Identification of Heat Threshold and Heat Hotspots IN NEPALGUNJ, NEPAL

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Rationale for heatwave study in Nepalgunj

The deadly impacts of extreme heat are rising globally. Heatwaves are causing an increase in morbidity and mortality rates and corresponding financial losses across the globe. In 2003, a period of intense heat in Europe contributed to the deaths of at least 70,000 people and led to 13 billion Euros of financial losses (Umair, 2019). The trend is continuing. In 2019, parts of southern France, particularly the commune of Gallargues-le-Montueux, recorded 45.9°C for the first time, resulting in around 1,435 heat-related deaths across the country (BBC, 2019). More intense and frequent heatwaves are now being experienced, and further increases in such events are expected due to the impacts of climate change.

South Asia is also facing the deadly impacts of extreme heat. According to a World Bank projection, the annual temperature in South Asia's hotspots is projected to increase 1.5–3°C by 2050 relative to 1981-2010. Almost half of the region's population, or 800 million people, live in South Asia's hotspots (Muthukumara & Gulrex, 2019).

Cities are particularly vulnerable to extreme heatwaves. Rapid urbanisation and associated impacts, including: increasing concrete infrastructure, deforestation, filling up of water bodies, increasing amounts of dry and impervious surfaces, diverse economic activities and the adverse impacts of climate change; all serve to exacerbate the heat island effect in cities. However, extreme heat impacts are preventable. Cities have a unique potential to adapt to changing heat risks through effective risk management at multiple levels; connecting policies and incentives and strengthening community adaptive capacity (Nullis *et al.*, 2019). Cities need to undertake a comprehensive plan for early warning systems, effective preparedness and adaptive measures to combat the impacts of extreme heatwaves. Many cities in the region such as Ahmedabad in India, have been taking proactive measures to reduce the risks of extreme heat by developing heat action plans since 2013 and further iterations to the heat action plans (Ahmedabad Municipal Corporation, 2019). But in parts of Bangladesh and Nepal, especially central and northern Bangladesh and the Terai region of Nepal, heat related morbidity, mortality and financial losses are rising (MoHA, 2019; Nissan *et al.*, 2017; Pakistan Times, 2005). Despite this, cities in the region are yet to mainstream their actions to combat extreme heat.

Nepalgunj Sub-Metropolitan City is located on the Terai plains and is one of the primary business hubs in Nepal, sharing a critical border with India. Extreme heat events are a growing concern in the city. The maximum temperature exceeds 40°C almost every year and humidity levels sometimes reach 80 per cent (DHM data, 1996-2020). The Ministry of Home Affairs has stated that 25 heatwaves occurred between 2002 and 2010 in the Terai region (Dhimal *et al.*, 2018). Heat-health impacts have also been reported in many newspaper articles. However, very little to no evidence has been found for systematic actions on heat-health management or overall heat resilience in Nepalgunj particularly and Nepal in general, hence the decision to undertake this first-of-its-kind initiative in Nepalgunj City.

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List of Abbreviations

CBS:	Center Bureau of Statistics
DDMC:	District Disaster Management Committee
DHM:	Department of Hydrology and Meteorology
DRR:	Disaster Risk Reduction
GoN:	Government of Nepal
HI:	Heat Index
KPI:	Key Personnel Interviews
LST:	Land Surface Temperature
ND-GAIN:	Notre Dame Global Adaptation Index
NDVI:	Normalised Difference Vegetation Index
NDWI:	Normalised Difference Water Index
NOAA:	National Oceanic and Atmospheric Administration
NWS:	National Weather Service
RCC:	Reinforced Cement Concrete
SOP:	Standard Operating Procedure
Tmax:	Maximum Temperature
UHI:	Urban Heat Island
WMO:	World Meteorological Organisation

Executive Summary

A heatwave is a meteorological phenomenon characterised by an extended period of unusually hot weather, frequently accompanied by high humidity, which commonly occurs in Nepal from April to June. Cities in the Terai region of Nepal, such as Nepalgunj, have been experiencing rapid urbanisation, with climate change impacts posing additional stress. Heatwaves have become more frequent, severe and lengthier, resulting in rising heat-related morbidity, mortality and financial losses in Nepal in general and Nepalgunj city in particular. In the city, the maximum temperature exceeds 40°C almost every year and humidity levels sometimes reach 80 per cent.

This report aims to support the Nepalgunj Upamahannagar Palika (Sub-Metropolitan City) and other emergency service providers in Nepalgunj, such as the disaster management department and the Banke branch of Nepal Red Cross Society (NRCS), the unit responsible for determining the heat thresholds and heat hotspots, indicating when and where to act before or during heatwave days. Moreover, the report intends to encourage city stakeholders to take fruitful actions in the upcoming heat seasons to reduce the city's heat risks and build stakeholder's capacity on city heat actions.

