2012). About 400,000 cases of meningococcal meningitis have been reported causing 32,000 deaths in the world (Shen *et al.,* 2024). Almost fifty percent of the world meningitis cases in children aged below 5 years occurred in sub-Saharan African countries including Nigeria (GBD, 2019). High percentage of these cases might have been meningococcal meningitis (Wunrow *et al.,* 2023).

Comprehensive and systematic review on the role of ambient temperature and humidity in the incidence and spatiotemporal distribution of meningococcal meningitis is highly important. However, the association of incidence and spatiotemporal distribution of meningococcal meningitis with ambient temperature and humidity remained unclear. This review paper helps to understand the associations between these meteorological factors and the occurrence, incidence, and transmission of meningococcal meningitis. Experimental, qualitative, and observational studies were the scope of this systematic review paper. The internet search for this review included keywords and terms relating to the impacts of temperature and humidity on meningococcal meningitis incidence and transmission. The relevant studies reviewed in this paper were searched through ScienceDirect, PubMed, Web of Science, MDPI, Scopus, and Medline.

The studies reviewed in this paper were sourced and recorded from the Global Burden of Disease (GBD) which contains important resources for researchers to assess global health challenges associated with various diseases, injuries, and risk factors (GBD, 2019). From 1990 to 2019, epidemiological data for more than 350 diseases and injuries in 195 countries were available in GBD (GBDD, 2020). Meningitis sources including that caused by *N. meningitides* (meningococcal), *S pneumonia* (pneumococcal), *H. influenzae* type b, and other pathogens (bacteria, fungi, viruses, etc.) were efficiently available in GBD. Data on meningitis incidences available in GBD were defined by International Classification of Diseases and Injuries (GBDM, 2016).

In this paper, the climate (temperature and humidity) related studies reviewed were searched via TerraClimate raster data. TerraClimate is a global gridded search tool of climate variables providing monthly temporal resolution of approximately 4 km from 1958 to date (Zhao *et al.,* 2022; Lobell *et al.,* 2022; Abatzoglou *et al.,* 2018). Several climate variables including maximum temperature, minimum temperature, precipitation accumulation, and wind speed, soil moisture, and snow water equivalent are available on TerraClimate. According to the reviewed literatures 204 GBD countries were categorized into 21 GBD geographical regions based on the geographical distribution, cultural characteristics, and local conventions. However, in the studies reviewed maximum temperature and humidity were observed from the Coupled Model Intercomparison Project Phase 6 (CMIP6) data. The CMIP6 contains past, present, and future climate data in a multimodal framework (Petrie *et al.*, 2021).

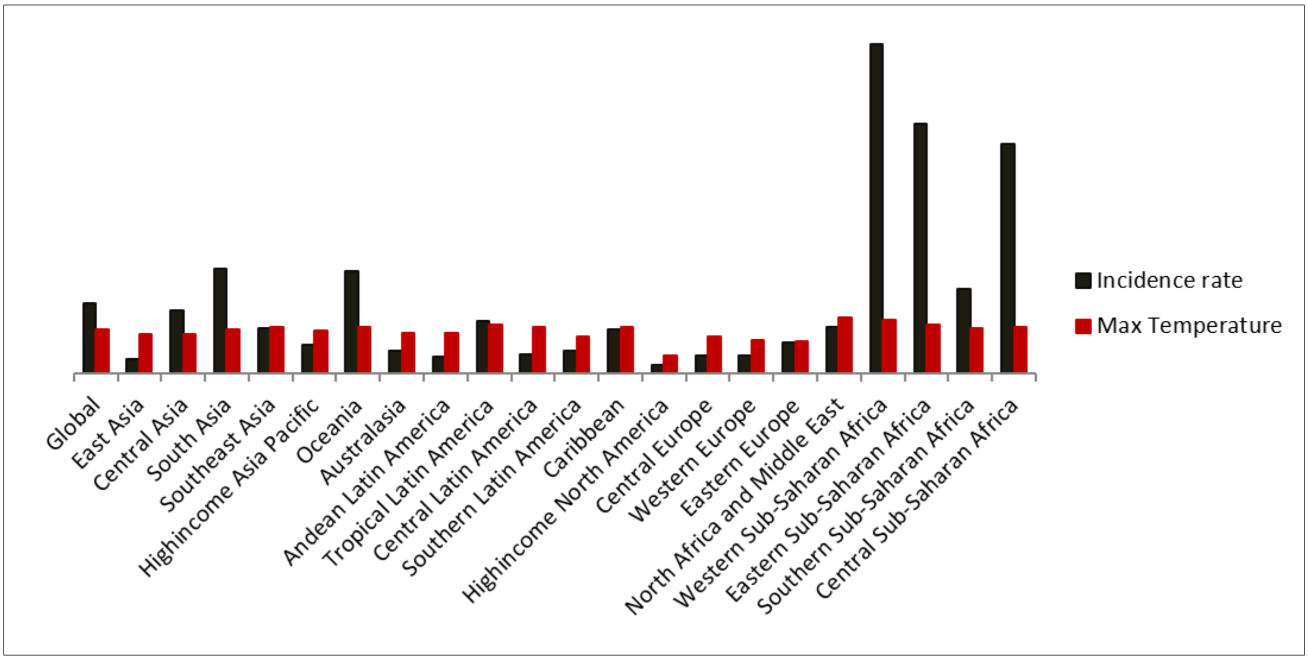
Impacts of Climatic Factors on the Incidence and Transmission of Meningococcal Meningitis

