Internship Report on

Assessment of the Public Health Implications of Climate Change: A Retrospective Study of Dengue in Delhi

Supervised By:

Dr. Ram Pravesh Kumar
Assistant Professor, School of Environmental Sciences
Jawaharlal Nehru University, New Delhi

Submitted By:

Akankshya Swain
M.Sc. Environmental Science
Utkal University, Odisha

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Department of Administrative Reforms and Public Grievances, Ministry of Personnel, Public Grievances and Pensions, Government of India

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CERTIFICATE

This is to certify that **Ms. Akankshya Swain**, a student of Utkal University, has satisfactorily concluded the research report titled **"Assessment of the Public Health Implications of Climate Change: A Retrospective Study of Dengue in Delhi"** as part of the internship program at the National Centre for Good Governance (NCGG) under my mentorship.

I, Dr. Ram Pravesh Kumar, hereby validate the successful completion of the internship report within the internship program at the National Centre for Good Governance (NCGG). The report submitted by Akankshya Swain is an authentic work carried out by her under my supervision and guidance. I have reviewed and assessed the intern's performance throughout the internship period.

5.7.24

Dr. Ram Pravesh Kumar
Assistant Professor, SES
Jawaharlal Nehru University
New Delhi-110067, India

Dr. Ram Pravesh Kumar
Assistant Professor
School of Environmental Sciences
Jawaharlal Nehru University, New Delhi - 67

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Declaration of Authorship

I, AKANKSHYA SWAIN, declare that this Internship report titled, '*Assessment of the Public Health Implications of Climate Change: A Retrospective Study of Dengue in Delhi*' and the work presented in it are my own, under the guidance of my supervisor. I confirm that;

- This work was done wholly while in candidature for Master of Science in Environmental Science at Utkal University, Bhubaneswar.
- This work, wholly or partially, has not been submitted to any other institute or university for any degree or diploma.
- I have abided by the norms and guidelines given in the Ethical Code of Conduct of the institute.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have used materials from the work of others, I have given due credit to them by citing them in the text of the report and giving details in the references. With the exception of such citations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the report is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself

Signature: Akankshya Swain

Date: 08.07.2024

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Abbreviations

Ae.- Aedes

AIDS- Acquired Immune Deficiency Syndrome

AT- Average Temperature

BMC- BioMed Central

CCR- Central Control Room

CDC- Centres for Disease Control and Prevention

CPCB- Central Pollution Control Board

DENV- Dengue Virus

DF- Dengue Fever

DHF- Dengue haemorrhagic fever

HIV- Human Immunodeficiency Virus

DSS- Dengue shock syndrome

ELISA- Enzyme-Linked Immunosorbent Assay

IDSP- Integrated Disease Surveillance Programme

IMD- Indian Meteorological Department

ICMR- Indian Council of Medical Research

IPCC- Intergovernmental panel on climate change

MCD- Municipal Corporation of Delhi

MDPI- Multidisciplinary Digital Publishing Institute

MLR- Multiple Linear Regression

NABL- National Accreditation Board for Testing and Calibration Laboratories

NCEI- National Centres for Environmental Information

NHM- National Health Mission

NVBDCP- National Center for Vector Borne Disease Control

PLOS- Public Library of Science

PMC- PubMed Central

RH- Relative Humidity

SEAR- South-East Asia Region

STD- Sexually Transmitted Diseases

TOT RF- Total Rainfall

UMS- Urban Malaria Scheme

WHO- World Health Organization

Abstract

Health has always been a basic social concern, but in recent times, there has been a surge in anxiety because of the widespread media coverage of disease outbreaks, the speed at which vector-borne illnesses are spreading, the effects of industrial by-products on health, and the ways in which changing climate patterns impact disease vectors. This retrospective study aims to assess the effects of climate change on public health by offering a thorough examination of how each season affects the dengue lifecycle and prevalence in Delhi from January 2020 to December 2023. This study uses data from the Municipal Corporation of Delhi and meteorological records from the IMD and CPCB to investigate the relationship between dengue incidence and environmental characteristics such temperature, rainfall, and humidity. The analysis used R-studio software to conduct the Multiple Linear Regression (MLR) analysis and the Spearman Rank Correlation Test. The findings reveal a noteworthy seasonal trend, wherein dengue cases reach their peak every year during the post-monsoon period, with the highest incidence in November. The results of the statistical study showed that there was a substantial positive association ($p < 0.05$) between dengue cases and relative humidity, while temperature had variable effects and rainfall generally exhibited a negative correlation. The results highlight the critical role that climate variables play in affecting dengue epidemics in Delhi. The study emphasizes the necessity of creating weather-based dengue forecasting models to help public health officials anticipate and control outbreaks, which will lessen the strain on healthcare systems and associated expenses.

Keywords: Climate Change, Vector-Borne Diseases, Dengue Epidemics, Public Health

1.0 Introduction

"The mosquito emerges victorious in the battle against climate change"

-Hugh Sturrock

Weather patterns and temperatures have changed over time due to climate change. Natural factors like oscillations in the solar cycle could be the source of these fluctuations (Harald Yndestad, 2016). With a population of over 1.3 billion, India is the nation with the second largest population in the world (Thakur, 2021). It is distinguished by a youthful demographic and a noteworthy linguistic and religious diversity. Due to the use of fossil fuels, human activity has been the primary cause of climate change since the 1800s (Harald Yndestad, 2016). Fossil fuel combustion produces greenhouse gases in the atmosphere, that trap solar radiation and elevate global temperatures. The hottest decade on record has been the past ten years, from 2011 to 2020 (NCEI, 2024). Earth is 1.1 ^{o} C warmer in 2022 than it was in the 19th century (NCEI, 2024). Increasing heat, unpredictable rainfall, severe weather phenomena and environmental degradation are just a few of the repercussions of climate variability that India is already experiencing. These effects pose major dangers to infrastructure, agriculture, public health, and water resources (Sudha Rani Kotha et al, 2011). India is among the world's top emitters of CO2 with annual emissions reaching 2.88 billion tonnes, largely due to its rapid economic growth (CO_2 Emissions by Country 2024). India wants to produce 50% of its electricity from renewable sources by 2030 and has committed to achieve net-zero emissions by 2070 (State of Carbon Emissions and Carbon Markets in India: 2023–24). As India continues to develop, balancing economic growth with environmental sustainability remains a challenge (Thakur, 2021).

Climate change has been exacerbating various environmental and health issues globally, and vector-borne diseases are among the significant challenges (Karamchandani, 1946). At COP 28 in UAE 2023, India highlighted the urgent need to tackle the health effects of climate change, such as rising vector-borne diseases, heat-related illnesses, and respiratory conditions (UNFCCC, COP 28 High-level Segment - National statement - India, 2023). The nation called for global collaboration to incorporate health into climate policies and develop resilient health systems to protect at-risk populations. India also reiterated its commitment to lowering emissions and fostering sustainable practices that benefit both the environment and public health (UNFCCC, COP 28 High-level Segment - National statement - India, 2023).

In developing countries, vector-borne illnesses pose a serious threat to public health. The National Vector Borne Disease Control Programme (NVBDCP) is a comprehensive project that was launched in 2003–04 with the intention of controlling and preventing diseases like Lymphatic filariasis, Dengue, Kala-azar, Japanese encephalitis (JE), Malaria, and Chikungunya that are spread by vectors (NVBDCP, Dengue-National-Guidelines-2014). The National Vector Borne Illness Control Program and the National Centre for Disease Control (NCDC) (NVBDCP) are in charge of carrying out national vector control and preventative initiatives. Environmental predictors as, Average Temperature (AT), Total Rainfall (TOT Rf) pattern and Relative Humidity (RH), it is established that seasonal variations affect the spread of disease (Ballani, 2014). Among the vector borne diseases, Dengue, in particular, is a significant concern due to the breeding of mosquitoes in fresh water (Srivastava, 2023).

The Dengue is an arboviral disease brought on by Dengue viruses, which are spread via female Aedes mosquito bites (Aedes aegypti and Aedes albopictus) (NVBDCP, Annual Report NVBDCP, 2014-15). *Aedes aegypti* is the most common species of Aedes mosquito in Delhi (Karamchandani, 1946). Delhi has reported all 4 serotypes during different years and most dominant and dangerous strain, D2/DENV-2 serotype reported in Delhi also raises concern for outbreak of severe Dengue in future years (Karamchandani, 1946). According to reports from the World Health Organization, dengue has spread geographically during the past 50 years, affecting a 30-fold increase in the number of countries afflicted and moving from urban to rural areas (WHO, Dengue guidelines, for diagnosis, treatment, prevention and control, 2009). The National Vector Borne Disease Control Programme's 2014–2015 report claims that Delhi and 35 other states and Union territories are endemic for dengue (NVBDCP, Annual Report NVBDCP, 2014-15). Delhi's high population density, rapid urbanization, water stagnation, poor waste management, heat waves and extreme weather events like floods further increase dengue risk, makes it a dengue hotspot (Karamchandani, 1946). Several global studies have shown that climatic factor’s such as; temperature, humidity, and rainfall are the most important factors influencing the spread of dengue, and these variables affect the severity and duration of the disease's transmission (Samal, 2020). Dengue fever (DF) is a moderate flu-like illness; dengue haemorrhagic fever (DHF) is a more severe form of the disease; and dengue shock syndrome (DSS) is a more severe form of the disease.

1.1 Life Cycle and Disease Transmission of Aedes Mosquito

Dengue is a complicated disease with a complex epidemiology that depends on the interaction of several epidemiological elements, encompassing the agent (virus), the host (human and mosquito), and the environment (biotic and abiotic variables) (Bisht, 2019). It is commonly known as the Tiger mosquito because of the presence of black and white patches over the leg. This mosquito started out in Africa. but it is most frequently found worldwide in tropical and subtropical regions (WHO, Vector-borne diseases, 2020).

1.2 Dengue Virus

Dengue is a severe febrile disease brought induced by an infection with four related positive-strand ribonucleic acid (RNA) viruses of the genus Flavivirus. There are 4 serotypes present in DENV-1, DENV-2, DENV-3, and DENV-4 dengue viruses (WHO, Vector-borne diseases , 2020). Each of these serotypes may circulate alone or in multiples in any one location at the same time. Lifelong immunity to that virus serotype is conferred by infection with one serotype, but not others (NVBDCP, Dengue-National-Guidelines-2014)

1.3 Study of Molecular Epidemiology

The quartet of dengue serotypes (DENV 1-4) named serotypes of the Dengue virus. There are reports of all four serotypes from India. However, The DENV-2 or D-2 strain is the most dominant strain, mostly found in Delhi (Times of India, 2023). In dengue, A single serotype infection results in lifelong immunity to that specific virus strain but only transient protection against other serotypes (Bureau, Dengue Epidemic, 2021). As a person infected with DENV-1 cannot become ill as a result of DENV-1 infection again (WHO, Vector-borne diseases , 2020).

Figure 9: *Aedes aegypti* mosquito

Taxonomic Classification

Kingdom: Animalia

Phylum- Arthropoda

Class: Insecta

Order: Diptera

Family: Culicidae

Genus: Aedes

Species: *A. aegypti*

Source: https://www.itis.gov

The genome of the dengue virus includes three genes for structural proteins that code for the Together with a number of non-structural (NS) proteins, including NS1, NS2A, NS2B, NS3, NS4A, NS4B, and NS5, there are also envelope (E), membrane (M), and core proteins (NVBDCP, Dengue-National-Guidelines-2014). The NS1 protein engages in interactions with the host defence mechanism and initiates T-cell reactions. It is detectable in the blood of infected patients and serves as a marker for infection (NVBDCP, Dengue-National-Guidelines-2014). Dengue infection is often asymptomatic, and infected individuals can spread the virus to new areas (Bisht, 2019).

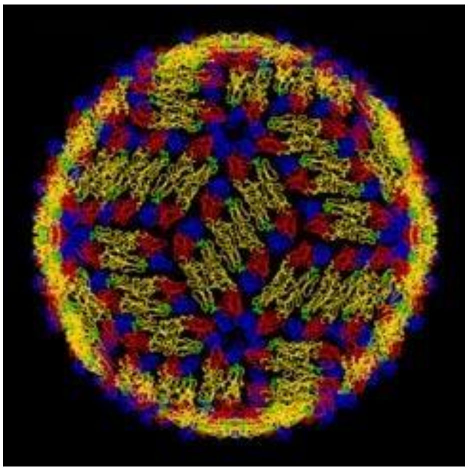


Figure 10: Structure of Dengue virus under electron microscope

1.4 Vector

When a female Aedes (Ae.) mosquito bites someone, it can spread the dengue virus to other people. Aedes aegypti is the primary vector in most Indian cities. The female Aedes mosquito deposits solitary eggs on damp surfaces just above the water's edge. In the ideal circumstances, the adult *Ae. aegypti* emerges after the aquatic stages in seven days. It can take several weeks for it to appear at low temperatures. When exposed to water, the eggs are able to endure drying out (staying in a feasible dry state) for more than a year and come out in under a day. This poses a significant challenge to dengue prevention and control as well. *Aedes aegypti* lives for about 30 days. Their extended survival during the rainy season increases the risk of virus transmission. Aedes aegypti breeds nearly exclusively in household, manufactured water bottles found in and around homes, as well as in water reservoirs, overhead tanks, desert coolers, abandoned tires, shells of coconuts, single-use plastic cup, and other household and industrial debris, as well as on building sites (NVBDCP, Dengue-National-Guidelines-2014).

1.5 Environmental Factors

Ae. aegypti population fluctuations are related to rainfall, temperature, relative humidity (RH) and water storage. The two factors affecting its longevity are average temperature and RH. It thrives in temperatures in the range of 16 to 30°C with 60–80% RH (CDC, 2024). The distribution is also limited by altitude, which is limited to a range of 1000 feet above sea level. Ae. aegypti prefers cool, shaded areas to repose and exhibits strong anthropophilia. The phenomena of Ae. aegypti is associated with modifications in rural society and lifestyle, together with development programs, improved transportation infrastructure, etc. Aedes is a daytime feeder, as temperature has an influence on its lifecycle. Aedes mosquitoes typically fly 100-200 meters (328-656 feet) from their breeding sites, but can go up to 500 meters (1640 feet) with wind assistance or when seeking blood (Bureau, Dengue Epidemic, 2021). Due to their limited flying range, it mostly affects the local area and localized control strategies and community-based interventions become effective in reducing their populations and the risk of dengue transmission.

1.6 Life Stages of Ae. Aegypti Mosquito

Eggs

- Water-filled containers are the nesting grounds for female mosquitoes.
- When placed in water, eggs can hatch in a few days to months, depending on the availability of water; otherwise, they can remain in a viable dry state (desiccation) for more than a year.

Larva

- In as little as five days, larvae that dwell in water can transform into pupae.
- Larval stage provides insights into environmental conditions favourable for mosquito development and effective larvicidal treatments.

Pupa:

- Pupae are aquatic insects that mature into adult flying mosquitoes in two to three days.
- The pupal stage is critical for targeting interventions before mosquitoes reach adulthood and begin spreading diseases.

Adult:

- Adult mosquitoes emerge from pupae and are capable of flying and reproducing.
- Under optimal conditions, an adult Aedes mosquito can live for about 21 days. This lifespan can vary with environmental factors such as temperature and humidity.

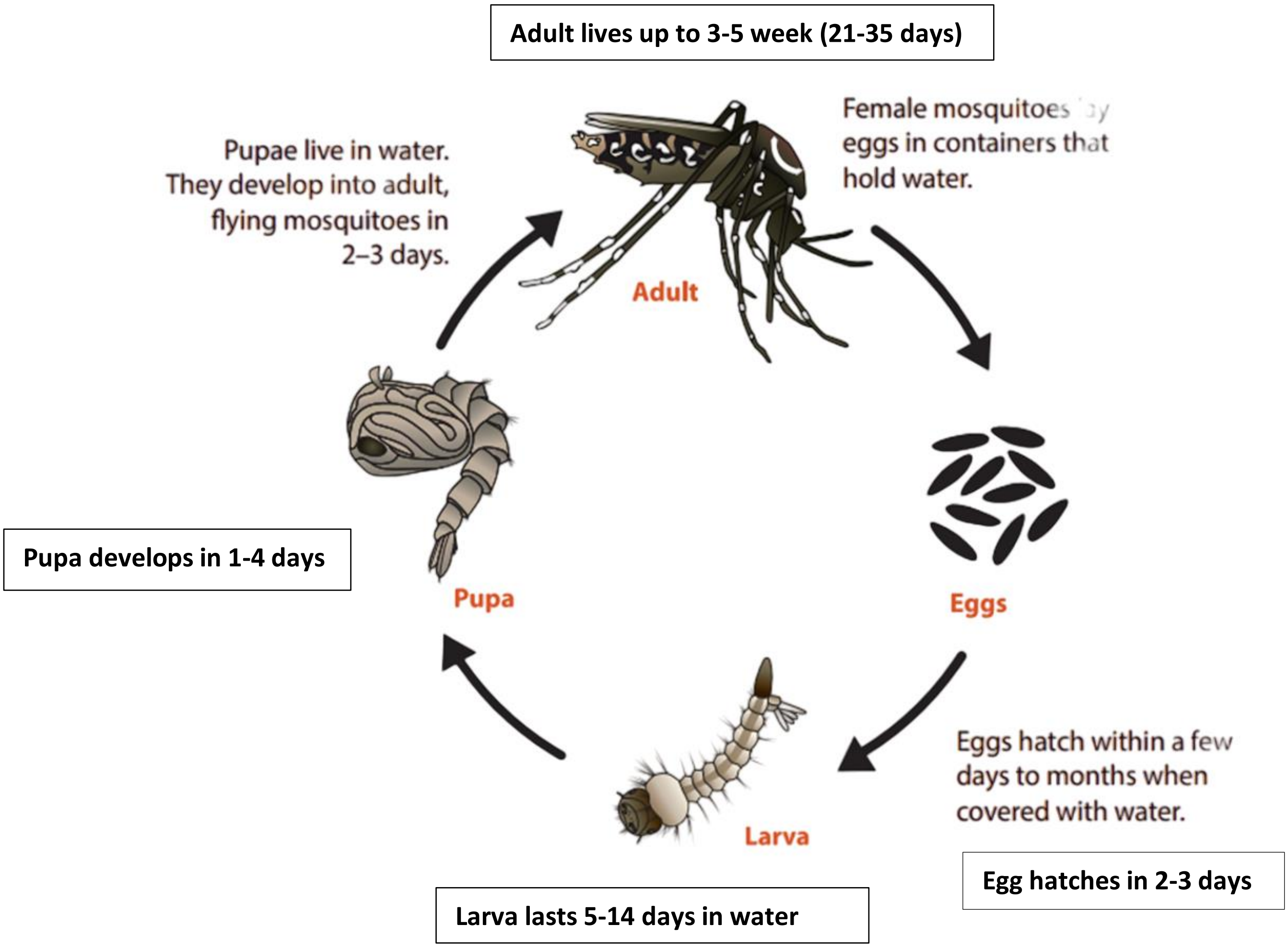


Figure 11: *Aedes aegypti* life cycle (*Source*- cdc.gov.in)

1.7 Transmission Cycle of Dengue Virus

When a female Ae. aegypti feeds on a human during an acute fever episode, it typically contracts the dengue virus. Viremia is the period of infectivity phase of dengue illness. After 8 to 12 days of extrinsic incubation, the mosquito contracts the infection (NVBDCP, Annual Report NVBDCP, 2014-15). The virus spreads when a female mosquito carrying the infection bites a human and injects her saliva into the wound. The dengue cycle continues because of this procedure. Dengue fever manifests abruptly following an inherent incubation period of 4 to 7 days (range 3-14 days). Additionally, there is proof that the dengue virus is vertically transmitted from female infected mosquitoes to their progeny (NVBDCP, Dengue-National-Guidelines-2014).