The approach of the study has been based on the investigation of both secondary and primary data. Secondary information such as demography and socioeconomic data, daily meteorological data on climate variables (temperature and humidity), and historical evidence of heatwave impacts, has been reviewed to design a model for understanding the heat threshold and exposed areas or heat hotspots. Satellite images and remote sensing data using GIS tools have also been investigated for the analysis as mentioned above. Primary data has been collected through field surveys, using tools such as key personnel interviews (KPI) to understand the impacts on the most vulnerable people in Nepalgunj City and for ground-truthing exercises to corroborate the secondary data and other satellite data analysis findings.

The Department of Hydrology and Meteorology (DHM), Nepal, defines a heatwave as the annual count of at least six consecutive days with a maximum temperature more significant than the 90th percentile. The threshold temperature of Nepalgunj has been determined by calculating the 90th percentile of maximum daily temperatures for 24years (1996-2020). The analysis suggests that 38°C is the maximum daily temperature, becoming an extreme event in Nepalgunj Sub-Metropolitan City. The study also indicates that Nepalgunj has been experiencing more frequent hot days with extreme temperatures (equal to or above 38°C) from 2010 onwards.

The ward-level extreme temperature and hotspots analysis exhibits that wards 13, 16, 19, 20, 21, and 22 embrace heat hotspots with higher temperatures than other city wards. The presence of a large industrial area, airport, major busy highway (blacktopped road surface), and limited to no vegetation and water bodies, are considered significant factors for maximum temperature in these areas. This analysis also helps to understand that 2012 and 2015 are the years when all the wards had a maximum temperature more significant than the threshold temperature, signaling that the heatwave exposure was most severe in 2012 and 2015. Further, the normalised difference vegetation index (NDVI) shows that Nepalgunj City has very little healthy vegetation, which might be one of the reasons for the increase in the temperature in the city.

To understand the heatwave risk, a combined exposure map and a vulnerability index is critical. A set of eight indicators have been used and normalised in assessing exposure and vulnerability to heatwaves in Nepalgunj City.

The exposure analysis suggests that the highly exposed wards are located in the eastern side of the city (wards 13, 14, 19, 21 and 22). Likewise, the vulnerability index indicates that wards 6, 15, 18, 19, 20, and 22 are the highly susceptible wards. The five highly exposed wards (13, 14, 19, 21 and 22) have been further ranked with the vulnerability index score to recognise the degree of vulnerability and where to act. This shows that ward 22 is highly vulnerable, followed by wards 19, 14, 21 and 13.

Heat impacts are majorly observed on the daily workers, auto drivers, rickshaw pullers, people with tin houses, street hawkers, etc. Among these vulnerable groups, the most highly impacted are rickshaw pullers and auto drivers as 23 per cent and 20 per cent, respectively, of their income is lost during a heatwave period when the temperature is more than 38°C for six consecutive days. It has also been found that the income of vulnerable people such as rickshaw pullers and auto drivers reduced by 20 per cent when the heat index is 47. Hence, heat index 47 is proposed as the impact threshold and 38°C as the maximum temperature threshold in Nepalgunj.

As next steps, the local city authority and other emergency service providers need to take stewardship of anticipatory actions and reduce human suffering and impacts on livelihoods due to heatwave events. Future work around heat action by the city authority and other emergency service providers in Nepalgunj includes: formulation of a trigger model and simulation in the city, particularly in the vulnerable wards; development of an Early Warning Early Action (EWEA) Standard Operating Procedure (SOP), together with in-depth analysis and validation of the heatwave impact analysis by investigating public health data, would be some of the future direction of work for the city authority and other emergency services for heat action in Nepalgunj. An effective coordination mechanism between stakeholders for various critical heat actions must be mainstreamed. For instance, DHM and the Department of Health Services, Nepal, can play an important role in issuing heat early warnings. Moreover, some of the simple city-level actions that the Nepalgunj Upamahannagar Palika can plan to undertake in collaboration with other city stakeholders, could include conducting public awareness campaigns, increasing access to water and organising home outreach visits to vulnerable people, ensuring the safety of outdoor workers etc.

Chapter 1: Introduction

Nepal is located in South Asia. The country's regions range from tropical forests in the south to the snow and ice-covered Himalayas in the North. The country borders India in the East, West and South and China in the North. An estimated 28 million people live in Nepal of which approximately 21 per cent live in cities, making Nepal less urbanised than other countries in the region and among the least urbanised countries in the world (Urbanisation, 2021). Nepal ranks 127 out of 181 countries in the Notre Dame Global Adaptation Index (ND-GAIN). This ranking indicates that Nepal has high vulnerability levels.