Climate change remains the major threats to global public health associated with high incidence of various diseases. The association between climate change and occurrence of meningococcal meningitis has been reported in many studies (Ayanlade *et al.,* 2020). Spatiotemporal association between meningococcal meningitis cases and climatic conditions has been documented (Tall *et al.,* 2022; Dione *et al.,* 2022). Climatic factors have significant impacts on meningitis incidence and transmission of meningitis outbreaks (Sheffield and Landrigan, 2011). Report showed that about 150,000 deaths were due to the influence of climate change on the occurrence and incidence of meningococcal meningitis (Maini *et al.,* 2017).

The occurrence and transmission of meningococcal meningitis is significantly influenced by temperature, wind, sunshine, and humidity variability (P¨ortner *et al.,* 2022). Global warming due to high temperature coupled with high humidity and more frequent heavy rainfall increase the incidence of meningococcal meningitis (Henne *et al.,* 2018). Change in temperature and humidity plays an important role in the spatiotemporal distribution of meningococcal meningitis (Junjun *et al.,* 2023). Research study revealed that high temperature and humidity significantly increase the risk of meningitis (Dione *et al.,* 2022).

Association between Temperature and Humidity Variability and Meningitis Incidence and Transmission

From the literature by GBD region the global average incidence rate of meningococcal meningitis per 100000 populations between 1990 and 2019 was 46.2 coupled with 29.4 ℃ global average maximum temperature. The highest (218.5) and lowest (5.9) average incidence rate was observed in Western Sub-Saharan Africa and High-income North America, respectively (Figure 1). The highest (37.0 ℃) and lowest (11.8 ℃) average temperature was reported in North Africa and Middle East and High-income North America, respectively (Figure 1). However, the average temperature in Western Sub-Saharan Africa region was 35.6 ℃. This indicated that the average temperature in Western Sub-Saharan Africa which recorded the highest incidence rate is higher than the average temperature observed in High-income North America which has the lowest incidence rate of meningitis (Figure 1). Thus, the higher the average temperature of a region the higher the incidence of meningococcal meningitis.



The global map showing the changes in global, regional, and local mean temperature variability and the incidence rate of meningitis from 1990 to 2019 is presented in Figure 2. From the map, it is observed that some countries and regions experience relatively higher temperature variability between 0.86 ℃ and 1.70 ℃. It was observed that the incidence rates in the Western Sub-Saharan African countries in the belt are significantly higher than those in other regions of the world (Junjun *et al.,* 2023). The incidence rates in Europe and the Americas both remain relatively low. However, the incidence rates can be slightly high in Central Asia and South/Southeast Asia (Figure 2).