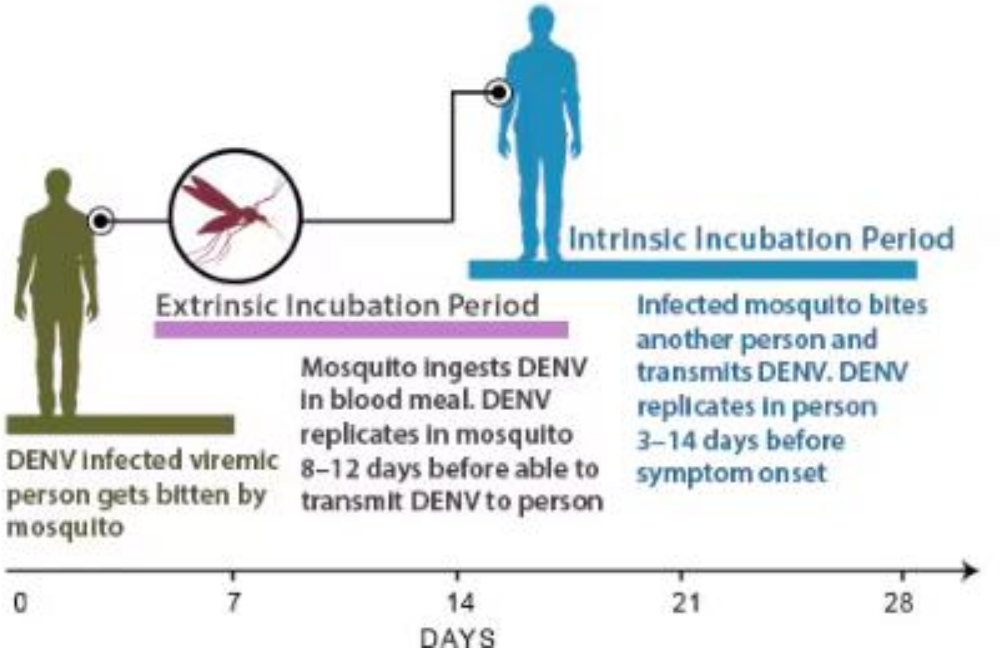


Figure 12 : DENV virus incubation period in mosquito and human- Fact Sheet (Source- cdc.gov.in)

1.8 Modes of Transmission

Sources of DENV:

1. Saliva of infected Aedes spp. mosquito
2. Blood or organs from an acutely infected person

Types of transmission are, Bite by a mosquito, Transmission during pregnancy (perinatal transfusion), Blood transfusion, Transplantation of organs etc.

1.9 Characteristics of Clinical Dengue Fever (DF)

An acute disease that manifests as a fever that lasts for two to seven days and at least two of the following symptoms: headache, ocular pain, joint pain, muscle pain, rash, or haemorrhagic condition (Murhekar M, 2019).

1.10 Characteristics Dengue Haemorrhagic Fever (DHF)

An instance of dengue fever symptoms additionally bleeding inclinations (like a positive tourniquet test, or spots and bruises on the skin, or bleeding from the nose, gums, or other sites), low platelet count (less than 100,000 cells/mm^3), and signs of vascular permeability-induced plasma leakage. Plasma leakage can be shown by a haematocrit rise over 20%, a haematocrit drops of more than 20% after fluid replacement, or symptoms like fluid in the chest, abdominal swelling, or low protein levels in the blood (less than 6 g/dL) (Murhekar M, 2019).

1.11 Characteristics Dengue Shock Syndrome (DSS)

A serious and sometimes fatal consequence of dengue infection, dengue Shock Syndrome (DSS) is identified by particular clinical symptoms. Patients usually experience a sudden onset of high fever lasting from two to seven days, often accompanied by severe abdominal pain and frequent vomiting. Bleeding can occur in various forms, including nosebleeds, gum bleeding, and skin haemorrhages like petechiae, ecchymoses, and purpura. The platelet count can drop to very low levels, sometimes below 20,000 cells/mm^3. Behavioural changes such as restlessness, irritability, or lethargy may also be present, alongside physical indicators like cool, clammy skin indicating compromised circulation. Cardiovascular symptoms include low blood pressure, which can lead to shock and is indicated by a narrow pulse pressure (less than 20 mm Hg) and a quick, weak pulse. Organ dysfunction is critical in DSS, with potential signs including altered mental status, liver enlargement, and reduced urine output. Plasma leakage, a hallmark feature, is evidenced by fluid build-up in the chest (pleural effusion) and abdomen (ascites), as well as low blood protein levels and a significant rise in haematocrit levels (Murhekar M, 2019).

2.0 Review of Literature

The phrase "climate change" refers to modifications to Earth's climate that result from human activity, whether directly or indirectly, and that have an effect on the composition of the global atmosphere in ways that go beyond variations in the climate observed naturally over comparable time periods. (UNFCCC, Climate change science - the status of climate change science today , 2011). The average global temperature has already increased by 1.1°C since 1900, with the previous 50 years seeing the most of the increase (IPCC, CLIMATE CHANGE, 2015). The World Metrological Organization (WMO) states that the atmosphere's radiative balance is changed when greenhouse gas concentrations rise. This results in the Earth's surface and lower atmosphere becoming warmer as a result of greenhouse gases absorbing part of the heat radiation that the Earth emits and reradiating it back towards the surface (UNFCCC, 2022).

Over time, there has been discussion over the balance between environmental preservation and human activities. The resource supplies of Earth are reducing, and our numbers are continuing to explode. We are already exceeding the "carrying capacity" of the planet, which is harming Earth (Ranjeet Kumar Singh et al, 2018). The primary problem is that the world's population is expanding too quickly, placing a pressure on food and water supplies and resulting in the development of a large number of new cities and towns. Aedes aegypti (L.), filariasis (Cx. quinquefasciatus), malaria (Anopheles stephensi Listen), and scrub typhus (Orientia tsutsugamushi) vectors have effectively adapted to a variety of urban habitats, causing many metropolises to become megapolises (Karamchandani, 1946). The environment's temperature is one of the most significant abiotic elements influencing an insect's life. Similarly, climate change and extreme weather events like heat wave, flood and drought etc. are affecting public health which is the matter of concern. Global factors such as rising temperatures and rainfall nowadays are making the weather more favourable to the formation of illnesses spread by vectors. Because of the numerous contributing variables, including land use, host abundance, and control tactics, it is difficult to link changes in vector and disease patterns to climate change (Ganeshkumar P, 2018). It can be difficult to distinguish between changes in the climate caused by humans and those that occur naturally, but new scientific techniques can help. However, it is clear that disease-causing agents adjust to their surroundings; changes in local climate are frequently correlated with variations in disease incidence (The New England Journal Of Medicine, 2022).

More than 17% of infectious diseases are spread by vectors, and each year they cause more than 700,000 deaths (CDC, 2024). They may be brought on by bacteria, viruses, or parasites.

Climate change's effects on precipitation patterns, temperature swings, and extreme weather events could all affect the emergence and spread of infectious diseases (Amy L. Greer, 2008).

2.1 Global Status

According to WHO's first report on neglected tropical diseases, dengue is one of the 17 neglected tropical disease (WHO, Vector-borne diseases, 2020). Over 1.8 billion people, or over 70% of the global dengue-at-risk population, reside in WHO member states. Approximately 75% of the dengue-related diseases that affect people worldwide currently occur in the Region of South-East Asia (SEAR) and the Region of the Western Pacific (Babita Bisht, Influence of environmental factors on dengue, 2019). Ten of the eleven SEAR countries—including India—have an endemic case of dengue (Bisht, 2019). The Democratic People's Republic of Korea is the lone outlier. About 0.29 million cases were reported by SEAR countries in 2012; over 30% of those cases were from Thailand, 29% were from Indonesia, and 20% were from India. Comparably, 0.33 million cases have been reported from Western Pacific countries; about 52% of these cases were from the Philippines, 24% from Vietnam, and 14% from Cambodia (WHO, Vector-borne diseases , 2020). According to reports from the World Health Organization, dengue has spread geographically during the past 50 years, affecting a 30-fold increase in the number of countries afflicted and moving from urban to rural areas (WHO, Dengue guidelines, for diagnosis, treatment, prevention and control, 2009). Dengue is prevalent in more than 128 countries worldwide, with South-East Asia and the Western Pacific areas being the most impacted (Bisht, 2019). During the past 50 years, the global incidence of dengue fever has increased thirty times, making it the fastest-rising mosquito-borne viral disease known to man. In all of the world's tropical and subtropical regions, it is a serious public health hazard. The majority of people on the planet reside in nations where dengue is prevalent. According to Vohra's research, there is a trend toward a higher incidence of DHF in a number of Indonesian tropical endemic regions, including Sumatra and Sulawesi. This trend may be related to climate change. Due to the burning of forests and land, which raised the temperature and humidity and changed the dynamics of big mosquito populations nearby, DHF cases also occasionally appeared in Kalimantan. Similar changes in the environment brought about by increased population density have also made humans and their communities more vulnerable to dengue virus infection in Java (Vohra, 2020). Different countries face varying climate-related health risks, leading to differences in the development of surveillance systems. Most commonly, countries have surveillance for vector-borne diseases (39%) (WHO, Health and climate change global survey report, 2021).

It was initially discovered during dengue outbreaks in Thailand and the Philippines in the 1950s. Severe dengue fever is currently widespread in many countries in Asia and Latin America, and it is the main reason why adults and children alike are admitted to hospitals and die from it. Four closely related Flaviviridae virus serotypes—DENV-1, DENV-2, DENV-3, and DENV-4—cause dengue; a fifth serotype was found in the Malaysian state of Sarawak (Bernard Cazelles, 2005). According to recent research by the WHO, dengue fever cases increased in multiple countries in 2020 Bangladesh, Brazil, Ecuador, India, Indonesia, Maldives, Mauritania, Mayotte, Nepal, Singapore, Sri Lanka, Sudan, Thailand, Timor-Leste, and Yemen are some of these nations. Global dengue fever cases hit record highs in 2019. Dengue fever has gradually returned in 2021, with reports from several nations. An estimate states that every year, 390 million cases of dengue virus infection occur (WHO, Vector-borne diseases , 2020). Vector-borne diseases pose a significant public health risk in less developed countries and are worsening. Seasonal variations, severe rainfall events, patterns of precipitation, and changes in air and water temperatures are recognized factors that impact the transmission of these diseases (Bernard Cazelles, 2005). Currently, dengue is spreading extensively following the COVID-19 pandemic (Kristie L. Ebi, 2016). In most Asian and Latin American nations today, severe dengue fever is a common occurrence and the primary cause of hospitalization and mortality for both adults and children.

Table 3: Countries with the highest number of deaths and cases of dengue during the first nine months of 2023.

Countries	Confirmed dengue cases	Deaths	Case fatality rate, CFR (%)
Brazil	2,569,746	912	0.04
Peru	264,764	431	0.16
Mexico	216,277	88	0.04
Bangladesh	208,884	1017	0.49
Bolivia	140,246	83	0.06
Nicaragua	134,239	2	0.00
Argentina	123,357	65	0.05
Colombia	94,527	74	0.08
India	94,198	91	0.10
Philippines	80,318	299	0.37

Source: European Centre for Disease Prevention and Control, Global Dengue Report. https://www.ecdc.europa.eu/en/dengue-monthly

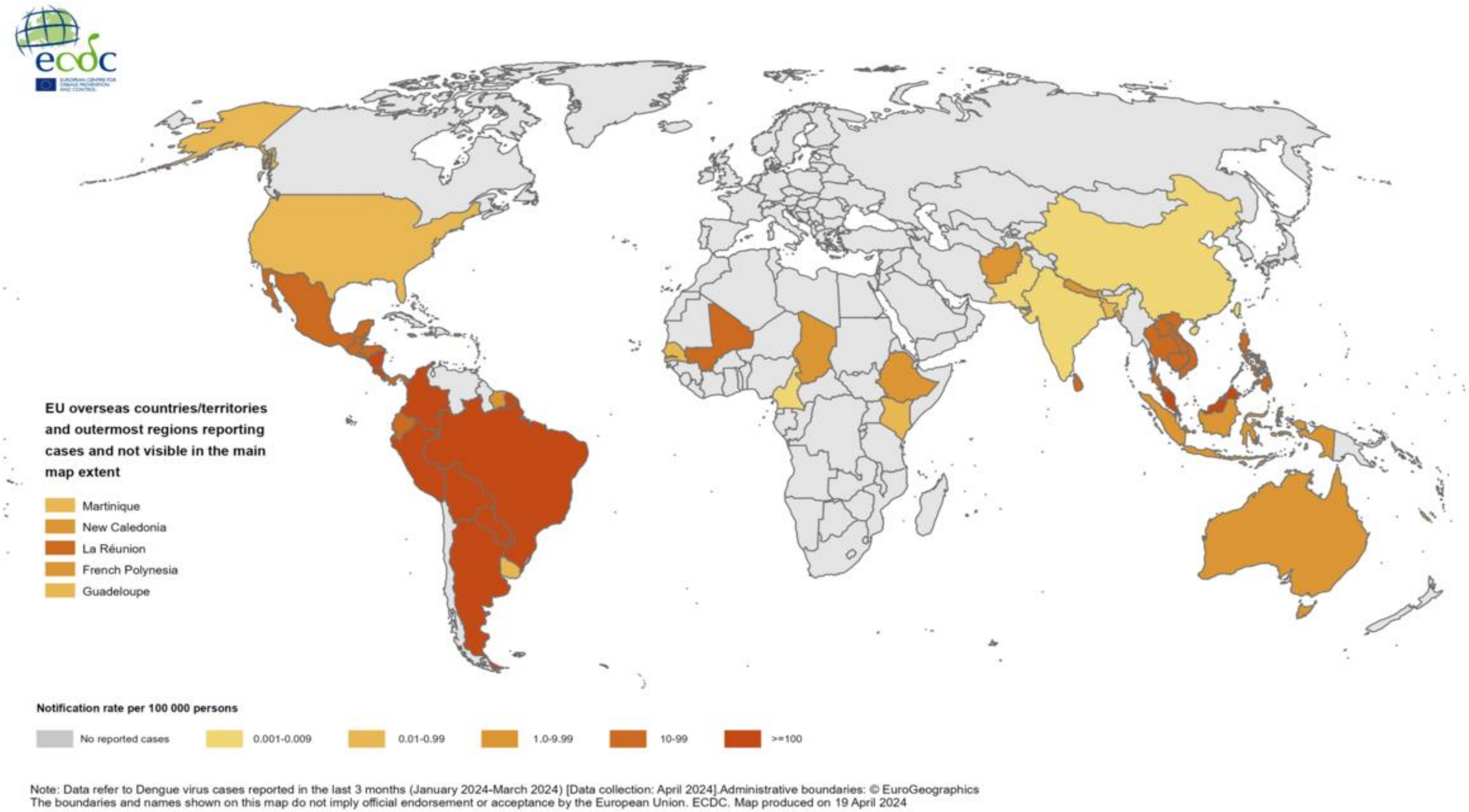


Figure 13: The dengue cases recorded globally by geographic distribution

***Source*-** European Centre for Disease Prevention and Control, Global Dengue Report. https://www.ecdc.europa.eu/en/dengue-monthly

2.2 National Status

India, standing as the fifth-largest economy on globally (Prasanna, 2014). It showcases remarkable diversity with its mix of religions, ethnicities, cultures, and languages. India, primarily reliant on agriculture, benefits from two monsoon seasons i: e, one the intense and the longer, more intense southwest monsoon runs from May to September, whereas the shorter, milder northeast monsoon occurs in November and December. (Prasanna, 2014). Climate change presents a complex array of health challenges for India, a densely populated developing nation with 1.4 billion people. The possible rise in vector-borne infections such as Chikungunya, Japanese encephalitis, Dengue, Kala-azar, malaria, and dengue fever is one cause for concern. Of the many illnesses caused by these mosquitoes, dengue has become a major and crippling health concern in recent years. It affects people of all ages and is prevalent throughout many states, especially in metropolitan areas. This is mostly because of its higher case fatality rate (Paulson W, 2022).

The dengue virus was initially discovered in India in 1945. The country's first dengue cases were reported in the Vellore region of Tamil Nadu in 1956 (Karamchandani, 1946). The first outbreak of dengue haemorrhagic fever (DHF) occurred in Calcutta, West Bengal, in 1963 (Karamchandani, 1946). Dengue cases have been reported in 35 states and one UT over the previous 20 years (excluding Lakshadweep) (NVBDCP, Dengue-National-Guidelines-2014). A number of states and union territories (UTs) have reported recurring dengue fever (DF)/DHF outbreaks, including Andhra Pradesh, Chandigarh, Delhi, Goa, Gujarat, Haryana, Karnataka, Kerala, Maharashtra, Rajasthan, Uttar Pradesh, Puducherry, Punjab, Tamil Nadu, and West Bengal. Delhi experienced one of the deadliest DF/DHF epidemics in history in 1996, with 10252 cases and 423 documented deaths (a total of 16 517 cases and 545 deaths nationally) (NVBDCP, Dengue-National-Guidelines-2014). A DF/DHF outbreak struck the nation in 2006, resulting in 12,317 illnesses and 184 fatalities. The past few years have seen a rise in dengue cases. There were 28292 cases recorded in total in 2010, 50222 cases in 2012, and 75808 cases in 2013—the greatest number since 1991. Case fatality ratio (CFR, or deaths per 100 cases) dropped from 3.3% in 1996 to 0.4% in 2010 after national recommendations for the clinical treatment of dengue shock syndrome (DSS)/DF/DHF were developed and disseminated in 2007. This decreased even more to 0.3% in 2023 (NVBDCP, Annual Report NVBDCP, 2014-15). According to estimations, the age range of 21 to 30 years old accounted for the majority of dengue cases, which led to 75,808 recorded cases and 195 deaths (Tyagi BK, 2006). (Tyagi BK, 2006). Kerala State was severely impacted; over 3,000 cases and over fifty deaths were reported (Tyagi BK, 2006). The increasing number of young adults affected by dengue, rather than just children and adolescents, indicates that non-immune adults are now becoming susceptible to the circulating serotype of the dengue virus (National Center for Biotechnology Information, 2015). Afterwards, many dengue epidemics have been documented in several Indian states. Experts and health authorities are concerned about how to prevent and control dengue in the nation given the ongoing increase in cases (Wilder-Smith A, 2019). The greatest indicators of dengue incidence are rainfall and the rising temperatures of the four months prior (2020–2023) (Samal, 2020). Climate variables, such as temperature, rainfall, and RH, are important correlates of dengue transmission, according to a large body of research from around the world. Variations in these variables dictate the strength and length of the transmission (Samal, 2020).

Every year, from July to November, there is a discernible rise in dengue and DHF cases, which follow a seasonal pattern with a peak that happens following the monsoons. However, several states in the nation's west and south see year-round transmission (Murhekar M, 2019).