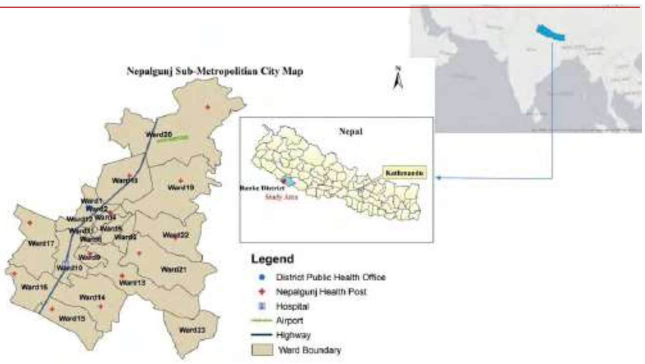


Figure 1. Study area

Source: Author's Illustration based on data obtained from Survey Department, Nepal

The study area is Nepalgunj Sub-Metropolitan City in Banke district. Nepalgunj is around 516 km west of Nepal's capital city, Kathmandu. The city is located on the Terai plains near the countries' southern border with the Indian state of Uttar Pradesh. Nepalgunj is one of Nepal's most developed and largest cities. It is the largest city in the mid-western development region with a high population in respect to other parts of the country (Sousa, 2017). Its urban areas are rapidly developing to the north, east and west of the city. Industries and trade, education, medical care, and tourism are the four major pillars on which Nepalgunj City is built (Integrated Urban Development Plan). The coordinates of the study area (longitude and longitude) are 81°37′0″ E and 28°3′0″ N. The area covers about 85.94km^2. Nepalgunj Sub-Metropolitan City is divided into 23 wards.

1.1 Heatwaves in Nepal

There is minimal documentation on heatwaves in Nepal. According to the government's disaster risk reduction (DRR) portal, there have hardly been any officially declared heat waves in the last decades and heatwave-related impacts have been minor. However, as per the data from the Ministry of Home Affairs, 25 heatwaves occurred between 2002 and 2010, with the most significant occurring in 2009 and 2010, mostly in the Terai region. Twenty-five people lost their lives and 280 people were affected due to the heatwaves between 2002 and 2010 (Dhimal *et al.*, 2018). During the summer, the maximum temperature can reach up to 45°C (DHM, 2020) and heatwaves are relatively common during lengthy periods of drought. The trends of hot days and hot nights are also increasing significantly in the majority of districts (Shrestha *et al.*, 2019). This study done by Shrestha *et al.*, (2019) reveals (below figure) that the population in most parts of the country perceives an increase in hot days and hot nights.

Moreover, a 2020 research study has found that, on average, households in Nepal stay inside their homes for 3.13 hours per day (range: 0–4 hours) to be protected from extreme heat during daytime, which reduces their working hours by at least two months every year (Paudel & Prasad, 2020).

1.2 Climatology and hydrology of Nepalgunj

Nepalgunj has a subtropical climate. April through June are the hottest months of the year, with maximum temperatures exceeding 40°C. April, May and June have the highest average temperatures, while night temperatures (low temperatures) are highest in June, July and August (Weather Atlas, 2021). The highest temperature ever recorded in Nepalgunj was 45°C in 1995 and 2012 (DHM, 2020). Extreme temperatures generally cool off at night. For instance, in June 2021, the average day time temperature was 37.4°C, but the average nighttime temperature cooled down to 26.2°C (Weather2visit, 2021). As observed from historical weather data, humidity during hot days reaches around 80 per cent. However, sometimes it is not cool enough for people who have been exposed to high temperatures all day, which can lead to higher cumulative heat exposure. The average precipitation in Nepalgunj City is 1,172 mm (46.1 inches).

The monsoon period has been recorded in Nepalgunj from June to September. High and severe precipitation is occasionally noted as the primary cause of flooding in Nepalgunj City (Chhetri *et al.*, 2020). There are no major rivers that flow through Nepalgunj City.