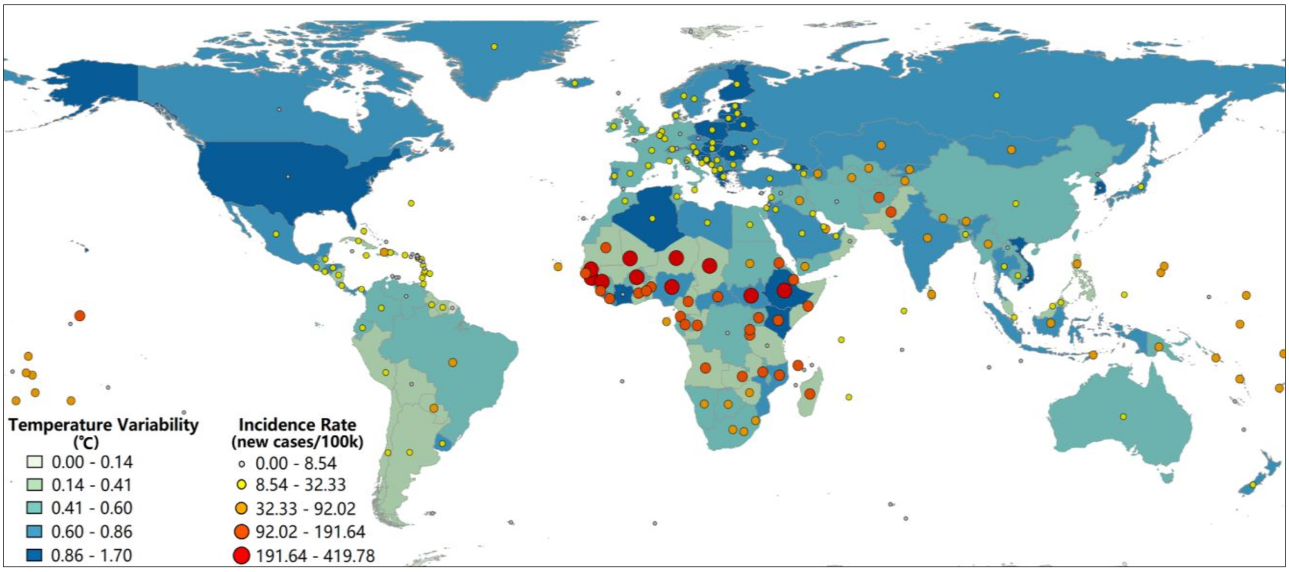


Figure 2: Global map of local mean temperature variability over 1990–2019. (*Source*: GBD from 1990 to 2019). Color-scaled dots show the severity of the local mean incidence rate of each country over 1990–2019

It was found that the incidence of meningitis is associated with temperature variability (Junjun *et al.,* 2023). Temperature variability derived from maximum temperature is significant to evaluate the severity and frequency of climate change (Junjun *et al.,* 2023). Countries within the belt, particularly Central and

Western Sub-Saharan African countries, continue to experience a high burden of meningitis (GBDM, 2016).

Effects of Temperature on the Incidence and Transmission of Meningococcal Meningitis

A significant association between temperature and meningococcal meningitis incidence and transmission has been documented (Ayanlade *et al.,* 2020). Studies showed that during the rainy season high temperature caused several meningococcal meningitis occurrences (Akanwake *et al.,* 2022; Mazamay *et al.,* 2020b). It has been reported that various meningococcal meningitis cases in African countries were due to increase in temperatures (WHO, 2025; Akanwake *et al.,* 2022). Several findings showed an association between increased meningococcal incidence and higher temperatures (Akanwake *et al.,* 2022; Pinilla-Monsalve *et al.,* 2023). Study by Chen *et al.,* (2023) showed that increase in temperature was significantly associated with higher incidence of meningitis.

African countries within the meningitis belt demonstrate higher temperatures due to the belt's proximity to both the Equator and the Sahara (Pinilla-Monsalve *et al.,* 2023). A significant relationship between the high temperature of the El Niño–Southern Oscillation (ENSO) and the 2009–2010 West African meningitis outbreaks has been reported (Oluwole *et al.,* 2015). Study by Loh *et al.,* (2013) showed that higher temperatures can enhance meningococcal defence against human immune inhibition. Investigation showed that high proportion of Central and Western Sub-Saharan Africa is likely to continue being at risk of meningitis epidemics due to high temperature variability (Tall *et al.,* 2022).