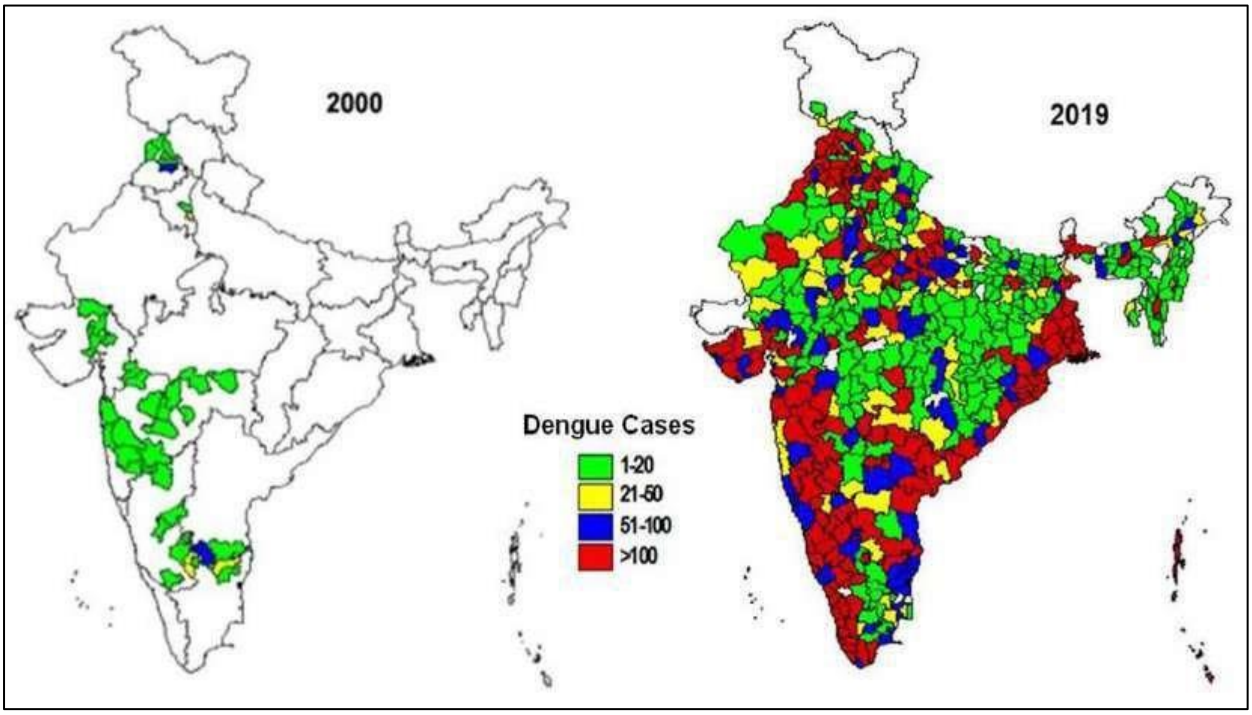


Figure 7: Geographical spread of Dengue over the last two decades in India.
(Baruah, 2021)

In the past, Ae. aegypti rearing was more abundant in cities, which led to a predominance of the disease in those places. However, Ae. aegypti mosquitoes have been able to spread to rural areas due to socioeconomic and artificial ecological changes. This change has made it much more likely that diseases will spread in rural areas (NVBDCP, Dengue-National-Guidelines-2014).

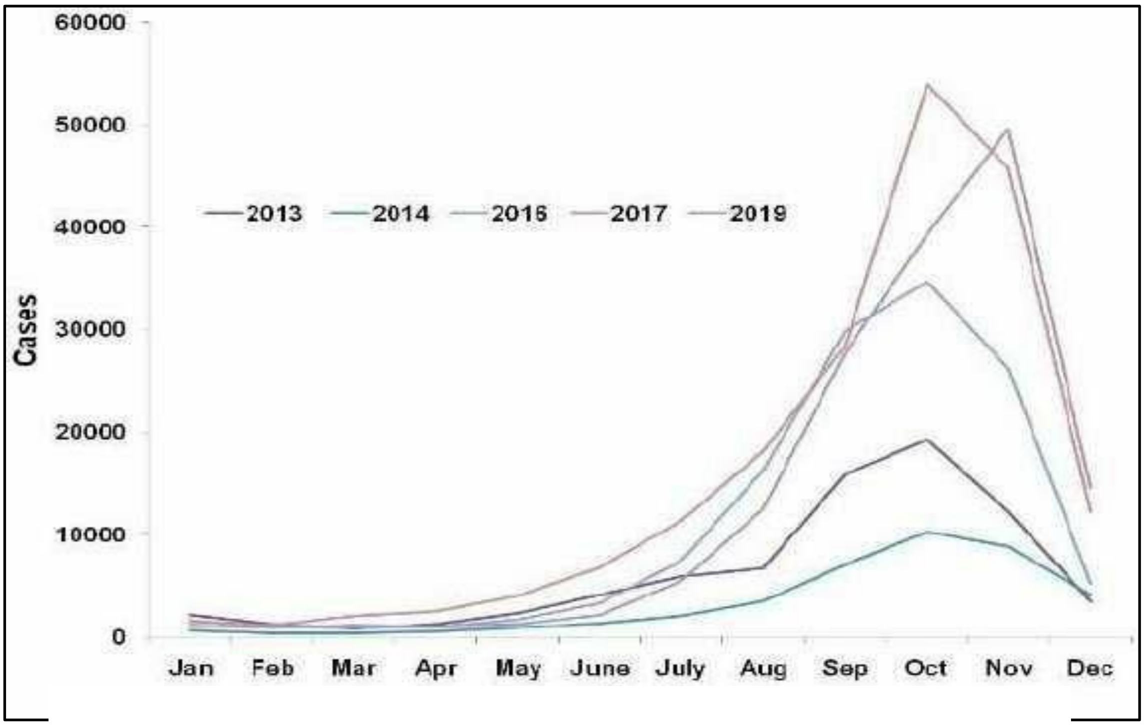


Figure 15 Seasonal pattern of dengue In India since 2013-2019
(Baruah, 2021)

2.3 Dengue Scenario in Delhi

The first significant dengue virus outbreaks since 1967 have occurred in India's capital city of Delhi (Ballani, 2014). Most Indian states have it as an endemic disease, and after the national outbreak in 1996, there were multiple further outbreaks (Ballani, 2014). Dengue was endemic in a few northern (Haryana, Punjab, Delhi, Rajasthan, and Chandigarh) and southern (Maharashtra, Tamil Nadu, Puducherry, and Karnataka) states around the beginning of the 20th century (Chakravarti A, 2012). However, in recent years, it has been spread to many other States and Union Territories. The dengue epidemic has been a serious public health concern since there have been notable dengue outbreaks in Delhi (1996, 2003, 2006, 2010, 2013, 2015) (Savargaonkar et al., 2018). There was a notable DSS and DHF outbreak in the Delhi area in 2006 (Savargaonkar et al., 2018).

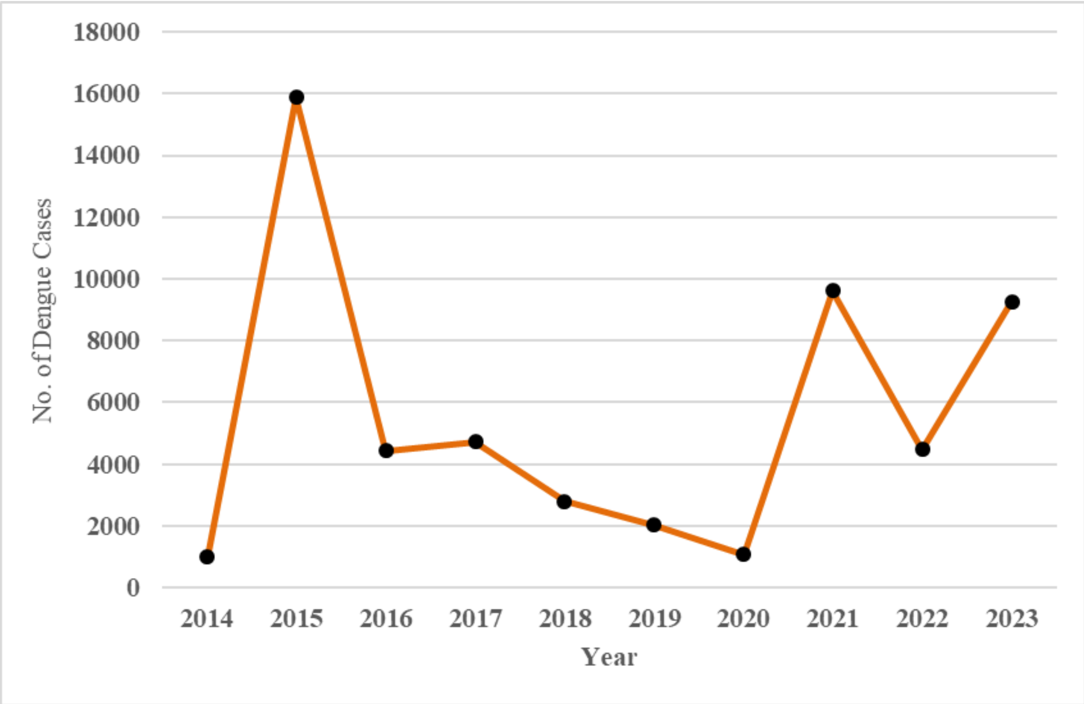
The Madhok Committee was established in 1969 to examine malaria control in urban areas (Babita Bisht, 2019). The Urban Malaria Scheme (UMS) was introduced in 1971–1972, and municipal entities were given the responsibility of implementing control measures in urban areas (Babita Bisht, 2019). Civic organizations have been given the responsibility of carrying out malaria and dengue control measures under UMS. Source reduction, anti-larval measures, small-scale engineering interventions, building bye rules, and restricted indoor residual spraying in peri-urban areas and hutments were among the tactics that were promoted (Babita Bisht, 2019). Since 2003, the Government of India's National Vector Borne Disease Control Programme has included dengue control (NVBDCP, 2014-15).

In Delhi, dengue cases began to appear during the monsoon season, reached their highest levels in the post-monsoon period, and then decreased as early winter set in (Poornima Suryanath Singh, 2022). The vector causing dengue transmission in Delhi is Aedes aegypti (Kumar et al., 2015). The epidemiology of dengue in Delhi has shown that patients with dengue infections move from urban to rural areas and across age groups as they become older (Babita Bisht, 2019). Controlling mosquito reproduction is still the only effective way to stop the spread of dengue fever in the absence of a specific therapy or vaccine. Due to a lack of piped water supplies, dengue risk has been reported to be higher in rural regions than in urban ones (Vishnampettai G. Ramachandran, 2016). Rapid urbanization and poor solid-water management, especially inappropriate water storage techniques in urban and peri-urban regions and lack of public amenities have raised the danger of dengue in recent years and resulted in an increase in mosquito breeding sites in Delhi (NVBDCP, Annual Report NVBDCP, 2014-15). A multi-institutional study carried out by the Indian Institute of Science (IISc) researchers and that has shown a steady increase in dengue cases during the previous 50 years. The virus is spread by mosquitoes and is primarily found in Southeast Asian countries (Baruah, 2021). The D2 strain of dengue has emerged as the predominant strain in recent times, with most cases occurring in Delhi (NVBDCP, Dengue-National-Guidelines-2014). In heavily crowded urban regions like New Delhi, the D2 strain of Dengue is the most dangerous and prevalent variety, capable of causing fatal haemorrhaging (NIH.gov, 2003).

Climate factors including temperature, humidity, and rainfall, among others, are also important in determining the prevalence of dengue (Ballani, 2014). Global warming caused by climate change is increasingly becoming a serious concern. Climate variables including temperature, humidity, and rainfall encourage the growth of mosquitoes and the spread of disease. An increase in dengue transmission has been observed in northern India with every 2 °C increase in temperature due to climate change. The effects of global warming have been seen, and reports of dengue cases have come in even during the winter (Karamchandani, 1946). The rainy season's favourable temperature and humidity levels boost the adult vector's survival rate, allowing the mosquito to finish the virus's extrinsic incubation period in the mosquito (Bernard Cazelles, 2005).

Present paper is focused on correlation between dengue cases and meteorological variables such as AT, RH and TOT Rf in Delhi. For this research study, the years 2020 to 2023 were selected based on a number of significant meteorological and epidemiological phenomena that were noted throughout this time. Delhi's annual average temperature has been trending increasing, with notable heatwaves occurred during the summer (Today, Climate Change, 2024). The summer of 2022 saw some of the hottest temperatures ever recorded—49°C (Today, Climate Change, 2024). Numerous studies have demonstrated the correlation between El Niño and dengue incidence periods, suggested that weather and climate might impact Aedes mosquitoes and DENV through a variety of interconnected pathways (Ebi, 2016). From 2020 to 2023, the monsoon seasons showed variation, with some years having more rainfall than usual and others having less. Notably, the Yamuna River saw major flooding as a result of the extraordinarily strong rains that the monsoon of 2023 brought. Delhi was severely damaged and existing infrastructure risks were exacerbated by Yamuna River flooding in 2023. Delhi also turned into a hub for dengue fever outbreaks, underscoring the problems with public health brought on by urbanization and climate change (mint, 2023). Residents in East, North-East, and South-East Delhi were forced to evacuate their flooded homes as a result of the inundation of low-lying districts. Authorities were actively monitoring the situation to prevent illness epidemics as a result of the Yamuna flood aftermath, which poses health dangers like Dengue (mint, 2023). The selected period includes significant climatic events, such as extreme temperatures, variable rainfall, and fluctuating humidity, which are critical factors influencing mosquito populations and dengue transmission in Delhi.

Dengue has no known effective treatment. A dengue vaccine has just been created, the only dengue vaccination that is currently offered in the US is dengvaxia (CDC, 2024). Children aged 9 to 16 who have a laboratory-confirmed history of dengue virus infection and reside in dengue-endemic areas are advised to take dengvaxia to avoid dengue, however it only works on seropositive infections (CDC, 2024). Currently, no antiviral drugs are available with a special purpose to treat dengue fever, and there is no vaccine that protects against every strain of the dengue virus. The primary goal of treatment is to help individuals manage their symptoms (Poornima Suryanath Singh, 2022). The most important correlates of dengue transmission, according to a plethora of international studies, are temperature, humidity, and rainfall. Variations in these variables impact the severity and length of the disease's transmission (Vishnampettai G. Ramachandran, 2016). This could be explained by how climate variables indirectly affect the lifecycles of the virus and vector, which in turn affects the incidence of dengue (Suchithra Naish 1, 2014). According to the Intergovernmental Panel on Climate Change (IPCC), the effects of climate change and global warming could put 3.5 billion people at risk of developing DF infection by the year 2080 (IPCC, IPCC Fourth Assessment Report: Climate Change, 2007). Although several published publications have examined the relationship between meteorological conditions and dengue incidence, the relationship differs throughout countries and geographical areas (Chakravarti A, 2012). Numerous studies have examined the connection between dengue incidence and climatic conditions, however the results vary across different countries and regions (Tuladhar, 2019). Due to the lack of a specific treatment and the current investigation into vaccines, education and vector control are crucial for preventing dengue. Moreover, inadequate health services provide significant challenges to dengue control in numerous regions where the disease is prevalent. Infections are easier to enter and spread into new areas due to climate change, which also raises the danger and burden of both factors (Semenza, 2021).



Source- MCD Yearly Report

Figure 16: Number of dengue cases in Delhi from 2014 to 2022

3. Objectives of the Study

1. To investigate how the season affects the dengue cases and the occurrence of dengue cases in Delhi from January 2020 to December 2023.

2. To assess the statistical analysis of Delhi's dengue incidence and meteorological parameters (relative humidity, average temperature, and total rainfall).

3. To predict future dengue outbreaks in Delhi using statistical modeling for 2024.

4.0 Study Area

Delhi was designated as the National Capital Territory in 1991 by the Government of the National Capital Territory of Delhi Act. Delhi's administrative system is divided between the Union and State governments, each of which has combined authority over the city.

Area

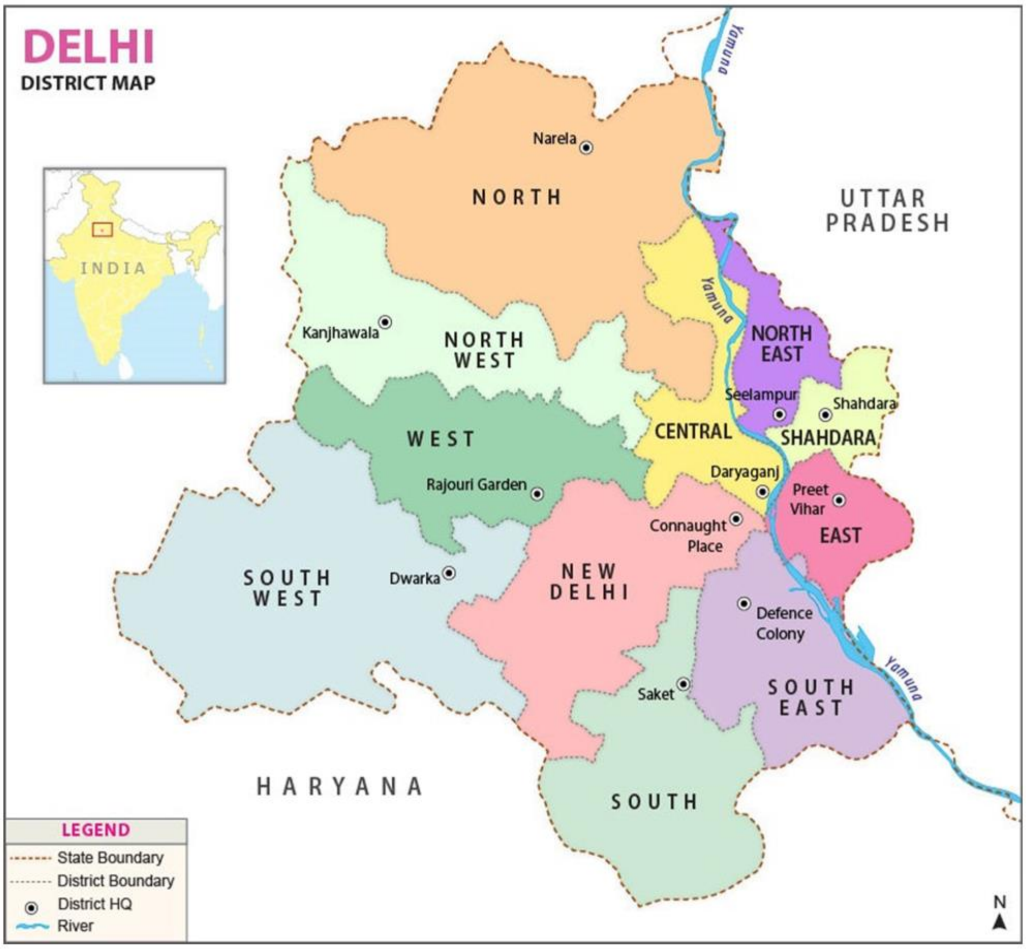
Delhi is the National Capital Territory and it is bordered by Haryana on three sides and by Uttar Pradesh in the east. Its coordinates are 28.24 to 28.53 degrees North Latitude and 76.50 to 77.20 degrees East Longitude. Delhi is the largest metropolis in terms of area in the nation, spanning 1483 km², of which 369.35 km² are classified as rural and 1113.65 km² as urban. It measures 51.9 km in length and 48.48 km in width. Delhi is divided into 11 districts and 33 Tehsils, or sub-divisions. The five administration zones that comprise Delhi, the capital of the country, are the Delhi Cantonment Board, New Delhi Municipal Corporation, South Delhi Municipal Corporation, North Delhi Municipal Corporation, and East Delhi Municipal Corporation. India is the world's largest democracy, has its capital city of Delhi. The Yamuna flood plains and the Ridge are two of Delhi's most notable features. Given that it is situated in seismic zone IV of India, significant earthquakes might easily cause damage (Economic Survey of Delhi 2023-2024).

