Introduction:
The project aims to assess and classify the impact of heat waves across different regions and states in India. By identifying and analysing the specific factors contributing to the intensification of heat waves, the project seeks to understand the regional vulnerabilities and the extent of heat wave impacts. The ultimate goal is to highlight the urgent need to address this escalating environmental issue and provide a framework for understanding how different areas are affected by extreme heat.

Overview of Heat Waves and Their Significance: Heat waves are characterised by abnormally high temperatures, often coupled with high humidity, and can vary in duration and intensity. Their impact is influenced by geographic and climatic factors.

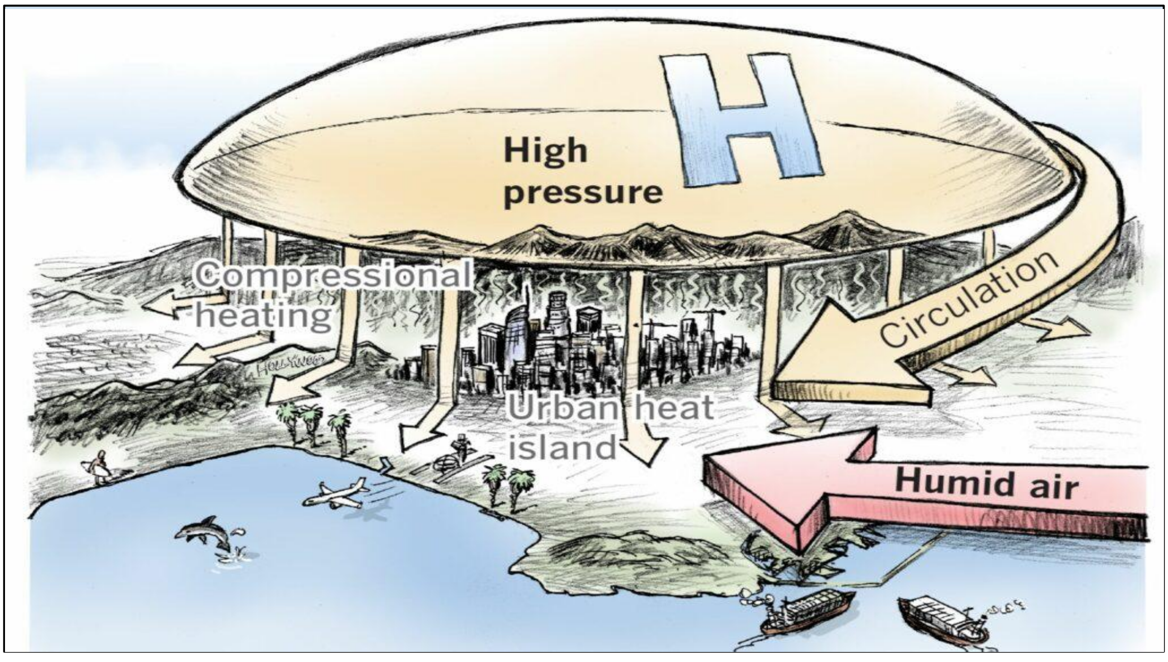
Significance:

Health: Heat waves increase the risk of heat-related illnesses, especially among vulnerable populations like the elderly and those with pre-existing conditions. They also strain healthcare systems, potentially leading to higher mortality rates.

Economic: Extreme heat disrupts infrastructure, lowers productivity, and increases energy demands. Agriculture suffers from reduced crop yields and livestock productivity, leading to economic instability and food insecurity.

Environment: Prolonged heat stresses ecosystems, reduces water availability, and heightens the risk of wildfires. These environmental impacts can lead to long-term degradation of natural habitats and biodiversity loss.