Figure 2. Heat in Nepal

Source: Shrestha et al. 2019

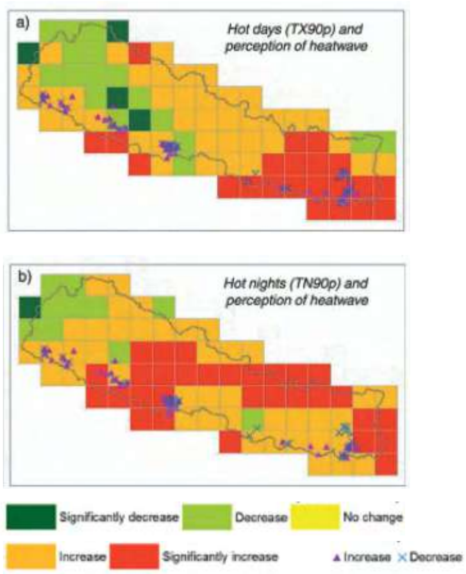


Figure 3. Climatology of Nepalgunj

Source: Weather Atlas, 2021

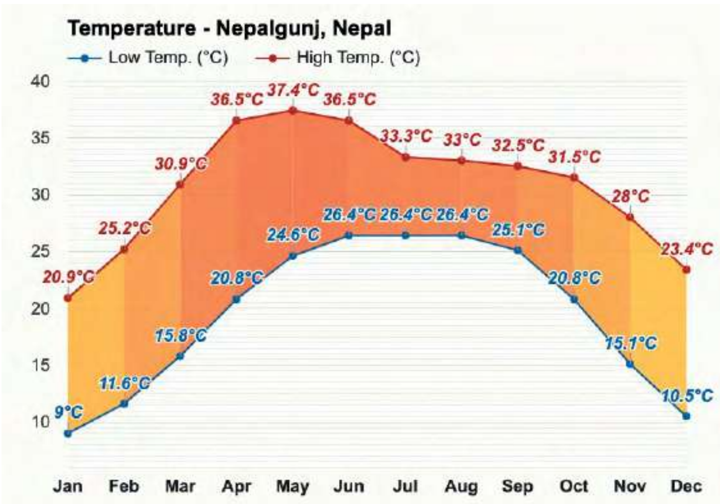


Table 1: Average precipitation of Nepalgunj City

Average precipitation mm (inches) (1981-2010)	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	22.8	24.3	14.9	16.3	71.4	199.4	430.7	353.8	235.2	58.3	5.1	11.7

Source: Department of Hydrology and Meteorology (DHM), 2014

1.3 Demography

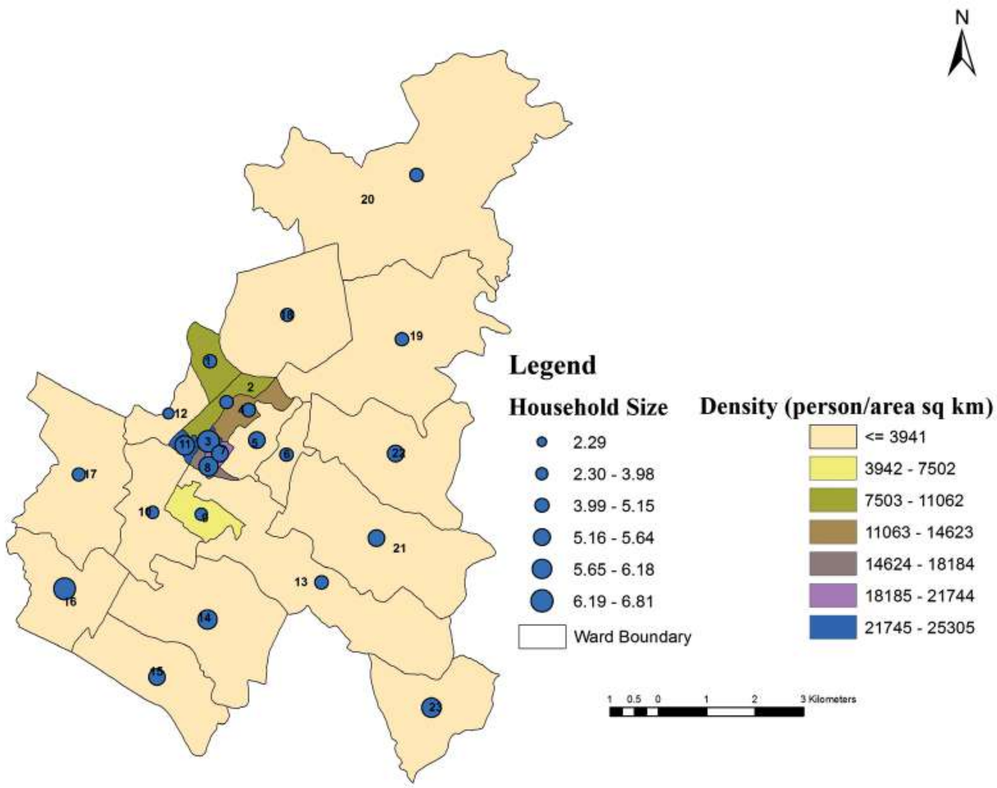
As of 2020, the total population of Nepalgunj City was 177,938. The maximum population is represented by the age group of 5-19 years (36.17%), followed by the age group of 30-59 years (29.59%). The lowest population age group is above 60 years (5.87%). The highest populated ward of Nepalgunj is ward 20 (9.00%), followed by ward four (7.32%). The most densely populated area and household size are shown in Figure 4 below.