Demographic Trends

One of the cities in the nation with the quickest growth is Delhi. Delhi's scenery has changed from predominantly rural to mainly urban due to the city's increasing urbanization. The growth in the urban area during 2001-2011 was observed at 20.44 percent. This pace of urbanization has reduced the number of villages in Delhi from 300 in 1961 to 165 in 2001 and 112 in 2011. Delhi accounts for about 0.05 per cent of India's geographical area, but comprises 1.39 per cent of the nation's population (Economic Survey of Delhi 2023-2024).

Geographical Significance

Delhi is located in the Indo-Gangetic Plains, which is in the northern region of India. The city is situated between 200 and 250 meters above sea level. Delhi is the result of the combination of India's central plains, Yamuna flood plain, and Delhi Ridge. Delhi has a climate similar to that of a tropical steppe. Delhi has a composite climate with substantial seasonal differences and temperature swings with distinct seasons, temperatures ranging (2 to 47 °C), average rainfalls of 886mm per annum with high humidity as 60-80%. Extremely hot during the summer, frequently reaching temperatures above 40°C. Wintertime brings cold, dry weather with sporadic fog and lows of about 5°C (Karamchandani, 1946).



Source- ResearchGate

Figure 17: Location Map of Delhi

5.0 Methodology

5.1 Data Source:

Various digital libraries, including Google Scholar, MDPI (Multidisciplinary Digital Publishing Institute), IEEE Xplore, ScienceDirect, PubMed, BMC (BioMed Central), PMC (PubMed Central), and PLOS (Public Library of Science), were utilized during this study. Dengue cases (monthly) data of Delhi have been taken from Delhi Municipal Corporation (MCD). These data provided by the Directorate General of Health Services (DGHS), Public Health Wing-IV, Dengue Control Cell, Integrated Disease Surveillance Programme (IDSP), National Vector Borne Disease Control Program (NVBDCP) in Shakarpur, New Delhi spanning from January 2020 to December 2023. Meteorological data i.e. monthly average temperature (°C), RH (%) were obtained from the Central Pollution Control Board (CPCB) and total rainfall (mm) from the Indian Meteorological Department (IMD), New Delhi.

5.2 Data Analysis:

In order to determine the seasonal distribution of dengue, a correlation analysis was performed between the monthly number of dengue cases reported and the monthly climate data, which included total rainfall, average temperatures, and RH. The number of reported dengue cases each month was the dependent variable, whereas the average monthly rainfall, temperature, and humidity were the independent factors. The Shapiro-Wilk Test was performed for the normality of the data set. The results found a non-normal distribution. Therefore, the Spearman Correlation Test was used to determine the most relevant environmental factors, including the months before the occurrence of dengue ($p<0.05$), due to the non-linear association between dengue cases and climate conditions. After used a number of models with different combinations of environmental factors (both total and subsets), the Multiple Linear Regression (MLR) values of the models were used to determine which model best fit the data for dengue prediction (p-value:0.041). Modeling employed environmental variables as predictors. In order to generate models for estimating dengue cases based on the independent variables (temperature, humidity, and rainfall), multiple linear regression (MLR) analysis was applied. Since there was a substantial correlation in the variability of dengue cases throughout seasons. this was done for the prediction analysis of the dependent variable i.e.; dengue cases.

5.3 Software Used for Data Processing

The R-studio software was used to analyse the data statistically.

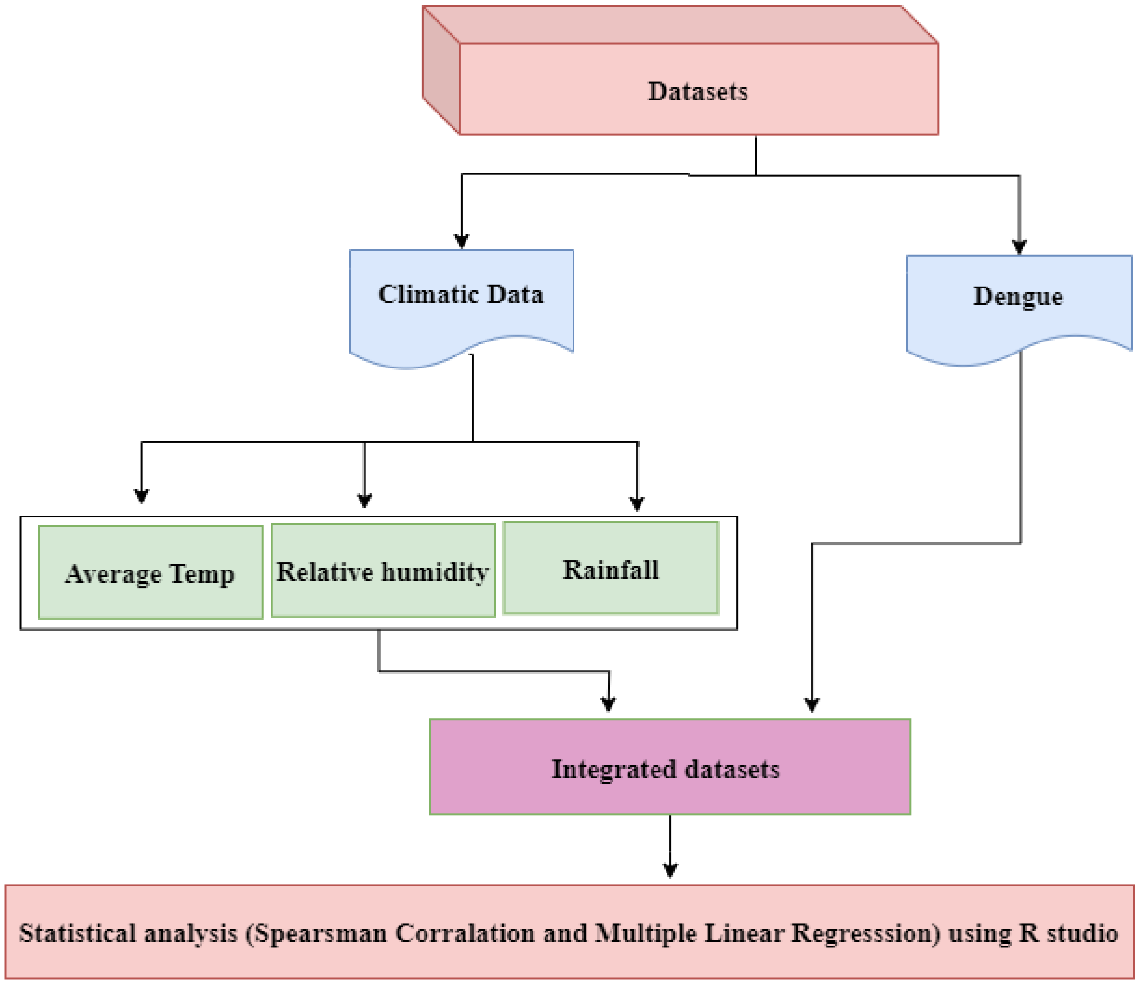


Figure 18: Methodological Flow Chart

Figure 19: Meteorological Data Collection Site-India Meteorological Department (IMD), New Delhi

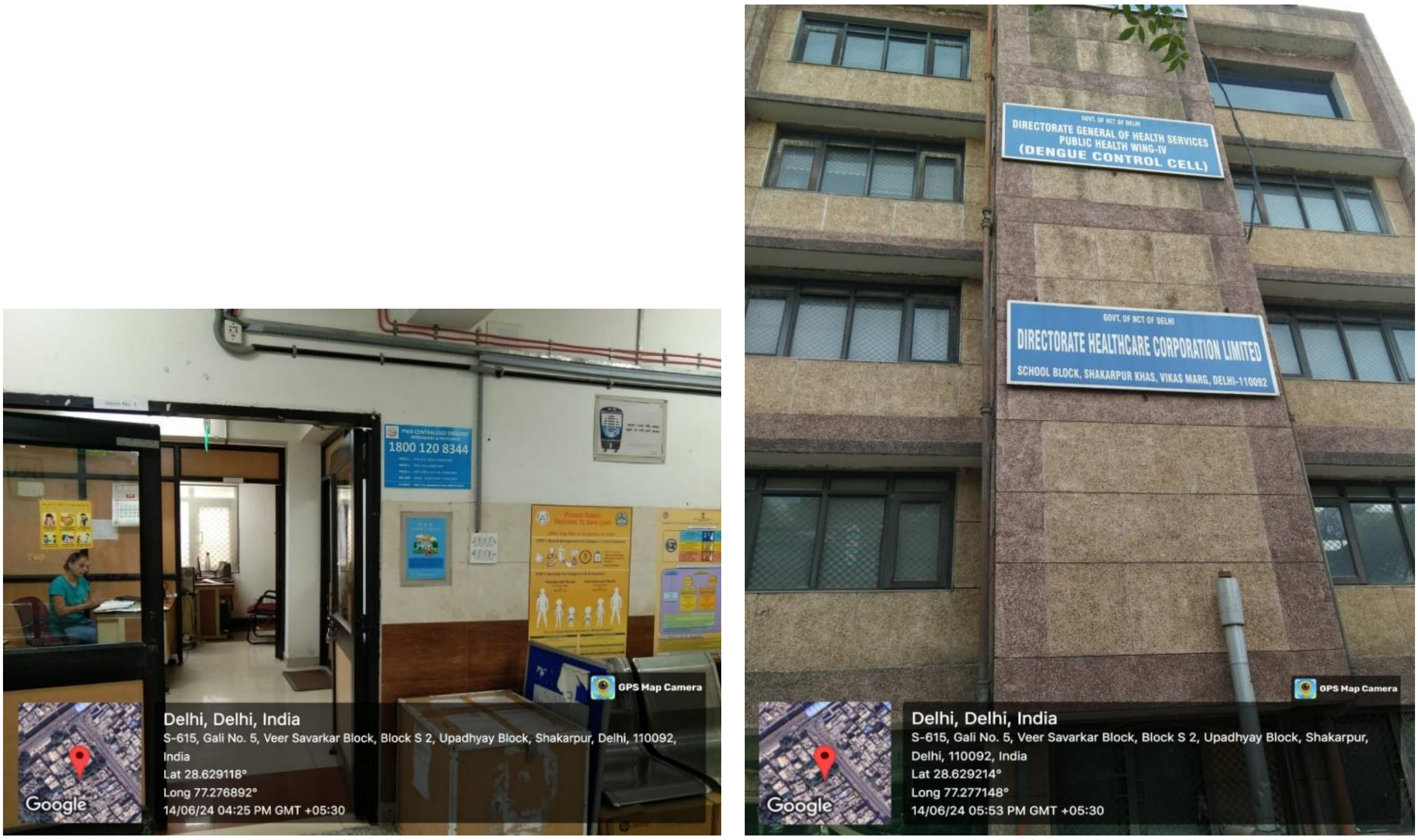


Figure 20: Dengue Data Collection Site- Public Health Wing-IV, Directorate General of Health Services, Dengue Control Cell

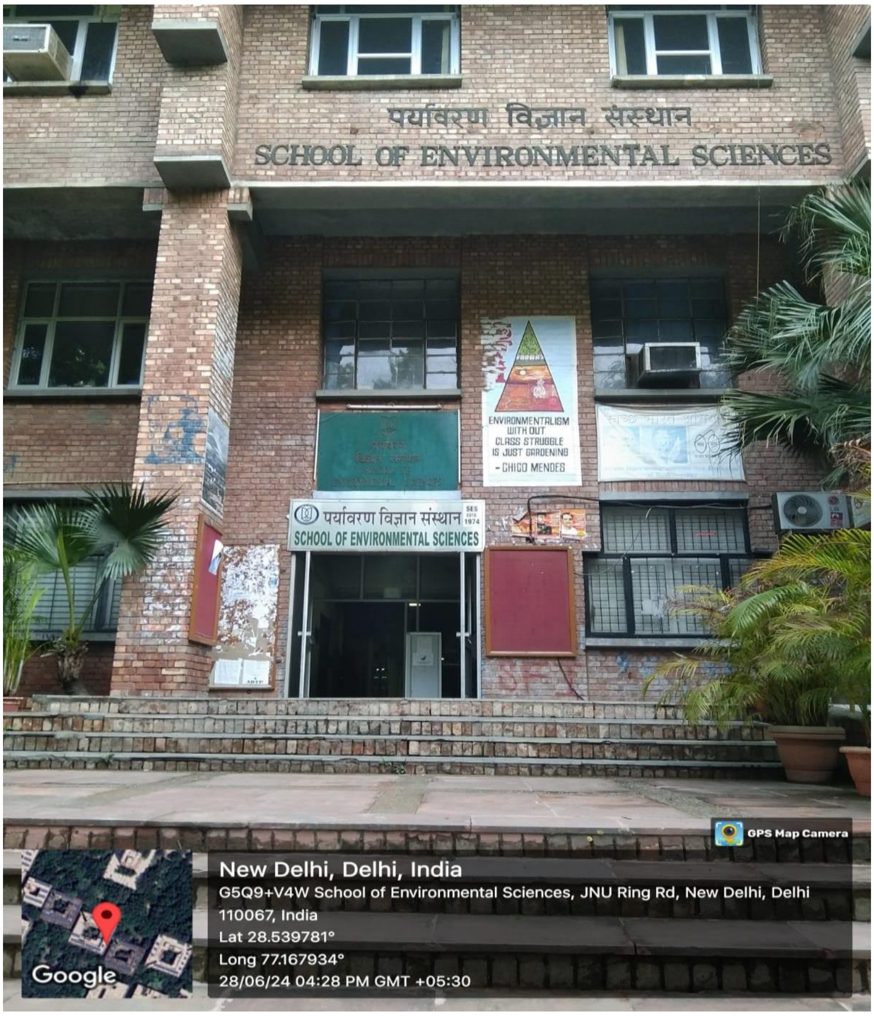


Figure 21: Data Analysis at School of Environmental Sciences (SES) Lab, JNU

6.0 Results

6.1 Descriptive Analysis:

A total of 24,420 confirmed dengue cases were recorded over the four years (2020-2023), with 2021 experiencing the highest number at 9,613 cases. As stated by the Delhi Municipal Corporation (MCD), with analysis of yearly dengue data from 2011 to 2023, 2021 marked the second-highest annual record for dengue cases till date after the worst year on record 2015((NVBDCP, Dengue-National-Guidelines-2014). The number of cases dropped sharply in 2020 to 1,072, decreased to 4,469 in 2022, and then significantly increased again in 2023 to 9,266 cases.

Table 4 shows the substantial variations in temperature, rainfall, and humidity during the pre-monsoon, monsoon, post-monsoon, and winter periods of each year. The Indian Meteorological Department (IMD) provided total rainfall (mm) for this study. The Central Pollution Control Board (CPCB) provided the monthly average temperature (˚C) and RH (%). Based on the data, the average monthly rainfall during the pre-monsoon, monsoon, post-monsoon, and winter were 52.92 mm, 169.81 mm, 32.89 mm, and 39.69 mm, respectively, for the four-year period (2020 to 2023). Pre-monsoon, monsoon, post-monsoon, and winter temperatures were reported at 27.54˚C, 31.36˚C, 21.15˚C, and 15.21˚C, respectively. The maximum RH are observed in winter (70.76%) and followed by monsoon (65.77%), post-monsoon (64.90%) and minimum in pre-monsoon (48.40%).

6.2 Seasonal Pattern of Dengue:

Dengue cases followed a seasonal pattern, peaking during the post-monsoon season from 2020 to 2023, with the highest incidence from August to November. Humidity trends showed that the most cases occurred when humidity ranged from 60% to 70%. Dengue cases increased from July to September, peaked from October to December, and declined by January, with November seeing the highest incidence. Starting in June, a slight decrease in temperature and an increase in rainfall and humidity corresponded with the annual rise in dengue cases in July.

Table 4: Seasonal differences in the annual count of dengue cases (2020–2023)

Year	Winter	Pre-monsoon	Monsoon	Post-monsoon	Total
2020	4	15	247	806	1072
2021	2	27	312	9272	9613
2022	39	72	826	3532	4469
2023	28	54	3396	5788	9266

* ***Data Source***: **Municipal Corporation of Delhi**

Winter- January, February; Pre-monsoon – March, April, and May; Monsoon- June, July, August, and September; Post-monsoon- October, November, December. (IMD Season Classification)

Table 5: Dengue cases and Case Fatality Rate (CFR %) each year (2020-2023)

Year	Cases of Dengue	Death	CFR (%): Case Fatality Rate
2020	1072	1	0.09
2021	9613	23	0.23
2022	4469	9	0.20
2023	9266	7	0.07

******Data Source***: Municipal Corporation of Delhi**

Table 6 Distribution of climatic parameters by season (2020-2023)

Year	Total Rainfall (mm)				Average Temperature (˚C)				RH (%)			
	Winter	Pre-monsoon	Monsoon	Post-monsoon	Winter	Pre-monsoon	Monsoon	Post-monsoon	Winter	Pre-monsoon	Monsoon	Post-monsoon
2020	29.46	80.69	143.32	0.17	13.485	26.84	31.93	21.50	69.78	49.81	63.65	56.17
2021	57.53	54.19	254.49	43.85	16.23	26.77	31.35	20.79	69.81	43.76	66.24	67.63
2022	59.69	15.91	117.22	79.92	14.73	30.50	30.69	21.14	73.53	47.64	64.75	66.85
2023	12.06	60.88	164.20	7.62	16.40	26.05	31.48	21.19	69.93	52.40	68.45	68.94
Average	39.69	52.92	169.81	32.89	15.21	27.54	31.36	21.15	70.76	48.40	65.77	64.90

*Data Source: Indian Meteorological Department (IMD) & Central Pollution Control Board (CPCB), New Delhi

Winter- January, February; Pre-monsoon – March, April, and May; Monsoon- June, July, August, and September; Post-monsoon- October, November, December. (IMD Season Classification)

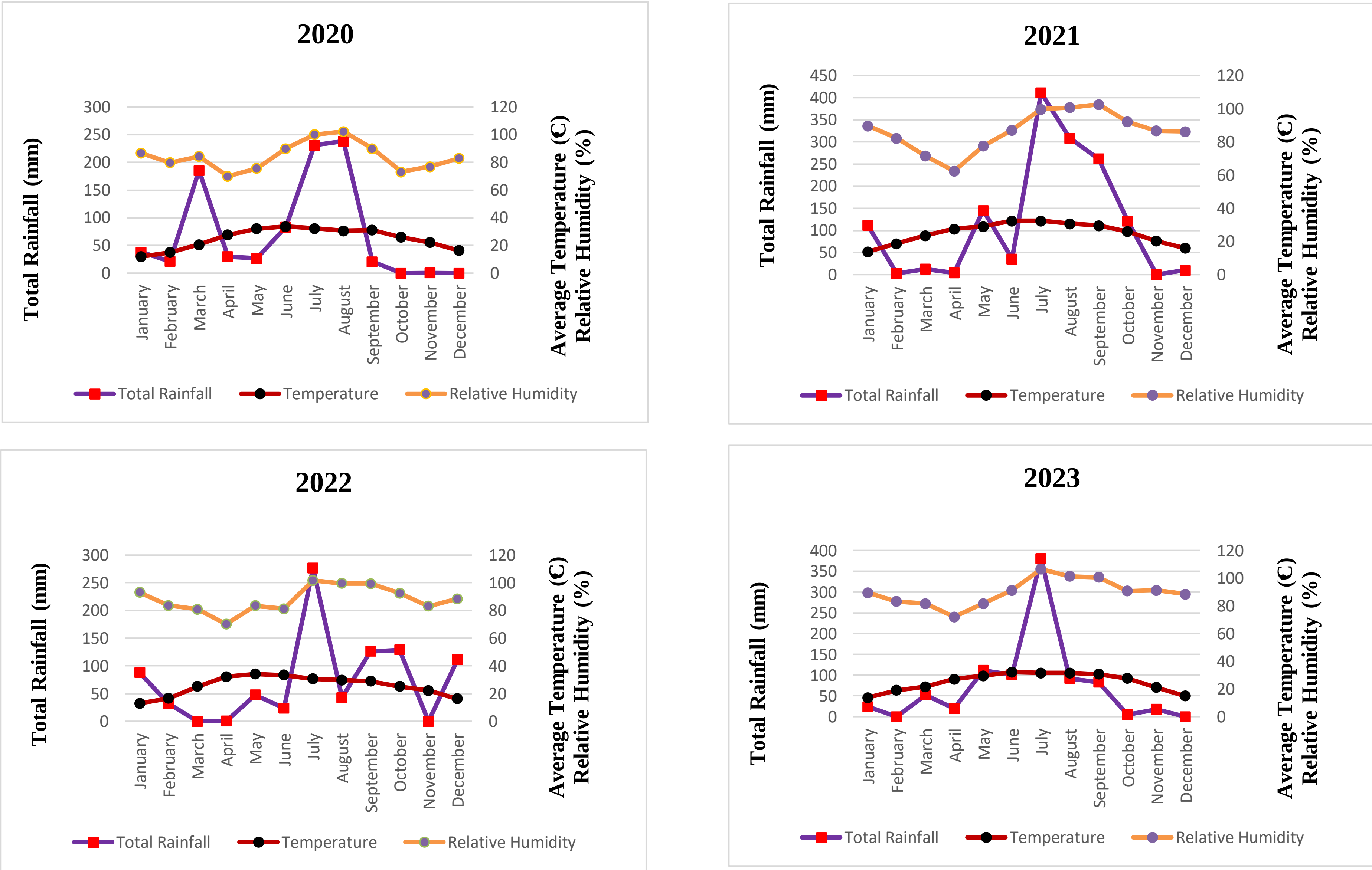


Figure 22: Line graphs displaying Delhi's environmental variables' month-by-month patterns (2020-2023)

Correlating environmental variables (Total Rainfall, RH, and average temperature) of year 2020-2023 (Fig-15) signifies, Rainfall is relatively low from January to May. There is a significant increase in June, peaking in July, and then gradually decreasing from August to December as the relevance of retreating monsoon. The highest rainfall occurs in July, reaching around 400 mm in 2021.