Formation and Characteristics of Heat Waves:
1. Scientific Basis of Heat Wave Formation:
Heat waves occur when a region experiences prolonged periods of excessively high temperatures, often due to a combination of atmospheric and environmental factors. Key drivers include:



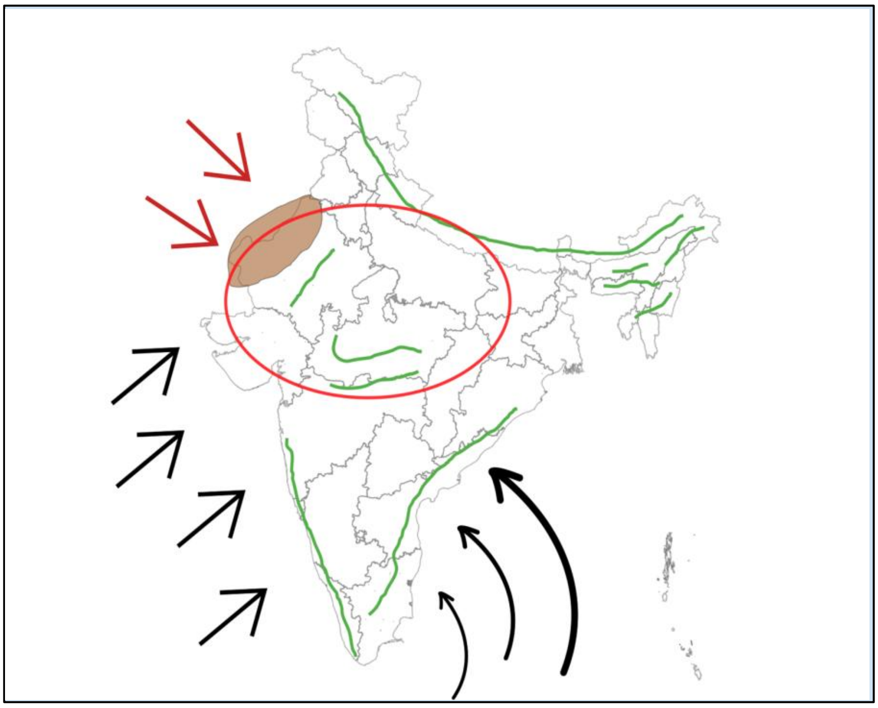
High-Pressure Systems: A persistent high-pressure system can trap warm air in an area, leading to extended periods of high temperatures. These systems inhibit the movement of cooler air masse and prevent cloud formation, which would otherwise provide shade and lower temperatures.

Heat Domes: A heat dome occurs when high-pressure systems create a "dome" of warm air that gets trapped over a region. This leads to prolonged heat as the air mass is compressed and heated. - **Urban Heat Island Effect:** Urban areas, with their dense infrastructure and reduced green space, can experience higher temperatures than surrounding rural areas. This effect exacerbates the intensity of heat waves in cities.

2. Key Characteristics and Indicators:

- Temperature Thresholds: Heat waves are often defined by exceeding specific temperature thresholds, which can vary based on regional climate norms. For instance, a heat wave might be defined as temperatures exceeding the 95th percentile of historical highs for a given area.
- Duration: The length of a heat wave can range from a few days to several weeks, with prolonged heat waves posing more severe risks.
- Intensity: Intensity is measured by the absolute temperature and the extent to which it exceeds normal temperatures. High humidity levels can further enhance the perceived heat and health risks.
- Heat Index: This combined measure of temperature and humidity helps assess the potential for heat-related stress and health impacts. Higher heat index values indicate more severe heat conditions.

3. Geographic Analysis of Heat Wave Formation: Why Northern and Central India Are Consistently Affected?



Red Arrow: Represents the Loo winds (dry winds) originating from the Thar Desert.
Black Arrow: Represents the southwestern winds (pre-monsoon winds) starting to blow from Arabian Sea.
Brown Area: Represents the Thar Desert.
Green Lines: Represent the mountain ranges.
Red Ellipse: Represents the area where heat waves are formed.

1. Intense Solar Radiation: During summer, the sun is directly overhead in the Tropic of Cancer region, which passes through northern India. This results in intense solar radiation, significantly increasing surface temperatures, particularly in the northern plains and central regions.

2. Dry Continental Air: The air mass over northern and central India during summer is dry and continental. With no significant moisture to moderate temperatures, this dry air heats up rapidly, leading to extremely high temperatures.

3. Subsidence of Air: High-pressure systems often form over these regions due to the subsidence (sinking) of air. As air descends, it warms adiabatically (due to compression), further raising surface temperatures and creating conditions conducive to heat waves.

4. Delayed Onset of Monsoon: Before the monsoon arrives, the region experiences a period known as the "pre-monsoon heat wave." If the monsoon is delayed, the land continues to heat up without the moderating effect of rain, exacerbating heat wave conditions.