1.4 Socioeconomic and physical characteristics

The social, economic, and demographic attributes of Nepalgunj City reflect directly on the social vulnerability of the city. Social exclusion or deprivation and urban poverty are some of the major social issues in Nepalgunj City. The following socioeconomic and physical characteristics are discussed in the below section, as these characteristics have been used as indicators for heat exposure and vulnerability assessment in the later segment.

Figure 4. Population density

Source: Author's Illustration based on data obtained from Center Bureau of Statistics (CBS)



Occupations: The majority of the population is engaged in service and sale work (32.09%), followed by craft and trade works (16.48%) (CBS, 2014). The major occupations of the active populations are shown in Figure 5.

Education: The majority of the population has primary level education (34.78 per cent). 18.28 per cent have lower secondary level education, the highest level of education available to people in Nepalgunj (CBS, 2014).

Photo 1: Fruit shop on the street of the main market of the city

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Health: There are four categories of healthcare facilities in Nepalgunj City: 15 hospitals, 33 clinics, 12 health posts, 13 health centres (Nepalgunj Sub Metropolitan City, 2021). As of 2019, the most common health conditions in the city are presented in the following Figure 6.

Roads: A total of 83km of road network with different types of road quality such as Bitumen, graveled, earthen roads are present. About 43.37 per cent of Nepalgunj's roads are graveled, followed by earthen (33.73 per cent) and blacktopped (22.90 per cent) (UN-HABITAT, 2010).

Housing structure: The majority of the population (65.14 per cent) living in Nepalgunj have reinforced cement concrete (RCC) rooftops followed by tile or slate rooftops (15.53 per cent) and thatch or straw rooftops (8.66 per cent) (CBS, 2014).

Figure 5. Major occupations

Source: CBS, 2014

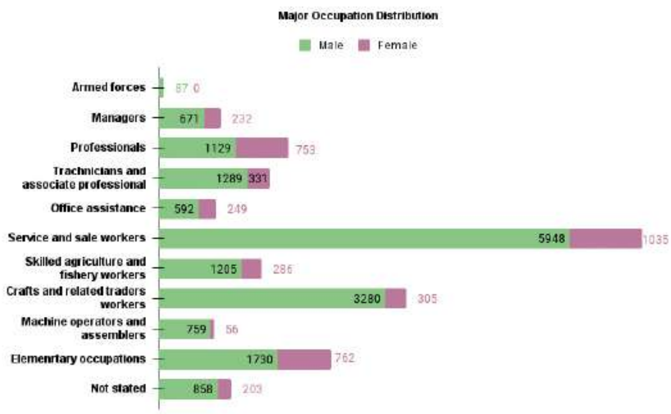
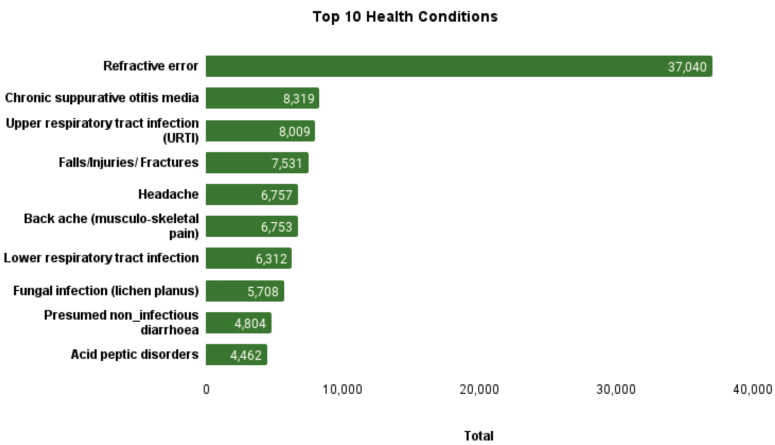