The temperature is fairly consistent throughout the years, ranging roughly between 20°C and 30°C. There is a slight increase in temperature from April to June, peaking in June, and then a gradual decline from July onwards.

RH throughout the years starts around 70% in January, dips slightly in April, and then rises steadily from May onwards. The highest humidity is observed from June to September, aligning with the monsoon season, and then it decreases slightly towards the end of the year. Peak humidity in the monsoon season is approximately 75%. The climatic data for Delhi for the years 2020–2023 shows a definite seasonal trend for temperature, rainfall, and humidity.

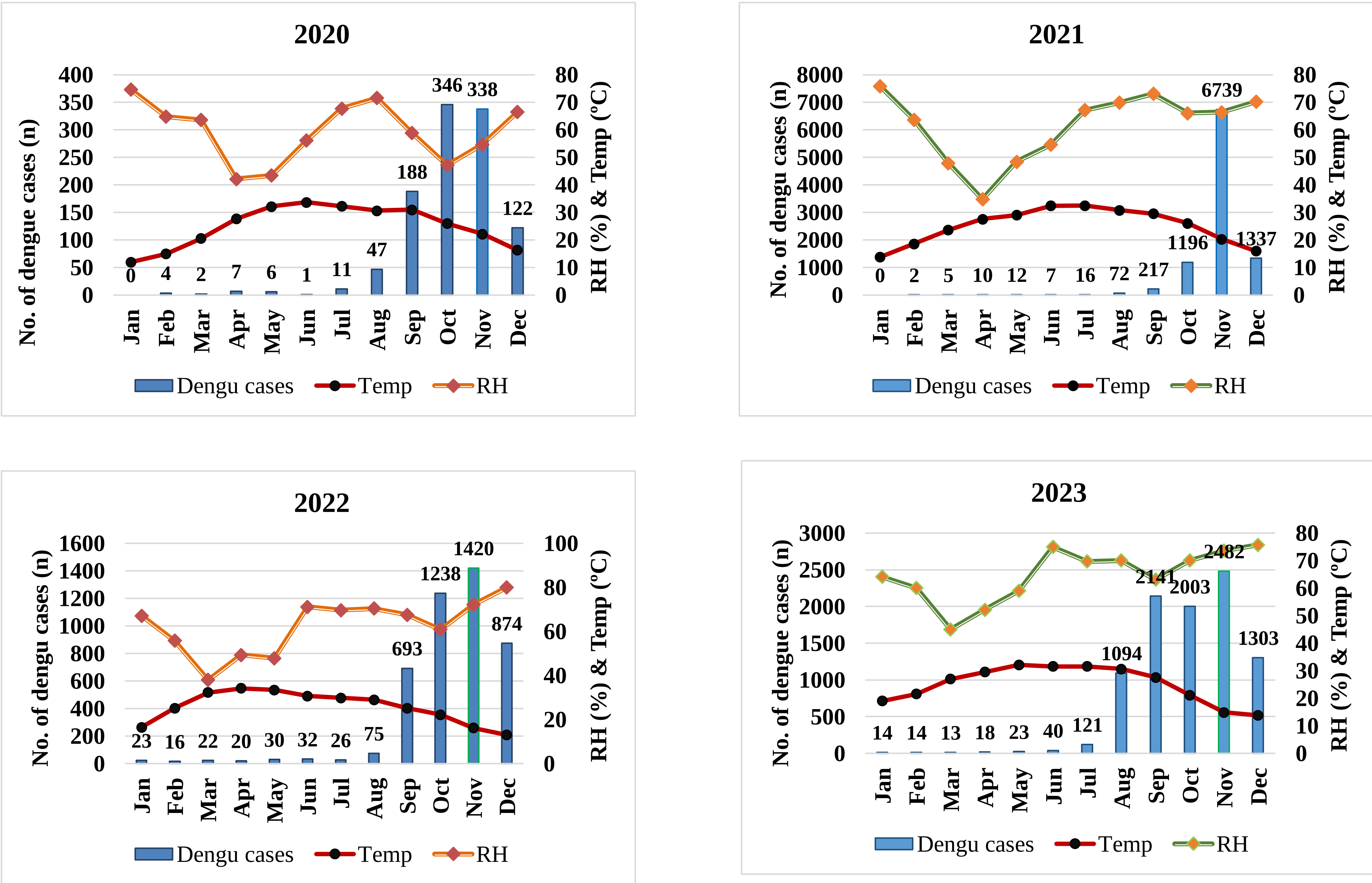


Figure 23: Average number of dengue cases, temperature, and RH by month in Delhi (2020-2023).

Correlating monthly averages for temperature, RH, and dengue cases since 2020-2023 in Delhi (Fig-16) signifies that, temperature remains relatively stable each year the years, with slight variations among the years. The pre-monsoon/summer are warmer than the rest of the year, and as the monsoon season approaches in July, the temperature begins to drop. The temperature curve shows a downward trend in the latter part of the years around post-monsoon seasons. RH shows a significant increase during the monsoon season (July to September), peaking around August and September. RH remains relatively high from July to November, followed by a slight decline in December.

From the combined analysis, it is concluded that the increase in dengue cases correlates with the monsoon season (July to September) when RH is high. Elevated RH creates ideal hatching grounds for mosquitoes, which dengue carriers. The peak in dengue cases during October may be attributed to the cumulative effect of high humidity in the preceding months. Although temperature remains relatively stable, it plays a crucial role in mosquito breeding and virus replication. Dengue cases rise as the temperature declines slightly after the peak summer months, indicating that moderate temperatures combined with high humidity create optimal conditions for mosquito activity. The monsoon season in Delhi (July to September) is critical for dengue growth due to increased water stagnation and favourable breeding conditions for mosquitoes.

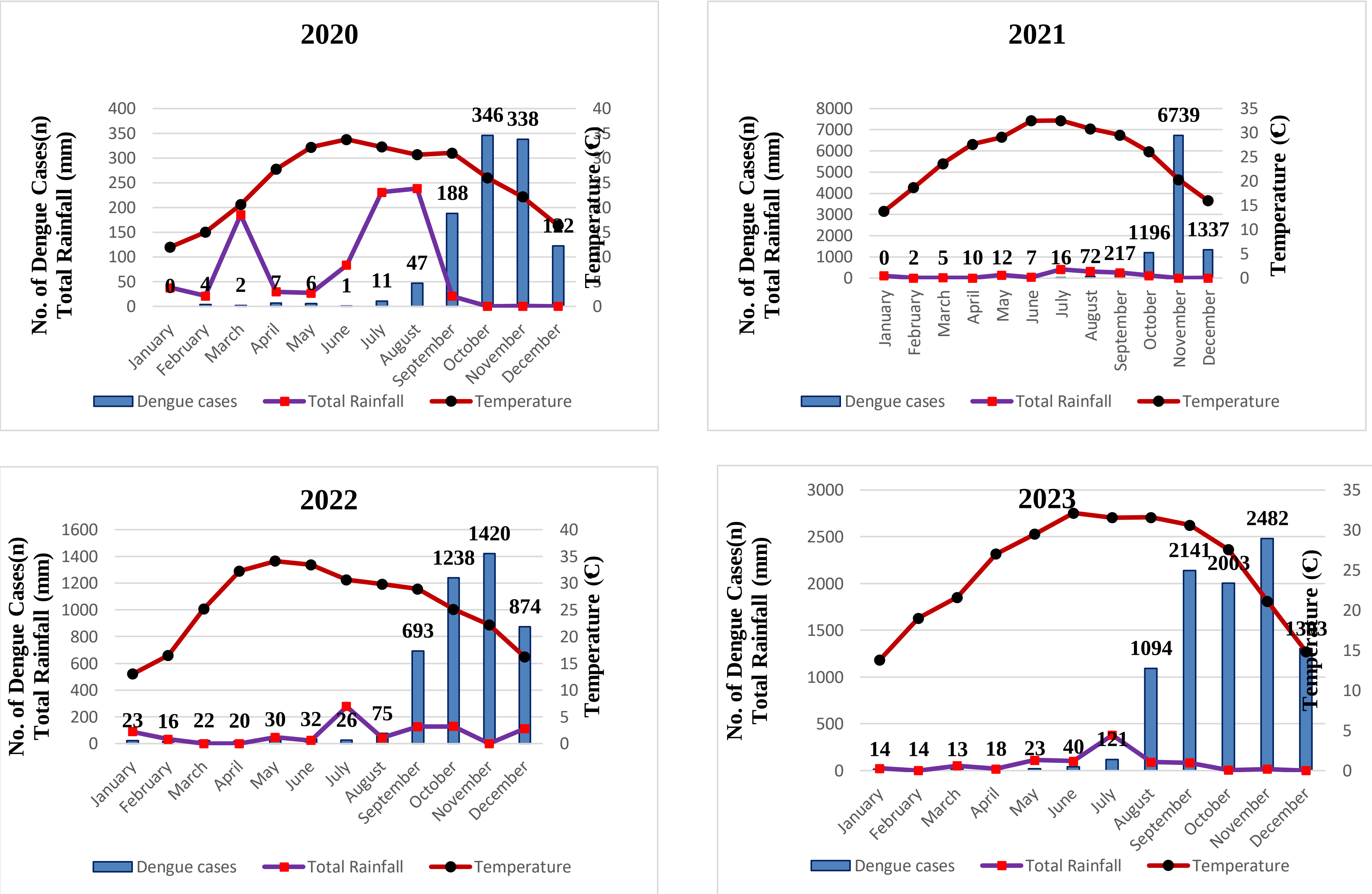


Figure 24: The average monthly temperature, total rainfall, and dengue case count in Delhi (2020-2023).

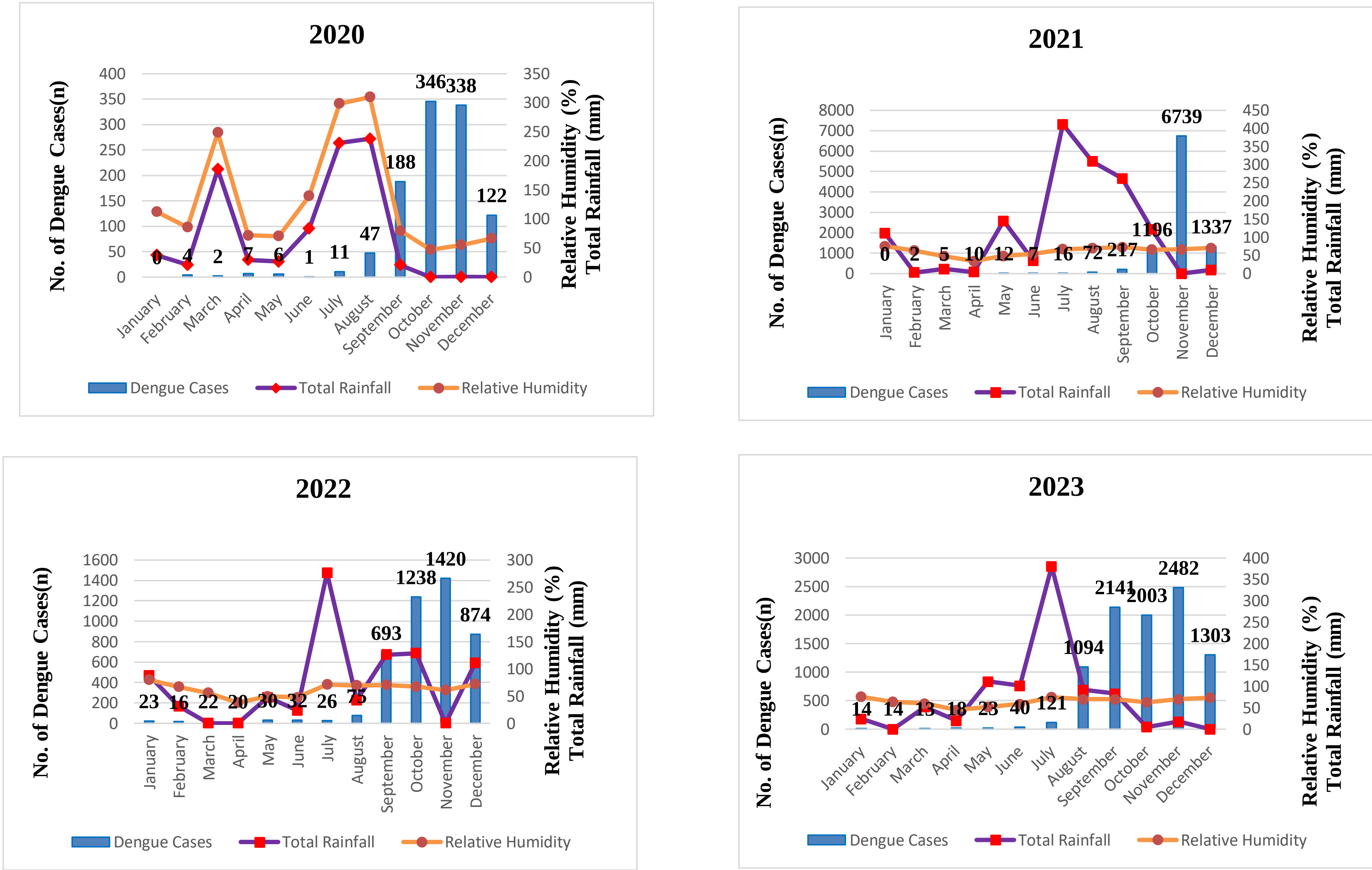


Figure 25: Dengue case counts per month with Delhi's average annual rainfall and RH (2020–2023).

6.3 Statistical Analysis:

6.3.1 Spearman Rank Correlation Test

A non-parametric statistical technique for determining the direction and strength of a relationship between two ranked variables is the Spearman Rank Correlation Test. The Spearman correlation analyses monotonic correlations, whether or not they are linear, in contrast to the Pearson correlation, which measures linear relationships.

Correlation coefficient (ρ or rho) ranges from -1 to +1

+1 indicates a perfect positive monotonic relationship

-1 indicates a perfect negative monotonic relationship

0 indicates no correlation

6.3.2 Multiple Linear Regression (MLR)

A statistical method for simulating the relationship between one dependent variable and two or more independent variables is called multiple linear regression (MLR). This model uses a regression coefficient and determines the association between input and output. It also optimizes the regression coefficients through minimizing prediction error (Verma Et al., 2023). This model was used in our study for the prediction of dengue cases in Delhi for the year 2024. The equation of MLR is given below:

Output: $yi=\beta 0+\beta 1xi1+\beta 2xi2+...+\beta pxip+\epsilon$

Hence, given an i=n of observations:

yi stands for dependent variable.

xi = explanatory factors

$\beta 0$=the constant term y-intercept.

For each explanatory variable, βp represents the slope coefficients.

ρ=the error term of the model (sometimes called the residuals)

Dependent Variable (Y): The outcome or the variable being predicted. Independent Variables (X1, X2, X3, X4..... Xn): The predictors or factors that influence the dependent variable.

6.4 Temporal Analysis of Environmental Variables with Dengue Cases (2020-2023)

The MLR analysis and Spearman rank correlation test both indicated that the total variation in all three environmental variables was statistically significant. The findings from (Fig. 18) indicate that the Spearman correlation test results for temperature, RH, and rainfall with Dengue incidence are (P) of 0.041 < 0.05. There is a correlation between relative humidity and the occurrence of Dengue. The study conducted a Spearman correlation analysis to determine the strongest association between dengue occurrence and three climate factors: average temperature, total rainfall, and RH. The analysis was conducted for four seasons i.e., Pre-monsoon, Monsoon, Post-monsoon, and Winter.

A correlation was found between dengue cases and meteorological variables (temperature, rainfall, and RH), according to the Spearman rank correlation test. Figure 19 indicates that, throughout the course of all years, rainfall continuously demonstrates a positive link with temperature and RH. However, it consistently showed a negative correlation with dengue cases, indicating that higher rainfall does not necessarily lead to more dengue cases and might even have a suppressive effect. RH has a mixed correlation with dengue cases. In some years (2021, 2022, 2023), it showed a slight positive correlation with dengue cases, suggesting that higher RH might be slightly conducive to dengue proliferation.

The relationship with temperature is consistently negative, especially in 2022 and 2023. It is suggested that higher temperatures may not favour the spreading of dengue. While, sometimes high temperature shortens the insects' extrinsic incubation period and limit virus replication. The temperature and rainfall showed a consistent negative correlation, although the correlation with RH varied and was marginally positive during the last three years (2021-2023). The data revealed that while temperature and rainfall often have negative relationships with dengue outbreaks, they have an impact on the feeding blood meal and vector maturation duration. Higher humidity during and after the rainy season promotes mosquito development and proliferation, increasing the number of infected mosquitoes.