5. Geographical Features: Northern and central India consists of vast stretches of land, including deserts (e.g., the Thar Desert) and semi-arid regions. These areas lack significant water bodies, leading to low humidity and high temperatures. The absence of vegetation in some regions also contributes to higher surface temperatures.

6. Urban Heat Island Effect: Urbanisation, especially in central and northern cities, has led to the Urban Heat Island effect, where built-up areas with concrete and asphalt absorb and retain more heat than rural surroundings, making these regions more prone to heat waves.

7. Prevalent Winds: During summer, the prevailing winds in northern and central India are often hot and dry, such as the "Loo" winds, which blow from the desert regions of Rajasthan and Pakistan. These winds exacerbate heat conditions in these areas.

8. Influence of Mountain Ranges: The Aravalli, Vindhya, and Satpura ranges influence regional weather patterns but do not entirely mitigate the impact of heat waves. While these mountains can affect wind patterns and precipitation, they are not high enough to significantly block the hot, dry winds originating from the Thar Desert. Additionally, the high-pressure systems that dominate during the summer can extend over these ranges, causing subsidence and further heating the air.

Summary: The frequent occurrence of heat waves in northern and central India during the summer is driven by a combination of intense solar radiation, dry air masses, high-pressure systems, geographical features, and sometimes a delayed monsoon onset.

3. Data Collection

For this project, data collected from January to June 2024 is used to examine factors contributing to heat wave formation and impact. The analysis incorporates a range of direct and indirect factors to provide a comprehensive understanding of heat wave dynamics across India.

Direct Factors:
- Air Pressure: High-pressure systems are critical in trapping warm air and determining the persistence of heat waves.
- Surface Air Temperature: Measurements of surface air temperatures help identify periods of extreme heat and assess their intensity.
- Land Surface Temperature: This reflects the heat absorbed and radiated by the ground, contributing to local temperature conditions.
- Precipitation: Lack of precipitation can exacerbate heat wave conditions by reducing cooling through evaporation.
- Air Moisture: Humidity levels affect the heat index and can intensify the perception of heat and health risks.

Indirect Factors:
- Greenness: Vegetation levels, often assessed through vegetation indices, influence local temperatures and cooling effects.
- Carbon Emissions: High carbon emissions contribute to global warming, which can increase the frequency and intensity of heat waves.
- Elevation Data (DEM): Elevation affects temperature gradients and local climate conditions, influencing heat wave patterns.
- Latent Heat Flux: The transfer of heat from the Earth's surface to the atmosphere through evaporation plays a role in temperature regulation.
- Surface Albedo: The reflectivity of the Earth's surface affects how much solar energy is absorbed or reflected, impacting local temperatures.

All data for this analysis was downloaded from NASA Giovanni, providing critical insights into the various factors influencing heat wave dynamics.(https://giovanni.gsfc.nasa.gov/giovanni/)

4. Data Processing and Analysis

Raster to Point Conversion:
Raster data was converted to point data to facilitate integration with other datasets and enable more detailed analysis.

IDW Interpolation and Masking:
Inverse Distance Weighting (IDW) interpolation was applied to estimate values at unsampled locations. The data was then masked using state boundary shapefiles to focus the analysis on specific regions.

Raster Calculations:
Several indices were calculated to analyse various factors influencing heat waves.

1. Adjusted Temperature:

Adjusted Temperature=Surface Skin Temperature × (1−Surface Albedo)

2. Temperature Heat Flux:
Temperature Heat Flux = Surface Skin Temperature /Moisture

3. Temperature Adjusted with greenness:
Temperature Adjusted with greenness=Surface Skin Temperature × (1- greenness)

4. Adjusted with CO:
CO Adjusted=Near Surface Air Temperature + (CO × k)

5. Adjusted Humidity:
Adjusted Humidity=Humidity + (Humidity × k)

6. Temperature Adjustment with Elevation:

Temperature Adjusted with DEM=DEM × (−0.0065)

7. Air Pressure Adjustment:

Adjusted Temperature=Surface Skin Temperature × (1 − Surface Albedo)

5. Weighted Raster Analysis

Weight Assignment:
Direct factors were assigned higher weightages due to their more immediate influence on heat waves. The assigned weightages are as follows:

- Adjusted Temperature: 30%
- Temperature Heat Flux: 20%
- Temperature Adjusted with NDVI: 10%
- Temperature Adjusted with CO: 10%
- Adjusted Humidity: 5%
- Temperature Adjustment with Elevation: 10%
- Air Pressure Adjustment: 15%

Final Raster Calculation:
The raster calculator was used to combine the weighted indices into a final composite raster, using the following formula:

Final Index = (Adjusted Temperature × 0.30) + (Temperature Heat Flux × 0.20) + (Temperature Adjusted with NDVI × 0.10) + (Temperature Adjusted with CO× 0.10) + (Adjusted Humidity × 0.05) + (Temperature Adjustment with Elevation × 0.10) + (Air Pressure Adjustment × 0.15)

6. Reclassification and Zonal Analysis

Reclassification:
The composite raster was reclassified into five classes to determine heat wave severity.

Zonal Analysis:
Zonal analysis was performed to summarise heat wave severity by state.

7. Integration with State-Level Data

State Classification:
Zonal analysis results were joined with state boundaries to classify heat wave severity by state.

8. Calculate the Total Area in Degrees²

Sum up the areas for each classification:

Total Area (deg²) = 28.122 + 19.136+ 73.905 + 64.233 + 97.795 = 283.191 deg²

1. Determine the Total Area of India

The total area of India is 3,287,263 km².

2. Calculate the Scaling Factor

To convert areas from degrees² to km², use the scaling factor:

Scaling Factor=3,287,263 km² / 283.191 deg² ≈ 11,606.86 km²/deg²

3. Convert Area for Each Classification

- Class 1 (Not Affected):
  Area (km²) = 28.122 deg² × 11,606.86 km² / deg² ≈ 326,361 km²
- Class 2 (Less Affected):
  Area (km²) = 19.136 deg² × 11,606.86 km² / deg² ≈ 222,014 km²
- Class 3 (Moderately Affected):
  Area (km²) = 97.795 deg² × 11,606.86 km² / deg² ≈ 1,135,293 km²
- Class 4 (Severely Affected):
  Area (km²) = 64.233 deg² × 11,606.86 km² / deg² ≈ 745,723 km²
- Class 5 (Extremely Affected):
  Area (km²) = 73.905 deg² × 11,606.86 km² / deg² ≈ 857,872 km²

4. Calculate the Percentage of Total Area

- Class 1 (Not Affected):

Percentage = 3,287,263 km² / 326,361 km² × 100 ≈ 9.93%

- Class 2 (Less Affected):

Percentage = 3,287,263 km² / 222,014 km² × 100 ≈ 6.75%

- Class 3 (Moderately Affected):

Percentage = 3,287,263 km² / 1,135,293 km² × 100 ≈ 34.53%

- Class 4 (Severely Affected):

Percentage = 3,287,263 km² / 745,723 km² × 100 ≈ 22.69%

- Class 5 (Extremely Affected):