Figure 6. Health condition of Nepalgunj City

Source: Government of Nepal (GoN), 2020

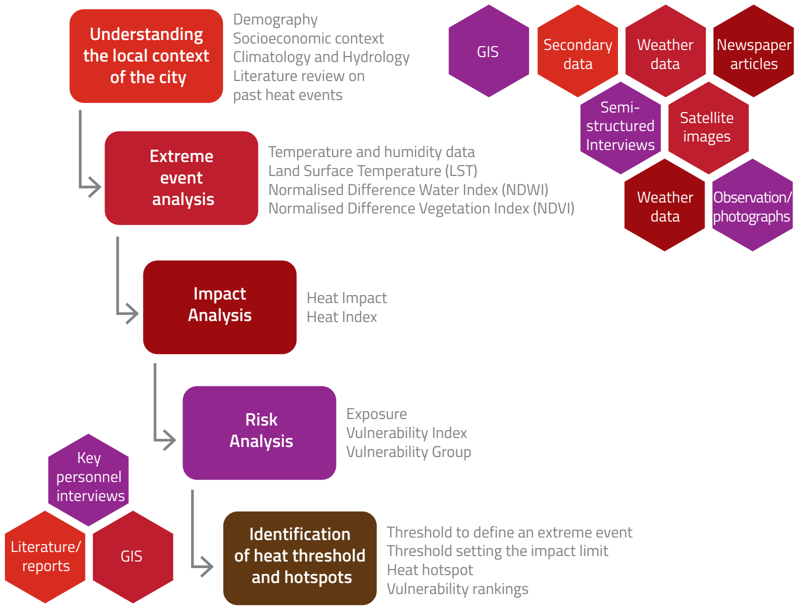


1.5 Approach and tools

The various steps and corresponding tools (defined by using different colour codes) that have been used to attain the aim of the initiative i.e. identification of heat threshold and hotspots, are illustrated in the following diagram.

Figure 7. Study approach and tools

Source: Author's illustration adopted from BDRCS, 2021



This study has been initiated by investigating secondary information such as demography and socioeconomic data, past studies on heatwaves and their impacts, to understand the local context in Nepalgunj. Daily meteorological data on climate variables (temperature and humidity) over the last 24 years for Nepalgunj Sub-Metropolitan City have been analysed for trend analysis. Likewise, satellite images and remote sensing data have been investigated using GIS tools for extreme events. The research on historical evidence of heatwave impacts in the study area has been done through literature review and newspaper articles. Some of the critical steps for this initiative are heat index analysis and exposure, vulnerability index (underlying factors for the heatwave impacts), and identification of vulnerable groups. Tools such as key personnel interviews (KPI) have been adopted to corroborate secondary data and other satellite data analysis findings. Additionally, ground visits or observation and photographs have been used for ground-truthing exercises. Finally, heat thresholds and hotspots are identified by investigating the above-mentioned processes and tools, which provide information on when and where to act in relation to extreme heat days.

1.6 Limitations

This study has a few limitations:

- The heat threshold has been developed based on the availability of secondary data. Due to time constraints, the heat threshold model could not be tested extensively for months. However, it helps establish a concept that the city authority and other relevant stakeholders can refine (if required) in the future heat season.

- "Both exposure and vulnerability are dynamic, vary across temporal and spatial scales, and depend on economic, social, geographic, demographic, cultural, institutional, governance related and environmental factors." (UNISDR, 2016). So, the heat hotspots can be varied over time due to climate change and developmental activities and other socioeconomic variations in the region.

- Due to the sudden spike in Covid-19 cases in Nepal in general, and Nepalgunj City specifically, and the strict restrictions to curb the spread of the pandemic – an extensive survey and other participatory exercises to corroborate the impacts and exposure findings from secondary data analysis could not be performed. However, a rapid and light survey to understand vulnerability levels was undertaken.

Photo 2: Agricultural land (paddy field) in ward 13 of Nepalgunj City

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Chapter 2: Extreme Temperature

2.1 Heatwave definition

The World Meteorological Organisation (WMO) defines a heatwave as: "five or more consecutive days during which the daily maximum temperature surpasses the average maximum temperature by 5°C (9°F) or more" (Rafferty, 2018).

The Meteorological Department of Nepal does not explicitly use the word heatwave, instead, they use: "**warm days** – percentage of days with maximum temperature > 90th percentile," and: "**warm spell duration** – annual count of days of at least six consecutive days with maximum temperature > 90th percentile" (DHM, 2017).

2.2 Heat Threshold Temperature

The maximum temperature data has been analysed to identify the threshold temperature. Figure 8 below shows the variation of annual extreme temperature in the past 24 years.

The threshold temperature has been determined by calculating the 90th percentile of maximum daily temperatures from 1996 to 2020, since, according to the definition of DHM, the extreme temperature is the temperature that crosses the 90th percentile of the given data sets.

Based on the investigation of a historical data set of climatic variables for 24 years (1996-2020), 38°C has been recorded as the threshold maximum temperature. It records that 90 per cent of the daily maximum temperatures from 1996 to 2020 is equal to or lower than 38° Celsius.

Considering the heatwave definition by DHM, i.e. exceeding a maximum daily temperature of 38°C for six or more consecutive days, the following chart illustrates the number of heatwave events occurring between 1996 and 2020 in Nepalgunj.