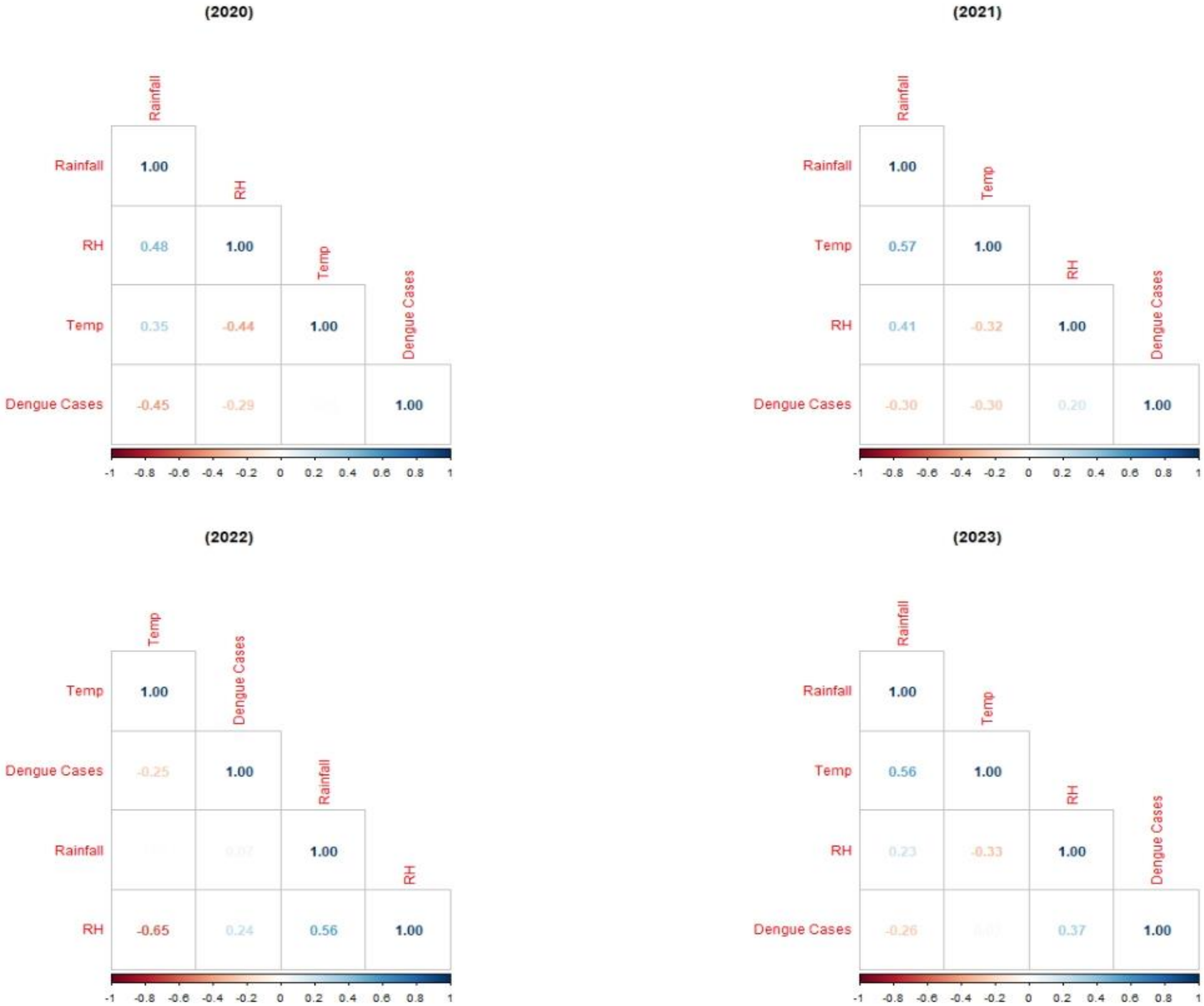


Figure 26: Seasonal patterns of dengue with relation to environmental variables by month (2020-2023).

6.5 Seasonal Analysis of Environmental Variables with Dengue Cases in Delhi (2020-2023)

6.5.1 Correlation Among the Variables with Dengue Cases during Monsoon Season

Environmental Variable	Incident of Dengue Cases	Significance
	Correlation coefficient (r)	
Temperature	-0.30	The week negative correlation suggested that higher temperatures were associated with decrease in dengue cases.
Humidity	0.27	The week positive correlation suggested that higher relative humidity have been associated with a slight increase in dengue cases.
Rainfall	-0.25	The weak negative correlation suggested that higher rainfall have been associated with decrease in dengue cases.

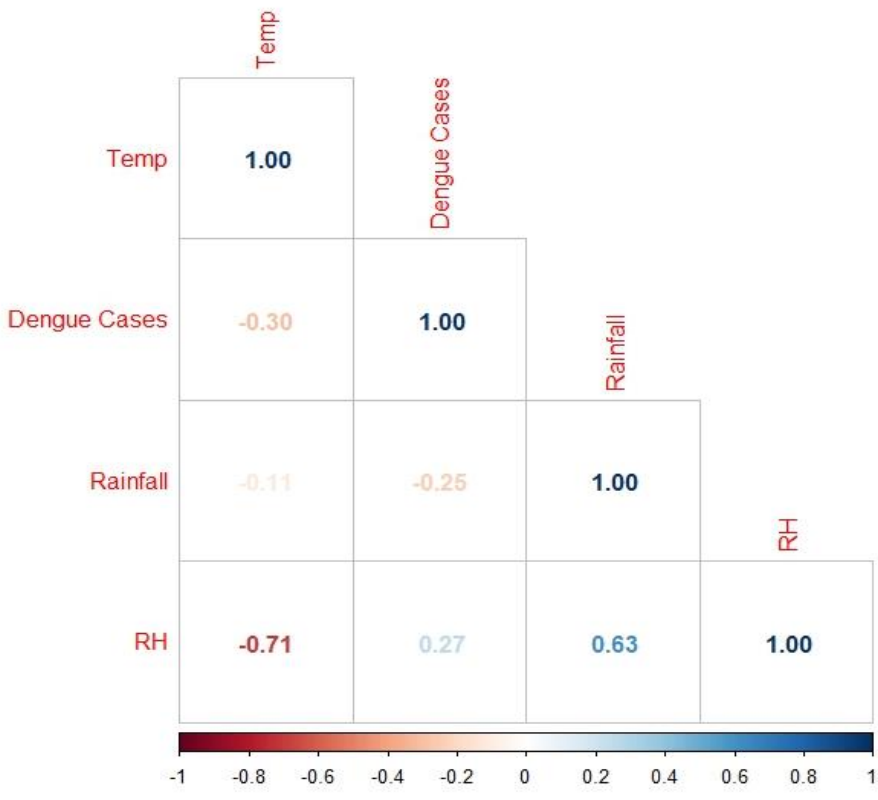


Figure 27: Correlation between Dengue Cases and Temp, RH, Rainfall in Monsoon from 2020 to 2023.

6.5.2 Correlation Among the Variables with Dengue Cases during Post-Monsoon Season

Environmental Variable	Incident of Dengue Cases	Significance
	Correlation coefficient (r)	
Temperature	0.12	The very week positive correlation suggested that moderate temperatures have been associated with increase in dengue cases, but the association is minimal.
Humidity	0.24	The week positive correlation was significant and suggested that higher relative humidity have been associated with increase in dengue cases.
Rainfall	-0.16	The very weak negative correlation suggested that moderate rainfall might have been associated with a slight decrease in dengue cases, but the association is minimal.

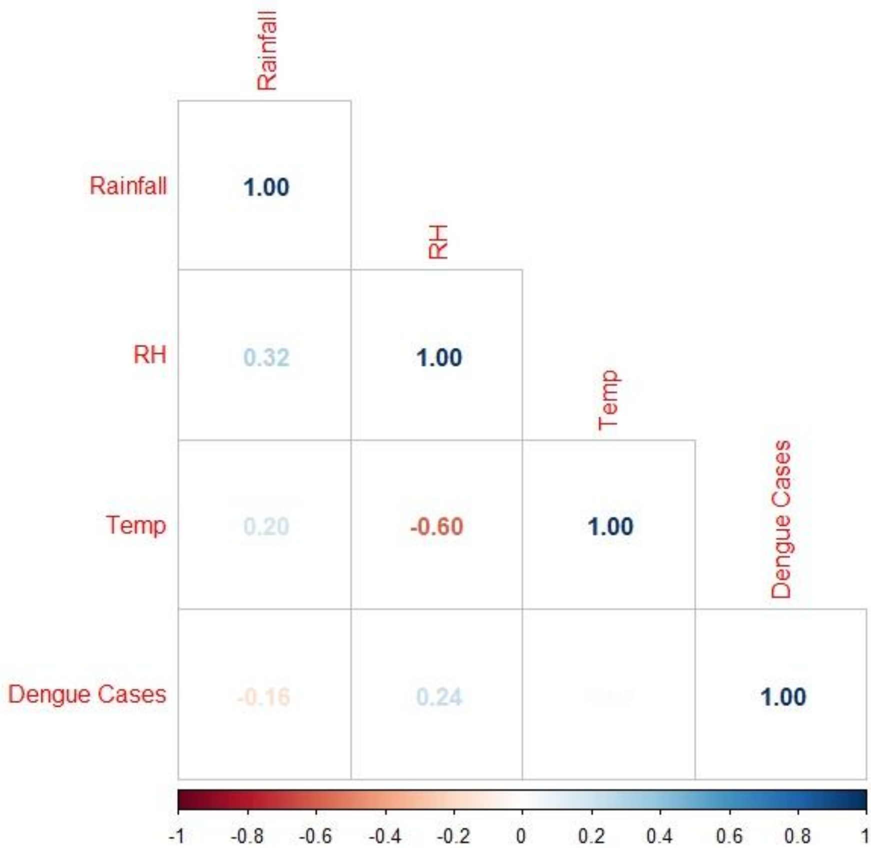


Figure 28: Correlation between Dengue Cases and Temp, RH, Rainfall in Post monsoon from 2020 to 2023.

6.5.3 Correlation Among the Variables with Dengue Cases during Winter Season

Environmental Variable	Incident of Dengue Cases	Significance
	Correlation coefficient (r)	
Temperature	0.05	The very week positive correlation suggested that no significant correlation found between temperature and dengue cases.
Humidity	0.23	The week positive correlation suggested that higher relative humidity have been associated with a slight increase in dengue cases.
Rainfall	0.02	The very weak positive correlation suggested that no significant correlation found between rainfall and dengue cases.

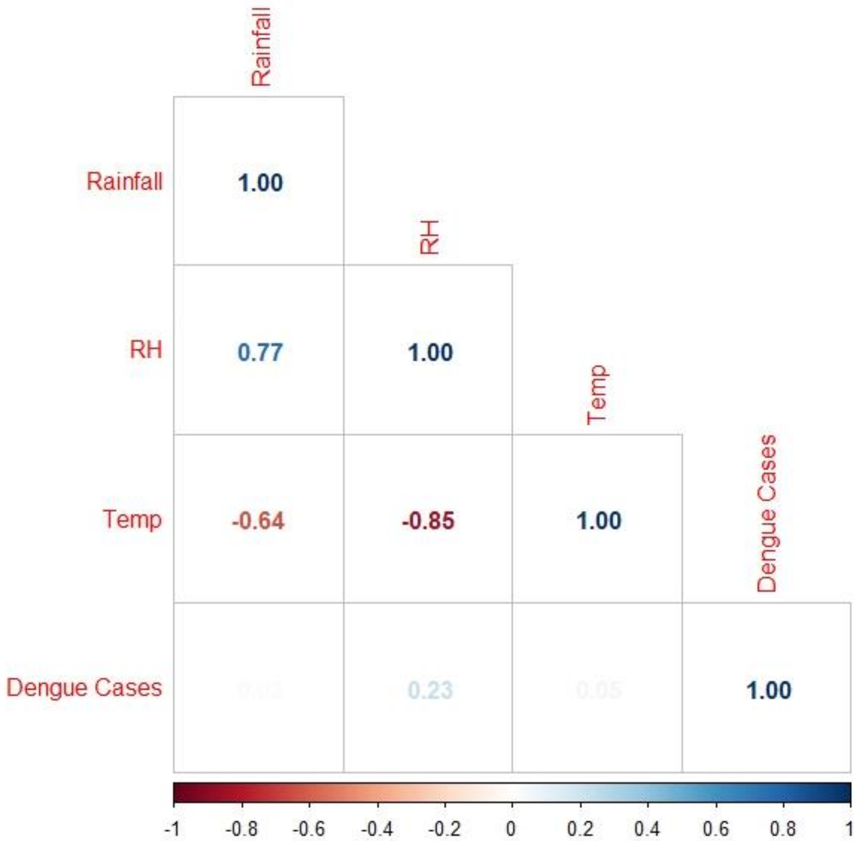


Figure 29 Correlation between Dengue Cases and Temp, RH, Rainfall in Winter from 2020 to 2023

6.5.4 Correlation Among the Variables with Dengue Cases during Pre-Monsoon Season

Environmental Variable	Incident of Dengue Cases	Significance
	Correlation coefficient (r)	
Temperature	0.53	The strong positive correlation suggested, higher temperatures have been associated with an increase in the number of dengue cases.
Humidity	-0.03	The very week positive correlation suggested that relative humidity have little to no direct association with the incidence of dengue cases.
Rainfall	-0.22	The weak positive correlation suggested that increased rainfall have been slightly associated with a reduction in dengue cases.

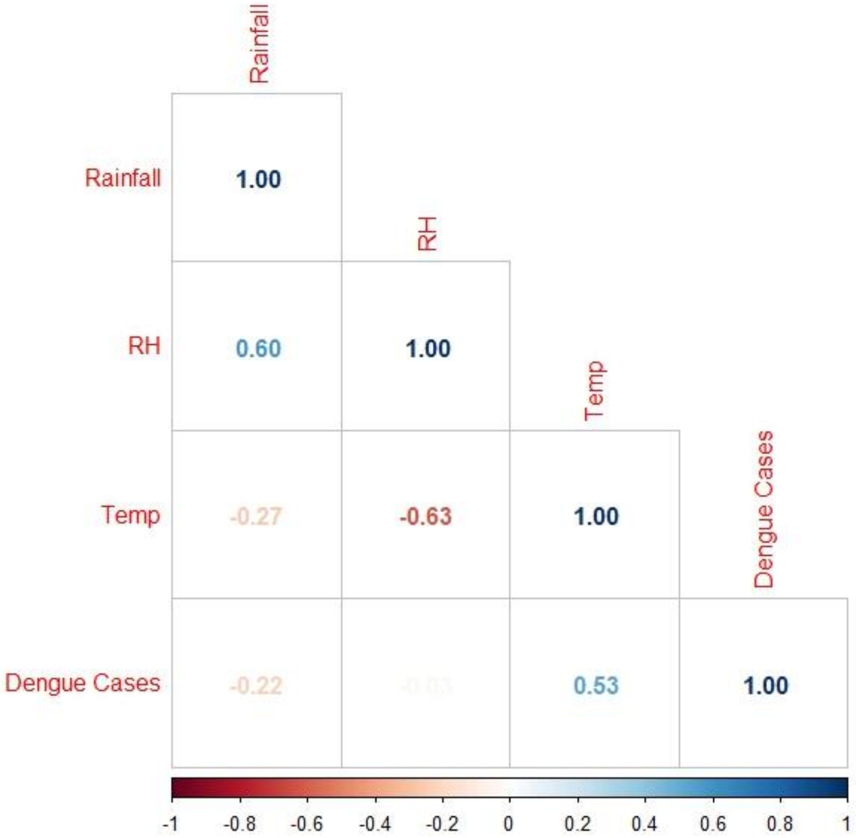


Figure 30: Correlation between Dengue Cases and Temp, RH, Rainfall in Pre-Monsoon from 2020 to 2023

6.6 Predication Analysis:

6.6.1 Multiple Linear Regression (MLR)

We have performed an MLR model to predict the number of dengue cases for the year 2024 by using average temperature, RH, and rainfall from 2020 to 2023. For the prediction, we have used the following variables as a predictor:

The MLR regression equation:

Dengue Cases (Y)= $-3482.03+45.73\times X1-5.36\times X2+53.08\times X3$

Where: X1 =Temperature, X2 = Rainfall, X3 = RH and Y= Dengue cases

Using the model, the predicted the number of dengue cases for specific values of the predictors (Temperature = 40°C, Relative Humidity = 80%, Rainfall = 300 mm) to be 4201.57. This estimate suggests that there might be approximately 4201 number of dengue cases are possible in 2024. This estimate is the result of a 10-year analysis (2014–2023) of data from the Delhi Economic Survey, the Health and Family Welfare Report, facilitated by the Municipal Corporation of Delhi (MCD).

The Q-Q plot (Quantile-Quantile plot) shown in Fig. 23 is used to assess whether the residuals from the multiple linear regression model follow a normal distribution. Points should roughly fall along the 45-degree reference line (dotted line), with significant deviations indicating departures from normality. The results of the Q-Q plot from the study showed that the points mostly followed the 45-degree line, but there were deviations, especially at the tails (the extreme ends), likely due to the inclusion of meteorological data. The Scale-Location plot (Spread-Location plot) shown in Fig. 24 helps to check the assumption of homoscedasticity (constant variance) of the residuals, and from the study, it indicated possible heteroscedasticity due to a slight rise in the residuals' spread as the fitted values increased, suggested that the variance of the residuals is not constant across all levels of the fitted values. The Residuals vs. Fitted plot shown in Fig. 22 checks the assumptions of linearity, however, the residuals in the plot shown a pattern rather than being randomly scattered around the horizontal line, suggesting non-linearity in the relationship between the predictors (temperature, rainfall, relative humidity) and the response (dengue cases).

Using a multiple linear regression (MLR) model, the dengue cases in Delhi in 2023 have been fully analysed. The MLR model predicted approximately 8,353 cases for 2023, while the actual number of cases reported was 9,266. This validation exercise has shown that the MLR model underestimated the 2023 dengue cases by around 10%. The comprehensive analysis of the 2023 data has provided valuable insights into the model's performance and the factors influencing dengue transmission in Delhi.