However, some studies reported negative association between high temperature and meningococcal meningitis incidence. Research conducted in Democratic Republic of Congo revealed a negative correlation between high temperature and meningococcal meningitis incidence (Mazamay *et al.,* 2020a). It was learned that one of the objectives of this study was to understand how meningitis vaccination affects the association between climatic variables and meningitis incidence. Hence, the negative association between high temperature and meningococcal meningitis incidence reported by the literature could be attributed to the introduction of MenAfriVac vaccine before the conduct of study. Oluwatimilehin *et al.,* (2022) reported that low temperature was significantly associated with meningitis incidence. This could be attributed to the seasonal period the research conducted. It understands that the research was carried out during Harmattan when there was high dust and wind speed both of which significantly influence the incidence of meningitis.

Effects of Humidity on the Incidence and Transmission of Meningococcal Meningitis

Low absolute or relative humidity increases occurrence, incidence, and transmission of meningococcal meningitis especially during the dry season in the African meningitis belt (Junjun *et al.,* 2023). Minimum humidity particularly in dry season enhances the population of *Neisseria meningitidis* in air leading to increase in the bacteria transmission rates. Studies showed that the central and western African regions have the highest risk of meningitis outbreaks due to persistently lower humidity and higher dust concentrations. Low humidity causes airborne of dust particles enabling the transmission of *Neisseria meningitidis*. In a relevant study, it was observed that humidity demonstrated high correlation factor with *Neisseria meningitidis* loads up to -0.43 (UCAR, 2008). This indicated that humidity not only influenced the growth and transmission of *Neisseria meningitidis*, but also altered the activities and characteristics of the bacteria, leading to dynamics of meningitis transmission (UCAR, 2008). However, it was found that higher humidity enhance the carriage of bacterial meningococci and decrease the incidence of meningococcal meningitis (Mueller *et al.,* 2008). Low humidity and high dust concentration have been documented as reliable factors for high number of meningitis cases (Junjun *et al.,* 2023).

Mechanisms of Effect of Temperature and Humidity on the Incidence and Transmission of Meningococcal Meningitis

Many hypotheses explained how temperature and humidity influence the incidence and transmission of meningococcal meningitis. In general, low absolute humidity and high temperatures are hypothesised to increase host susceptibility and facilitate the transmission of *Neisseria meningitides* (Cliff *et al.,* 2025; Bassat *et al.,* 2024). Specifically, low absolute humidity and high temperatures are hypothesised to increase nasopharyngeal susceptibility to *Neisseria meningitides* colonisation and invasion (Hadley *et al.,* 2024). The hypotheses stated that during dry season high temperature and/or low humidity could increase meningococcal occurrence and transmission through respiratory droplets (Bassat *et al.,* 2024). This would lead to an increase in the number of the disease outbreaks and cases. Cooper *et al.,* (2019) found that meningococcal carriage odds increased during the dry season, then increased again during meningococcal meningitis outbreaks.

High temperatures increase the incidence of meningitis by damaging the protective linings of the nose and throat. Hot and dry weather causes atmospheric evaporation leading to mucosal dried and damage. In other hand, high temperatures increase levels of soil drying resulting to accumulation of dust into air which when inhaled irritates and damages the respiratory tract (Yuan *et al.,* 2022). Through the damage tract *Neisseria* *meningitidis* can easily enter into the bloodstream causing meningitis. This increases the risk of meningococcal meningitis outbreaks (Yuan *et al.,* 2022).

During dry season, low absolute humidity increases the population of meningitis causing bacteria in the air resulting to increase in transmission rates of meningitis. The mechanism of effect of low humidity on incidence and transmission involves direct irritating the nasal mucosal barrier or inhibiting mucosal immune defenses, enhancing meningococcal invasion (Obiakor, 2013). However, the mechanism involves dehydration of the nasopharyngeal mucosa by dry air due to low humidity causing damage of the mucous membranes of the respiratory tract (Cliff *et al.,* 2025; Bassat *et al.,* 2024). This damage enables penetration and entering of *Neisseria meningitidis* into the bloodstream causing meningitis.

CONCLUSION

Ambient temperature and humidity significantly influenced the incidence and transmission of meningococcal meningitis particularly in countries located on African belt. It is important to understand the association between climatic factors particularly temperature and humidity and their impact on meningococcal meningitis incidence and transmission. Central and Western Sub-Saharan Africa regions are at the highest risk for meningococcal meningitis due to increasing temperature variability and low absolute and relative humidity.

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