Figure 8. Maximum temperature of each year from 1996 to 2020 Nepalgunj Airport Station, Nepalgunj

Source: Author's Illustration based on data obtained from DHM

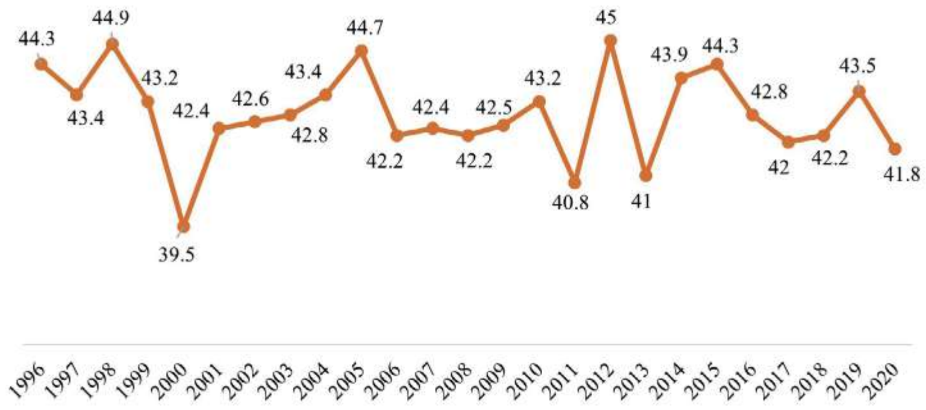
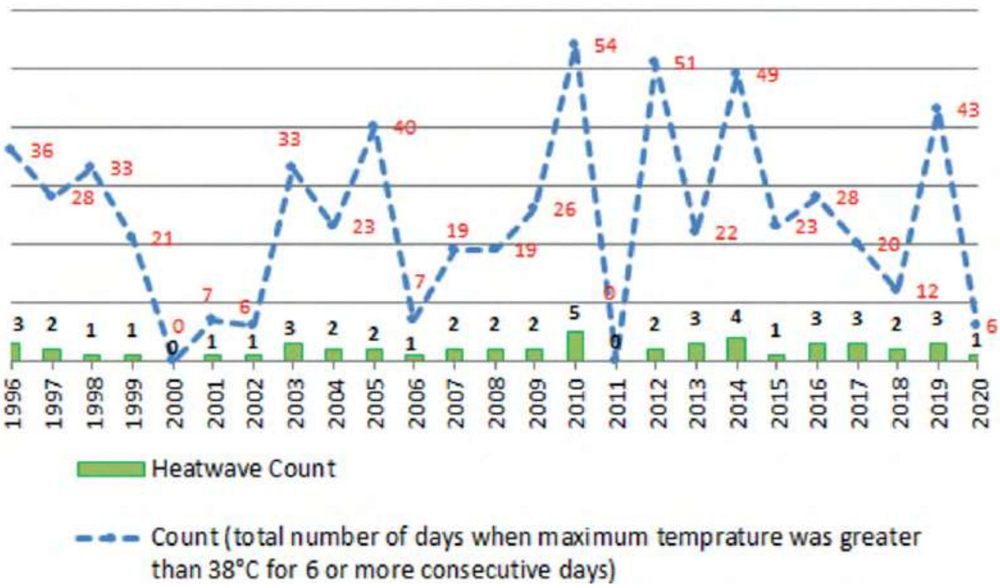


Figure 9. Number of heatwave events and respective number of days in the heatwave events from 1996 to 2020 in Nepalgunj City

Source: Author's Illustration based on data obtained from DHM



This chart helps to visualise the number of heatwave events that occurred in each year from 1996 to 2020. The numbers highlighted in red showcase the total number of hot days (i.e. above 38°C) in the spells of heatwave events in the respective year. For instance, in the year 2015, only one heatwave event occurred, and the duration of this heat wave period was 23 days, i.e. from 21 May to 12 June. In 2019, three heat waves occurred and the duration of this heat wave period was 43 days, i.e. from 25 April to 2 May, 5 May to 2 June and 13 June to 18 June.

It appears that Nepalgunj has been experiencing more frequent hot days with extreme temperatures (equal to or above 38°C) from 2010 onwards. 2010, 2012, 2014 and 2019 are the years that experienced the maximum number of days reaching the extreme temperatures limits. In 2010, the city experienced 54 extreme temperature days, the highest in number to date. The frequency of heatwave incidents is also rising. From 2010 to 2020, on average, at least two heatwave events occurred in the city. The perception of stakeholders in the city supports this inference to a great extent. Stakeholders also reported that the city's pace of urbanisation and related developmental activities had increased from 2009. This could be one of the reasons for the growing temperature extremes and heat wave events in the city.

Chapter 3: Land Surface Temperature

Land surface temperature (LST) is the temperature felt while touching the land surface with one's hands or the ground's skin temperature (Rajeshwari & Mani, 2014). LST mapping aims to demonstrate a flexible and straightforward conceptual framework relying upon satellite thermal data that shows surface temperature trends and variability and areas at high risk (i.e. areas with high temperature compared to surrounding) in Nepalgunj City.

The data used to determine LST and surface emissivity are Landsat satellite images from 2010 to 2020, which are downloaded from the official website of the US Geological Survey (USGS). The study area is located in the Landsat path/row of 140/40.