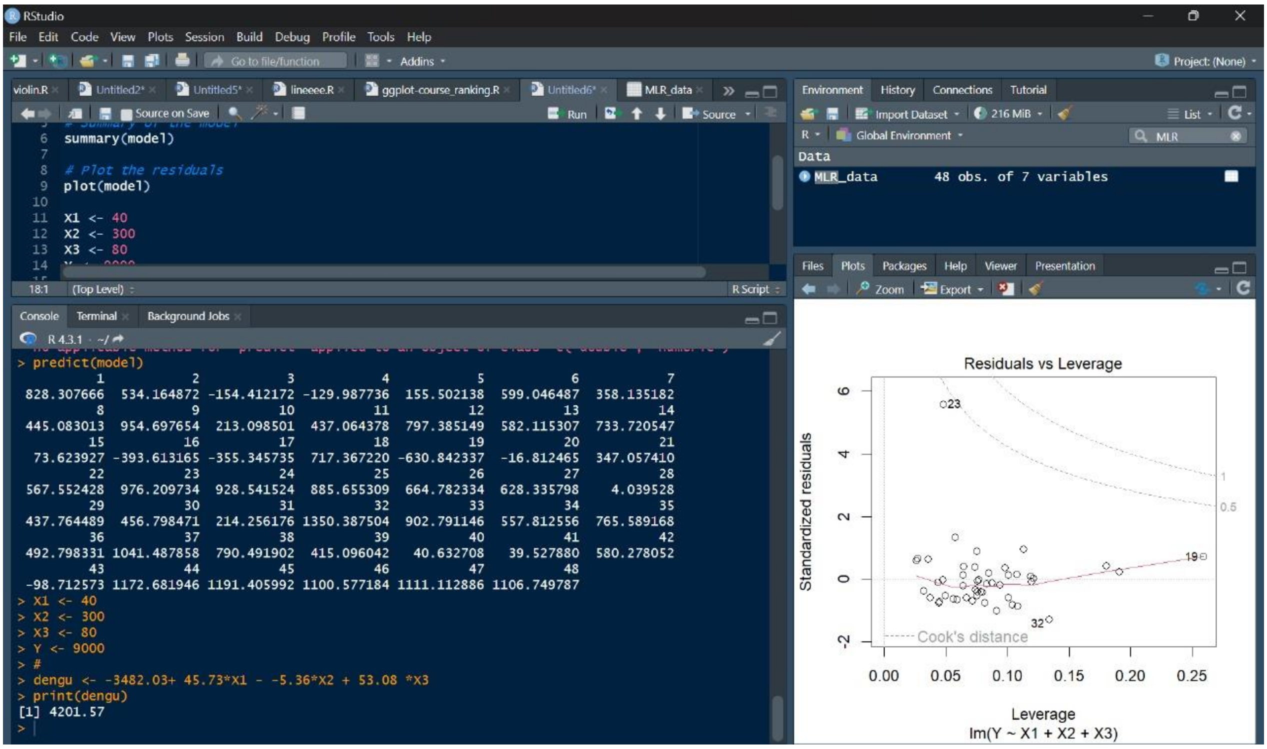


Figure 20: Climate Based Dengue Prediction Model for 2024

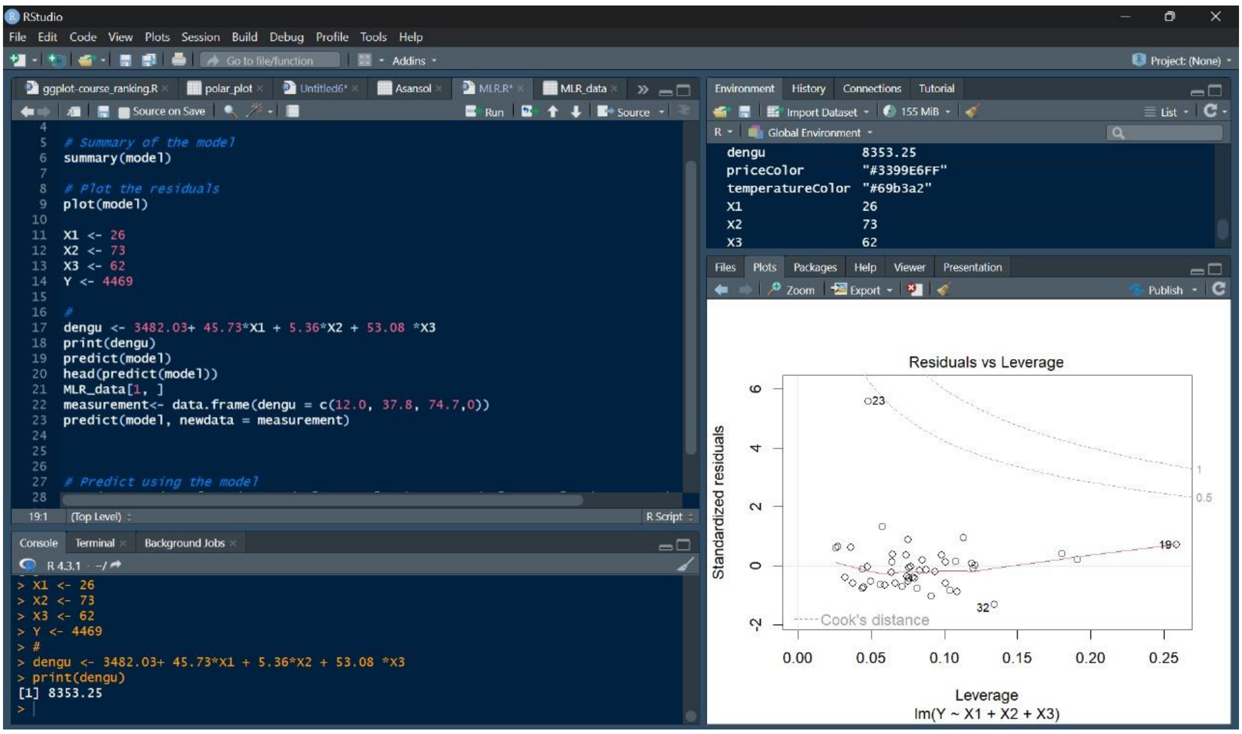


Figure 21: Climate Based Dengue Prediction Model for 2023 Actual Cases (n=9266) & Prediction cases (n=8353)

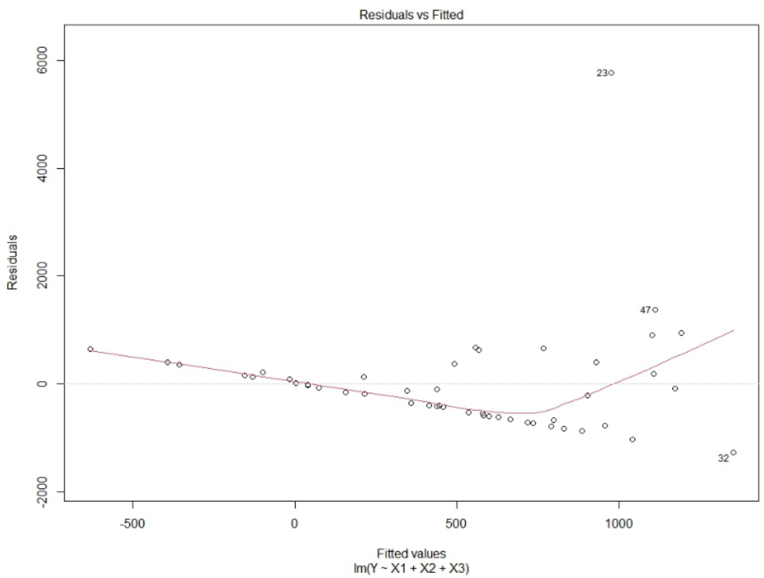


Figure 22: Residual vs Fitted Plot

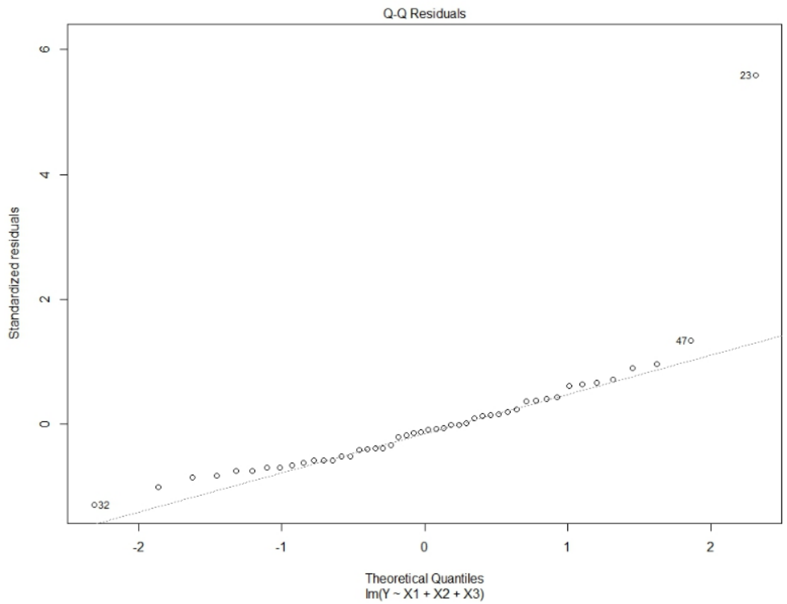


Figure 23: Deviation of the Q-Q (Quantile-Quantile) plot

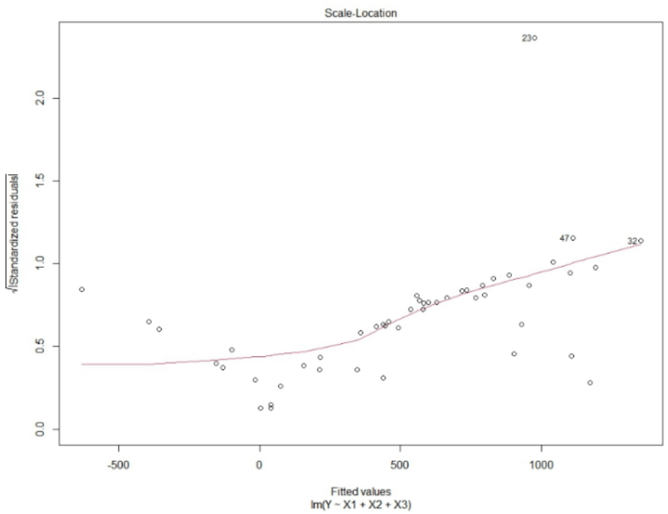


Figure 24: Scale-Location plot

7.0 Discussion

Despite the fact that numerous researches were conducted earlier, it is essential to re-examine and revaluate the relationship between climate change and the frequency of dengue cases due to the changes in climatic conditions (Babita Bisht, Influence of environmental factors on dengue, 2019). Climate change has the potential to impact dengue ecology's regional and temporal dynamics by expanding the ranges of vectors, lengthening the duration of vector activity, and extending the mosquito's infectious period (Bureau, Dengue Epidemic, 2021). According to reports from other sources, Delhi experienced a consistent seasonal pattern of dengue incidence from 2020 to 2023 (Baruah, 2021).

According to the study findings, dengue infections increased from August to September, reached the peak point in October to November and continued to decrease after December. There was a spike in dengue cases during the post-monsoon season. Weather affects dengue vector growth and development (Kristie L. Ebi, 2016). We classified seasons based on the India Meteorological Department (IMD) definitions, ensuring research consistency (Karamchandani, 1946). The CPCB's high-resolution temperature data were used to study the impact of temperature variations on dengue. Our analysis showed that dengue cases peaked from August to November, a few months after the highest temperatures. We collected dengue case data for Delhi from 2020-2023 from the DGHS and other health organizations. The Integrated Disease Surveillance Programme (IDSP) provides comprehensive data for trend analysis (NVBDCP, Dengue-National-Guidelines-2014). Dengue's seasonal fluctuation is influenced by meteorological factors like temperature, humidity, and rainfall (Narain, 2021).

Dengue, a tropical disease caused by an arbovirus, is widespread in tropical regions (Poornima Suryanath Singh, 2022). An examination of Delhi's dengue statistics reveals that the transmission window for the years 2020 and 2023 was widened because cases were also recorded in January and February. Sometimes, extending the transmission window can result in perennial transmission, which could be riskier. Changes in weather patterns could lead to a rise in dengue cases, which would reduce manpower and output (Baruah, 2021). Delhi, the nation's capital, offers a wide range of business opportunities and medical services. Variations in the number of cases may also result from a patient who may have contracted an infection outside of Delhi at their place of employment or residence, receiving treatment in Delhi, then reporting their experience to the Directorate of NVBDCP for cross-notification (NVBDCP, Dengue-National-Guidelines-2014).

Present study highlighted correlation between meteorological parameters (Relative humidity RH (%), Average temperature (^{0} C), and Total rainfall (mm)) and dengue cases that explain weather conditions and their impact on mosquito populations, virus replication and subsequent impact on transmission patterns. The study also identified temperature, relative humidity, and rain as the main environmental variables that, either separately or in combination, cause outbreak circumstances (Sudha Rani Kotha et al, 2011). Comparing Delhi case data to rainfall and humidity, similar circumstances are found. Only the amount of rainfall that occurs after three months in Brazil, as determined by a study of climate parameters, positively correlated with dengue occurrences (Bisht, 2019). Significant connection ($p>0.01$) was seen at one month in Cairns and at three months in Townsville in a North Australian study (Bernard Cazelles, 2005).

Dengue cases in Delhi shows distinct seasonal pattern, increased significantly during the monsoon period (June-September) peaking in August, with the highest number reported in the post-monsoon period (October-December) before gradually declining towards the end of the year and barely any cases reported in the pre-monsoon season (March-May) (Karamchandani, 1946). In the present study rainfall was found to be least correlated with the dengue cases throughout the years since 2020-2023. It takes approximately 7-10 days for mosquitoes to complete their development from egg to adult during the monsoon season (CDC, 2024). Although increasing rainfall during the monsoon season initially provides breeding grounds for mosquito so that it lead to increases mosquito numbers, the post-monsoon period creates a more favorable environment for the vector's subsequent growth and maturity, which causes a delayed but more severe dengue outbreak (Bernard Cazelles, 2005). extrinsic incubation period about 8-12 days and intrinsic incubation period in patients 5-8 days, time taken for reporting of Dengue cases by hospitals to SDMC, and investigation by concerned zones and notification by SDMCThe length of time needed for the mosquito life cycle and the dengue virus to spread is probably the cause of this delayed rise in dengue cases (Baruah, 2021). Dengue fever incidence and heavy rainfall events have a complicated link that might be influenced by the availability of water in mosquito breeding locations beforehand (Naish, 2014). It has been discovered that high rainfall during the monsoon season lowers the chance of contracting dengue cases (Cheng, 2023). Heavy rainfall have the potential to sweep away mosquito breeding grounds and larval stages when there is a high preceding water supply, such as during the monsoon season. As a result, the aquatic life stages of the Aedes mosquitoes that spread dengue are unable to thrive in their current environment, upsetting the mosquito life cycle. Furthermore, mature mosquitoes may be physically displaced as heavy rainfall can also impact the flight range of adult mosquitoes and have restricted movement as a result of the severe rains, which will lessen their capacity to locate human hosts and transmit the dengue virus (Cheng, 2023). Rainfall provides breeding grounds for mosquitoes, and human activities can create artificial habitat (Bisht, 2019). Record-breaking rainfall and floods in North India, made worse by climate change, led to the Yamuna flood disaster in Delhi in 2023 (mint, 2023). The immediate impact of the Yamuna floods may have disrupted existing dengue larvae, the potential for new mosquito breeding grounds emerging as the waters receded posed a significant risk of dengue outbreaks in Delhi and according to MCD's annual data, Delhi saw 9,266 dengue cases and 19 deaths in 2023, making it the city's third-worst dengue outbreak. Our results show that temperature and RH significantly influence mosquito seasonality. We found a negative relationship between dengue cases and rainfall (-0.25) monsoon and pre-monsoon (-0.22), aligning with previous studies (Cory W. Morin, 2013). This study was able to resolve the contradictory results from previous studies by stratifying the analyses by previous water availability. This allowed for a more sophisticated understanding of the intricate relationship between heavy rainfall and dengue transmission (Cheng, 2023).

The ideal temperature for mosquito growth is 25–30 °C. Temperature affects the mosquito's lifecycle, including biting frequency and virus growth (Vishnampettai G. Ramachandran, 2016). According to epidemiological data, Delhi had seen a notable rise in the number of dengue infections reported between 2020 and 2023. In Delhi, the relationship between temperature and dengue transmission is intricate and non-linear (Kakarla, 2019). The warm and humid climate in 2021, with high temperatures and increased precipitation, had provided favourable conditions for mosquito proliferation and dengue virus transmission (mint, 2023). In a study conducted in Brazil, it was quoted that temperature interferes with the dengue virus incubation period, dropping from 10 to 7 days as the temperature rises from 27°C to 37°C (Martins et al., 2021). In a Colombian investigation, average and maximum temperatures above 28°C and 32°C, respectively, were found to have an inverse connection with the incidence of DENV, matching regions in Colombia with higher temperatures (Gutierrez-Barbosa, 2020). According to a different Brazilian study, the mosquito cannot survive at low temperatures long enough for the virus to properly grow (Xavier, 2021). Elevated temperatures have the potential to intensify epidemics by diminishing virus replication and the extrinsic period in mosquitoes (Gutierrez-Barbosa, 2020). Research indicates that Delhi's pre-monsoon season (March- May) has a lower incidence of dengue cases than the post-monsoon period. This is likely due to the negative impact of high temperatures on the survival of dengue vector eggs (Vishnampettai G. Ramachandran, 2016). Dengue incidence in Delhi has been related to El Niño episodes; the heat and corresponding changes in rainfall patterns create ideal circumstances for mosquito reproduction and the spread of the dengue virus. The dengue mosquito's life cycle is further hampered by the existence of air pollution (Naish, 2014).

Our study highlighted week correlation among the dengue cases and temperature in monsoon, post-monsoon and winter. However, it shown strong positive correlation in pre-monsoon throughout the year suggesting association of increase in temperature can lead to slight increase in dengue cases in Delhi during pre-monsoon also. High humidity and optimal temperatures promote vector reproduction (Ballani, 2014). Dengue cases rose sharply post-monsoon due to climatic impacts on vector lifecycles (Karamchandani, 1946). This study found a strong positive relationship between moisture and dengue haemorrhagic fever cases, with humidity affecting mosquito lifespan and behaviour (Bernard Cazelles, 2005). A positive correlation exists between increased moisture and the rise in dengue haemorrhagic fever cases, although sometimes dengue incidence decreases with higher humidity (S Chandy, 2013). Mosquitoes' respiratory systems, featuring a trachea and spiracles, are highly sensitive to humidity. Low humidity causes bodily fluids to evaporate, reducing mosquito survival. Conversely, high humidity and optimal temperatures promote mosquito reproduction (C.R. Williams, 2014; Ballani, 2014). Dengue cases surge post-monsoon due to climate variations affecting viral and vector lifecycles (Naish, 2014). Humidity favours the life span of mosquitoes therefore with rise in humidity, the life days of mosquito is increased leading to completion of extrinsic incubation period of Dengue virus in Aedes (Bisht, 2019).

Additionally, it was observed that rainfall continued to occur for a while after the month of November. This could be because fresh surface water from the outdoors was still available in leftover containers and man-made housing structures. Moreover, relative humidity and temperature also contributed to the ambient conditions outside until November after which low temperatures reduce outdoor breeding. Mosquitoes can survive even at 10 °C, but their activity slows below 4.5 °C (Babita Bisht, Influence of environmental factors on dengue, 2019). There are still a few dengue cases being recorded in Delhi during the winter, which suggests that the virus and *Aedes aegypti*, the mosquito that transmits it, can endure for a while (Poornima Suryanath Singh, 2022). Delhi's winters have gotten comparatively milder in recent years, with lows of less than 10°C. This creates an environment that is more favourable for viral proliferation and mosquito survival (Poornima Suryanath Singh, 2022). Because *Aedes aegypti* is acclimated to indoor environments, it can also survive in harsh weather conditions and become challenging to control. Eggs are resistant to desiccation for several months during periods of low temperature (Murhekar M, 2019). Water containers inside homes provide suitable breeding sites. Urban areas with dense populations and inadequate sanitation can sustain mosquito populations year-round, facilitating continuous transmission of dengue virus (Narain, 2021). A single dengue serotype infection only offers transient immunity, leaving a person susceptible to contracting various serotypes in ensuing seasons. Urban areas with dense populations and inadequate sanitation can sustain mosquito populations year-round, facilitating continuous transmission of dengue virus (Narain, 2021).

Temperature, humidity, and rainfall significantly impact mosquito populations and dengue outbreaks (Naish, 2014). Studies show that climate variables like temperature and RH are crucial for predicting dengue transmission (Rakesh Katyal, 1996). In 2021, dengue cases peaked (n=9,613), with the highest cases during the monsoon due to optimal climatic conditions. The geographic spread of Aedes mosquitoes increases with global temperatures, potentially expanding dengue to new areas. Our study highlights the importance of developing a weather-based dengue forecasting model for effective vector management and prevention. Prior research indicates that dengue is prevalent in both urban and rural areas in India, and developing a seasonal forecasting model is vital to predict dengue incidence and guide preventive measures. Our study provides basic data on temperature and rainfall thresholds to support a dengue early warning system. We found significant differences in rainfall, RH, and temperature between pre-monsoon, monsoon, post-monsoon, and winter periods.

Limitation

This study has limitations, including the use of data for the entire city of Delhi without differentiation between serologically positive and negative cases or specific areas. Consequently, dengue cases have been aggregated for the entire Delhi. Accessing climate data and dengue cases at the municipal level could help identify dengue-prone zones in Delhi more accurately.