Percentage = 3,287,263 km² / 857,872 km² ×100 ≈ 26.10%

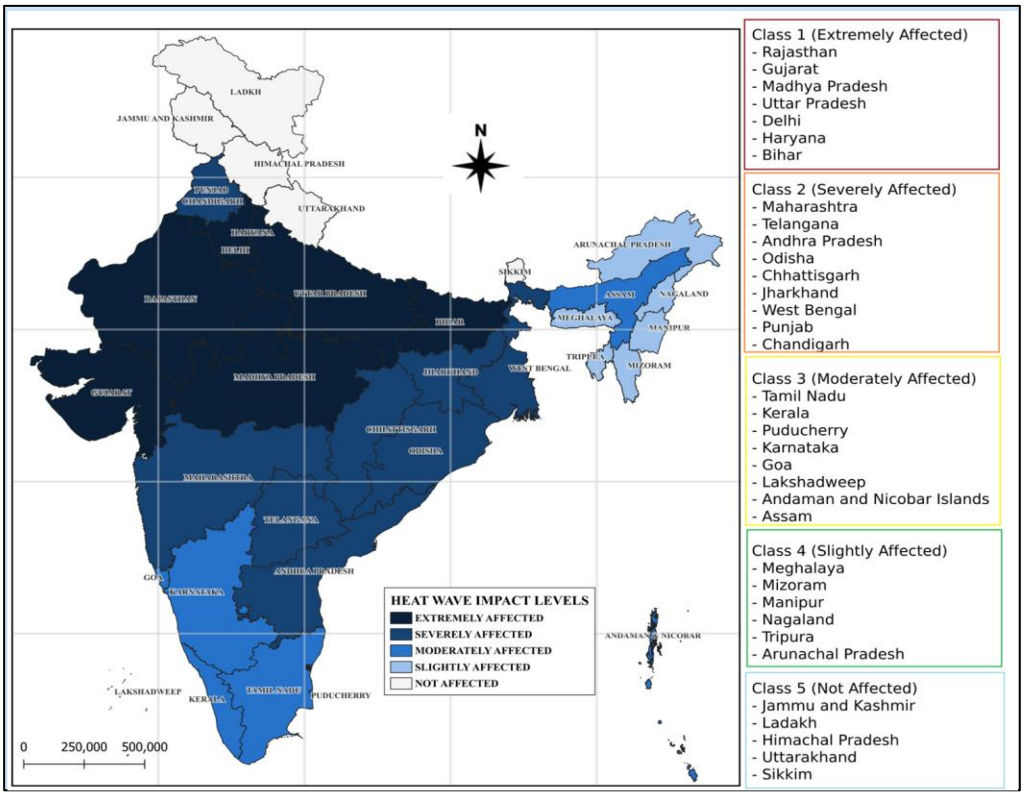
Summary Table:

Class (Name)	Approximate Area Cover (Sq.km)	Percentage of Total Area (%)
Class 5 (EXTREMELY AFFECTED)	857,872	26.10
Class 4 (SEVERELY AFFECTED)	745,723	22.69
Class 3 (MODERATELY AFFECTED)	1,135,293	34.53
Class 2 (SLIGHTLY AFFECTED)	222,014	6.75
Class 1 (NOT AFFECTED)	326,361	9.93

5. Results:

State Level Analysis:

The majority value from each zone is used to classify heat wave severity at the state level, providing a clear, state-wise classification.



Classification of Heat Wave Impact:

Extremely Affected: Regions experience frequent and severe heat waves, leading to high rates of heat-related illnesses and fatalities. The intensity and duration of these heat waves can severely disrupt daily life and strain healthcare systems.

SeverelyAffected: Areas face regular and intense heat waves that pose significant health risks. These conditions can lead to increased cases of heat exhaustion and heat stroke, with potential long-term health impacts.

Moderately Affected: High temperatures are common but not extreme, causing general discomfort such as dizziness, fatigue, and dehydration. While not life-threatening, these conditions can affect overall well-being and productivity.

Less Affected: Temperature increases are minor and infrequent, resulting in occasional discomfort. The impact is usually manageable with simple precautions, and the health risks are minimal.

Not Affected: Heat waves do not directly harm people in these regions. However, the environment may experience subtle effects, such as accelerated snowmelt and minor changes in natural landscapes.

Applications:

Disaster Management: Enhancing preparedness and response strategies for heat wave-related disasters.
Climate Change Adaptation: Informing adaptation measures to mitigate the effects of increasing heat waves.
Environmental Impact Assessment: Evaluating the impact of heat waves on ecosystems and natural resources.
Urban Heat Management: Guiding the development of cooling strategies to reduce urban heat island effects.
Economic Impact Analysis: Assessing the economic consequences of heat waves on productivity and infrastructure.

Sourse:

Giovanni (Data source): Giovanni (nasa.gov)
QGIS (Software used)
Copernicus(DEM Data): Copernicus Data Space Ecosystem | Europe's eyes on Earth
Indian Boundary Map: Survey of India

9. About Me

I’m Gurumurthy R, currently in my 3rd year of a bachelor's degree in Geo Informatics Engineering at Anna University Regional Campus Tirunelveli. As an individual participant, I took on this project titled "Mapping the Impact of Heat Waves in India" for the IIT Bombay Mapathon 2024. I chose this project because heat waves are a major issue in India.

I worked on this project entirely by myself, putting in the effort to learn and apply new skills along the way. I’d like to thank IIT Bombay and other organisers for the opportunity to participate in this competition.

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