8.0 Conclusion

This study concluded that there is a non-linear link between Delhi's dengue load and meteorological conditions. One of India's tropical endemic zones, the capital city of Delhi has a high population density and distinctive seasonal variations in temperature and humidity in the air. Delhi's geographical and climatic characteristics make it a unique and challenging environment, impacting its public health dynamics, particularly with regard to vector-borne diseases like dengue. An extensive study was conducted to forecast dengue outbreaks in relation to climate change using R-studio's machine learning tools. Program managers can take advantage of this chance to implement vector control measures in addition to source reduction, as the study demonstrates a clear correlation between dengue cases and meteorological conditions and reveals a delay between the onset of cases and rainfall. Comprehending these seasonal impacts is essential to developing targeted and effective disease surveillance and intervention initiatives. A weather-based dengue forecasting model must be created in order to support program managers in forecasting and controlling outbreaks, minimize their size, and potentially lower disease transmission and mortality, which would lower the burden on healthcare systems and operational expenses. To both comprehend existing climate-health relationships and forecast future scenarios, new research programs should concentrate on gathering high-quality, long-term data on climate-related health outcomes.

9.0 Prevention & Control Measures

Dengue is a common public health issue that can cause serious circulatory damage, a drop-in blood platelet count, and, in most cases, liver dysfunction (Punnee Butthep 1, 2012). Developing seasonally appropriate preventative and control methods and strategies is crucial for managing dengue effectively and minimizing the spread of the disease.

1. Season-Specific Dengue Control Initiatives:

In summer, bird pots (37%) and coolers are the main mosquito breeding sites. During the monsoon, breeding shifts to road potholes, empty cans, and plastic containers. High humidity in the post-monsoon season fosters mosquito breeding. In winter, mosquitoes typically breed indoors (Express, 2023)

- Remove the mosquito's nesting sites, which include man-made water-holding containers.
- Clean the interior of water containers (pet water bowls, flower planter dishes) to get rid of mosquito eggs.
- Barrels used to store water should be covered. At least once a week, empty and clean indoor vases and other containers with standing water.
- Empty or dispose of any outside water-holding containers or objects, such as abandoned tires, trash cans, buckets, planters, play structures, swimming pools, and birdbaths.
- Fill potholes and repair roads in pre-monsoon to prevent water accumulation, which can serve as breeding grounds for mosquitoes.
- Ensure proper drainage systems are in place to avoid water stagnation. Clear blocked drains regularly.
- Implementation of personal protection measures like, apply repellent to exposed skin and reapply it every few hours, put on long sleeve shirts and pants, verify that the screens on windows and doors are tight and hole-free, and make use of the air conditioning and periodical cleaning is necessary.
- Since Aedes mosquitoes are active throughout the day and often bite during the day, especially in the early morning and late afternoon, it's important to remember to take preventative measures to avoid being bitten.
- To prevent mosquitoes from getting to the dengue fever patient, it is advised to cover them with a mosquito net during the first five to six days of the illness.

This will lessen the likelihood that other members of the community will have dengue fever.

2. Community Involvement

- Organize community clean-up efforts to remove debris and stagnant water from streets and public areas.

- Formation of Community groups for monitoring and management of breeding sites.

3.Enhanced Surveillance

- Early detection and timely response to dengue outbreak is crucial.

- Strengthen the Dengue Sentinel Surveillance Healthcare facilities in rural and sub-urban areas also so that disease spread due to human mobility also reduce.

1. Use of Environment Friendly Alternatives

<u>Biological Control</u>

- Use of natural predator larvicidal fish and introducing viviparous species (like *Poecilia reticulata*) into confined water bodies (such huge water tanks or open freshwater wells).

- Endosymbiotic management involves using mosquitoes carrying the internal parasite Wolbachia, as these mosquitoes show a lower vulnerability to DENV infection than do wild-type Aegypti mosquitoes.

- Promote the use of mosquito fish (*Gambusia affinis*) and Tilapia fish to control mosquito larvae during monsoon season.

- Bacillus thuringiensis israelensis, or Bti, is a naturally occurring bacterium that generates toxins that are safe for people, animals, and the environment but detrimental to mosquito larvae. In areas of water where mosquitoes develop, Bti is frequently used.

<u>Chemical Control</u>

- In large breeding containers, use larvicidal.
- Use space sprays, which can be applied as cold aerosols or thermal fogs, to apply pesticide sprays and use compositions based on oil because they prevent evaporation
- To battle dengue, a comprehensive plan involving chemical control, biological mosquito control methods, and environmental management is required.

2. **Ensure a Clean Environment**

- Make sure that trash is disposed of appropriately and doesn't build up in areas where it may gather moisture.
- To keep water from stagnating, keep gutters and drains clear of debris.

3. **Policy and Institutional Strengthening**

- Strengthen dengue control policies, enforce laws against stagnant water, and promote eco-friendly control measure.

4. **Capacity Building**

- Capacity building program for researchers and healthcare workers on surveillance, diagnosis and treatment protocol. Work with local authorities and NGOs to implement large-scale fumigation and mosquito control programs.

5. **Health Education**

- Effective public health interventions need educating people about the dengue virus. The first steps in spreading information about the virus can be taken at the individual and societal levels by utilizing public awareness campaigns and multimedia materials.

9.1 GOI INITIATIVES FOR DENGUE

The Indian government has implemented a number of measures to prevent and manage dengue across the nation:

- Technical guidelines and 15 advisories were provided to states and Union Territories in 2021 for effective dengue prevention, control, and community participation.
- Free diagnostic services are available through 713 Sentinel Surveillance Hospitals and 17 Apex Referral laboratories, with 7.26 lakh IgM tests supplied by the government and additional funding for NS1 kits.
- The National Health Mission provides states and Union Territories with adequate funding to support dengue control initiatives.

Source- Bureau of Press Information, The National Centre for Vector Borne Diseases Control (NCVBDC) is part of the Ministry of Health and Family Welfare of the Government of India (NVBDCP, Dengue-National-Guidelines-2014)

10.0 Recommendation

The study's conclusions lead to the following suggestions for improvement:

- **Enhanced Dengue Surveillance via Integrated Health Information Platform (IHIP)**

The IHIP is an open platform that connects with e-Hospital Systems and the National Health Management Information System, linking public and private hospitals, labs, and research centres. It securely exchanges health data, analyses geographic disease variations, and captures geocoordinates and socio-demographic details (Vision 2035: Public Health Surveillance in India. A White Paper. NITI Aayog, 2020).

In contrast, the traditional IDSP system in most Indian states uses paper-based data collection, tracks only 13 health conditions, and offers weekly updates without integrating data from Syndrome (S), Presumptive (P), and Laboratory (L) forms (Vision 2035: Public Health Surveillance in India. A White Paper. NITI Aayog, 2020). The IHIP captures individualized data by age, gender, and locality, links S, P, L, and Early Warning Signals 1 and 2 forms, and provides near real-time or daily surveillance data. It monitors over 33 health conditions, is cost-effective, and accessible on mobile and electronic devices (Vision 2035: Public Health Surveillance in India. A White Paper. NITI Aayog, 2020).

There's a need to enhancement of the existing Integrated Health Information Platform (IHIP) to further improve dengue data collection and reporting in India. The current IHIP framework, which allows real-time and near real-time reporting from District Surveillance Unit (DSUs), Central Surveillance Unit (CSUs), and State Surveillance Unit (SSUs), has significantly improved the ability to monitor and respond to vector-borne diseases (Vision 2035: Public Health Surveillance in India. A White Paper. NITI Aayog, 2020). The IHIP is already integrated with the NVBDCP, however, there are opportunities to further refinement this system for enhanced public health outcomes.

Enhancement of Mobile Reporting Interference for Remote Areas

- Implementation of additional features in the mobile reporting system like, Integration of meteorological data with disease data so that health authorities can refine their assessments regarding the patterns and trends of dengue transmission.

- Development of supportive policies and regulations that promote the adoption of “Edge computing solutions” in healthcare along with implement pilot programs in high-dengue transmission areas like Delhi, to test and refine edge computing solutions (atlan, 2023). Edge computing, a data integration method that helps reduce the amount of data that needs to be sent to centralized cloud servers (atlan, 2023). By processing data locally, only the most relevant or summarized information is transmitted, which optimizes bandwidth usage and significantly reduces data transmission costs, which is essential in a cost-sensitive economy like India (energizecap, 2024) This enables real-time data management of dengue transmission in rural and remote areas with poor internet connectivity, so that results will be accessible at all levels for action.

Advancement of Sustainable public Health Surveillance in Delhi

System for Early Warning Based on Emergency Data (SEED) was a collaborative project co-funded by the Indian Council for Medical Research (ICMR) and the German Ministry of Research and Education. The goal of the GEOMED Research study in Germany and the GVK Emergency Management and Research Institute (EMRI) in India was to use emergency data for syndromic surveillance at the primary care level in Andhra Pradesh. It integrates GIS tools, algorithms, and a database. By comparing real-time data against present thresholds, emergency management system (EMS) data, which is automatically generated and captured at the state dispatch centre in Hyderabad, acts as an early warning system for disease outbreaks (Vision 2035: Public Health Surveillance in India. A White Paper. NITI Aayog, 2020).

In the Philippines, the implementation of a near real-time syndromic fever surveillance system significantly improved dengue response efforts. This system enables timely detection of outbreaks and facilitates a rapid response by providing health authorities with up-to-date information. Additionally, applications like Mozzify have been developed for real-time reporting and mapping of dengue cases, promoting effective communication and enabling prompt action (Shi, 2013).

However, there are opportunities to further refinement this system in Delhi for enhanced public health outcomes.

- Provide rules and legislation that facilitate the establishment of a centralized state dispatch centre, resembling the one in Hyderabad, with enhanced data collection and processing capabilities in Delhi. The real-time collection and processing of EMS data will be managed by this centre. Work with the emergency services and local health authorities to integrate the SEED framework into Delhi's healthcare system.
- Integrate advanced analytics tools within the centralized system to provide predictive modeling and trend analysis for dengue and other disease outbreaks. Spatio-temporal analysis using GIS tools can help in mapping and visualizing outbreak patterns, aiding in swift response and resource allocation.
- Foster collaboration between different departments such as health, environment, and urban planning to ensure comprehensive data integration. Share data across relevant stakeholders for coordinated public health responses.
- Establish metrics to continuously monitor and evaluate the performance of the SEED system. Regularly update the system based on feedback and emerging public health needs.

Enhancement of Dengue Data Quality, Accessibility, and Availability:

Dengue fever is a common illness in India. Underreporting of cases is common, and clinical sample confirmation is frequently challenging due to the lack of government-certified or government-contracted laboratories (Rao, 2017). Any cost calculation for the social and economic burden of dengue fever in India is limited due to the paucity of health data for cases of the disease that have been gathered (Rao, 2017). Additionally, research professionals surveyed believe that 30% and 70% of patients in India receive care from the public and private sectors, respectively. The Indian government's reporting of infectious diseases falls mostly under the purview of public data in terms of usage, accessibility, and availability (Rao, 2017). However, this needs further refinement to;

- Establishment of a comprehensive reporting system that includes data from private healthcare providers and development of a unified data platform should be highly necessary which accessible to both public and private healthcare providers for reporting and accessing dengue case data.

- ➢ Establishment of accountability frameworks and oversight systems for dengue testing with strict quality control for labs recognized by Indian Council of Medical Research (ICMR) and authorized by National Accreditation Board for Testing and Calibration Laboratories (NABL) is essential. Utilize clinical IgM and IgG ELISA (Enzyme-Linked Immunosorbent Assay) tests, which have 90% sensitivity and 98% specificity, for accurate diagnosis and management. This will uphold the legitimacy and efficacy of dengue testing procedures in India.

- **Improved and Upgrade Drainage Systems**

India's urban population is expected to rise to 40 per cent by 2030 (CLIMATE CHANGE IN GOVERNANCE, 2022). Delhi's drainage issue is now become a chromic issue. City-level Climate Action Plans should be developed by urban local bodies as soon as possible using a participatory approach, taking into consideration population growth trends and the disproportionate consequences of climate change on the impoverished and marginalized members of society. Upgrade and maintain drainage infrastructure are necessary to prevent waterlogging and stagnant water, which are breeding grounds for mosquitoes. At present, 25-40% of sewage is being disposed of in open drains and this is why there is need of desilting in Delhi. Modernizing the existing drainage infrastructure is critical, as the current system can only handle 50mm of rainwater per day due to its outdated design, which dates back nearly 50 years (1976). By investing in upgrades, the capacity to manage increased rainfall volumes will significantly improve, mitigating flood risks during monsoon seasons. Further, the solid waste and the sewage has been managed in such a way that they do not interfere with the storm water drainage.

- **Enhance Community Participation:** Community participation is vital. Organizing cleanliness drives can eliminate mosquito breeding sites by removing stagnant water and ensuring proper waste management. Educational campaigns can raise awareness about maintaining a clean environment and taking personal protective measures against mosquito bites, fostering collective action to reduce dengue spread. Launch public health campaigns to educate the community on the importance of reporting dengue cases and the available diagnostic and treatment facilities. Leverage local healthcare Infrastructure which includes facilities like Mohalla Clinics, is essential to the prevention and treatment of dengue as patient will receive timely treatment at the closest clinics in the event of symptoms. These clinics allow early diagnosis and treatment, provide fast and easily accessible medical care, and give educational resources on preventing dengue. Incorporating features like small fountains or bubblers in bird pots can prevent water from becoming stagnant. Mosquitoes prefer still water for breeding, so introducing movement disrupts their lifecycle and deters them from laying eggs. Based on the report from The Indian Express, in summer, bird pots (37%) are the most common mosquito breeding sites. Ensure that the water in bird pots is changed at least every 2-3 days. This practice prevents the development of mosquito larvae, as they require still water to breed. If complete water removal is not possible, consider using biological larvicides that are safe for birds, such as Bacillus thuringiensis israelensis (Bti). These can effectively kill mosquito larvae without harming birds or other beneficial insects.

Punjab has experienced a successful dengue control initiative by adopting a proactive approach to surveillance and response. The state government implemented a combination of community involvement and real-time data collection to identify hotspots for potential dengue outbreaks. By fostering partnerships with local communities to engage in mosquito control and sanitation efforts, Punjab saw a reduction in both the number of cases and the mosquito breeding sites. This comprehensive strategy emphasized the importance of localized data and community engagement in preventing dengue outbreaks (Shi, 2013)

In Uttar Pradesh, health officials implemented a smart surveillance initiative to tackle the rising dengue cases. The program utilized **text mining techniques** to monitor social media and news reports for public health threats, including dengue outbreaks. By analysing this real-time data, health authorities were able to orchestrate timely interventions and increase public awareness. This innovative approach not only enhanced the response capabilities of health officials but also provided valuable insights into public perception and concern regarding dengue, contributing to a more informed response (Villanes, 2017)

- **Screening of Blood Donors for DENV-** Aedes mosquitoes are the main vectors of dengue virus (DENV), although blood transfusions can also carry the infection, which puts endemic areas at serious danger (D. Arellanos-Soto, 2015). Several cases of DENV transmission through blood transfusion have been reported. Six cases of dengue transmitted by transfusion were documented in Brazilian research; among blood donors who tested positive for DENV RNA, the transmission rate was 37.5% (Paul A. Tambyah, 2008). As far as we know, dengue linked to transfusions is quite uncommon, there was a report from Hong Kong, where the disease is not endemic (Chuang, 2008). Addressing DENV transmission through blood transfusion is crucial, as asymptomatic donors in endemic areas can carry the virus, threatening blood safety and public health.

There have been reports of dengue virus transmission via blood transfusion in various states in India. For example, in Tamil Nadu, a study found that 0.92% of blood donors were seropositive for dengue during an outbreak. In Maharashtra, research in Mumbai identified 0.7% of donors positive for dengue virus RNA. In Delhi, around 1.1% of blood donors tested positive for dengue antibodies (Munar, 2024). These studies highlight the importance of rigorous screening protocols in blood banks to mitigate the risk of transfusion-transmitted dengue.

According to the Department of Health and Family Welfare Services, Blood banks test for compatibility, jaundice, malaria, Human Immunodeficiency Virus (HIV)/ Acquired Immune Deficiency Syndrome (AIDS), Sexually Transmitted Diseases (STDs), and blood group, but not routinely test for the dengue virus (DENV) in India. The Centres for Disease Control and Prevention (CDC) note that individuals infected with DENV can transmit the virus to mosquitoes during the viremia phase (period of infectivity), which lasts approximately 7 days. Symptoms of dengue often appear 1-2 days after the onset of viremia, making it possible for donors to be viremic but asymptomatic at the time of donation. To address this, a robust surveillance system and mandatory DENV screening standards in blood donation facilities are essential, with collaboration from public health authorities.

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Appendices

Formulas and Calculations

1. Case Fatality Rate, CFR (%) for Calculation of Dengue Death Cases

$$\text{CFR}(\%) = \left(\frac{\text{Number of deaths due to dengue}}{\text{Number of diagnosed cases of dengue}}\right) \times 100$$

MONTH WISE DATA OF DENGUE (From January 2020 to December 2023); DELHI

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
2020	0	4	2	7	6	1	11	47	188	346	338	122	1072
2021	0	2	5	10	12	7	16	72	217	1196	6739	1337	9613
2022	23	16	22	20	30	32	26	75	693	1238	1420	874	4469
2023	14	14	13	18	23	40	121	1094	2141	2003	2482	1303	9266

*Data Source: Weekly report of Municipal Corporation of Delhi

2. Spearman Correlation Test Code Performed on R-Studio

```
library(corrplot)
library(gridExtra)
library(png)
library(grid)

# Define a function to save a corrplot as an image
save_corrplot <- function(data, title, filename) {
  corr_matrix <- cor(data, use = "pairwise.complete.obs")
  png(filename)
  corrplot(corr_matrix, method = "number", type = "lower", order = "hclust", title = title,
outline = TRUE, mar = c(2, 2, 2, 2))
  dev.off()
}

# Save each correlation plot as an image
save_corrplot(data2020, "(2020)", "plot2020.png")
save_corrplot(data2021, "(2021)", "plot2021.png")
save_corrplot(data2022, "(2022)", "plot2022.png")
save_corrplot(data2023, "(2023)", "plot2023.png")

# Load the images
img2020 <- rasterGrob(readPNG("plot2020.png"), interpolate = TRUE)
```

```
img2021 <- rasterGrob(readPNG("plot2021.png"), interpolate = TRUE)
img2022 <- rasterGrob(readPNG("plot2022.png"), interpolate = TRUE)
img2023 <- rasterGrob(readPNG("plot2023.png"), interpolate = TRUE)

# Combine the images into a single plot
combined_plot <- grid.arrange(img2020, img2021, img2022, img2023, ncol = 2)
print(combined_plot)
```

3. Multiple Linear Regression Model Code Performed on R-Studio

```
Call:

lm(formula = Y ~ X1 + X2 + X3, data = data)

Residuals:

   Min      1Q  Median      3Q     Max

-1275.4  -586.1  -114.6   256.6  5762.8

Coefficients:

            Estimate Std. Error t value Pr(>|t|)

(Intercept) -3482.03    1828.01  -1.905   0.0634 .

X1             45.73      33.47   1.367   0.1787

X2             -5.36       2.12  -2.529   0.0151 *

X3             53.08      20.51   2.588   0.0130 *

---

Signif. codes:  0 '*' 0.001 '*' 0.01 '' 0.05 '.' 0.1 '.' 1

Residual standard error: 1056 on 44 degrees of freedom

Multiple R-squared:  0.1687,  Adjusted R-squared:  0.1121

F-statistic: 2.977 on 3 and 44 DF, p-value: 0.04164
```

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