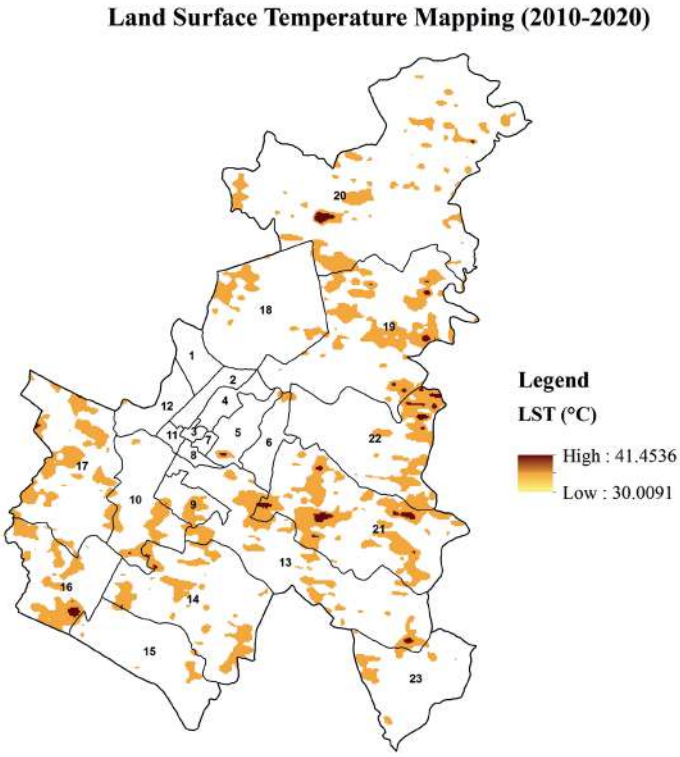


Figure 10. Combined LST mapping for 2010 to 2020 to understand ward level max. temperature and hotspots

Source: Author's illustration based on data obtained from Landsat satellite images

The LST analysis of the last 11 years (i.e. 2010-2020) shows that wards 13, 16, 19, 20, 21 and 22 embrace the most heat hotspots with higher temperatures than other city wards. The presence of a large industrial area, airport, major busy highway (blacktopped road surface) and limited to no vegetation and water bodies, can be considered significant factors for maximum temperatures in these areas.

The maximum and minimum land surface temperatures have been extracted for each ward using a clipped raster by a mask layer, which uses a raster extraction tool in QGIS. The maximum temperature for each ward from 2010 to 2020 is presented in Figure 11.

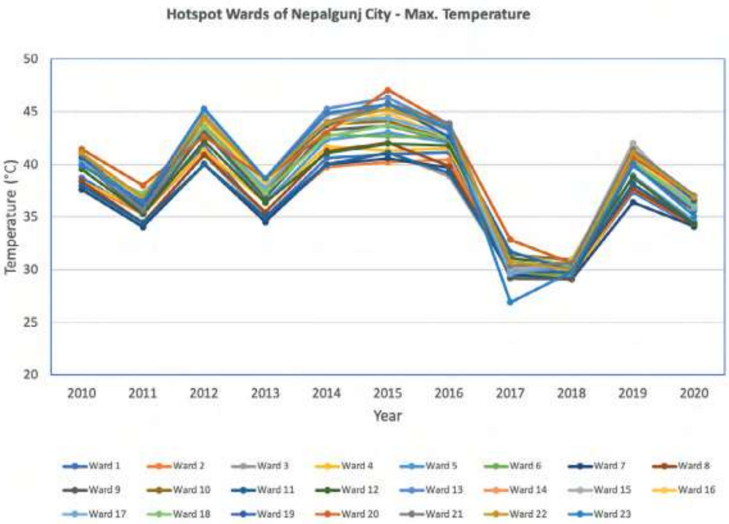


Figure 11. Ward level maximum land surface temperature in Nepalgunj

Source: Author's illustration based on data obtained from DHM

This analysis aims to identify the wards where maximum temperature reaches above 38° Celsius i.e. the threshold temperature. The above analysis exhibits that 2012 and 2015 are the years when all the wards experienced a maximum temperature significantly higher than the threshold temperature. It signals that heatwave exposure was most severe in 2012 and 2015, with 2012 considered to be the hottest year in Nepalgunj (as per the DHM data, illustrated in Figure 8). So, the analysis of heat risks has been conducted considering the ward level maximum temperature of 2012 heat data and corresponding hotspots.

3.1 Normalised difference water index (NDWI) and normalised difference vegetation index (NDVI)

To analyse the relationship between landcover changes and urban heat island effect (UHI), a quantitative method in studying the relationship between temperature and the NDVI and NDWI has also been investigated. Data for the year 2020 has been analysed for NDVI and NDWI investigations to get an overall understanding of the latest situation.

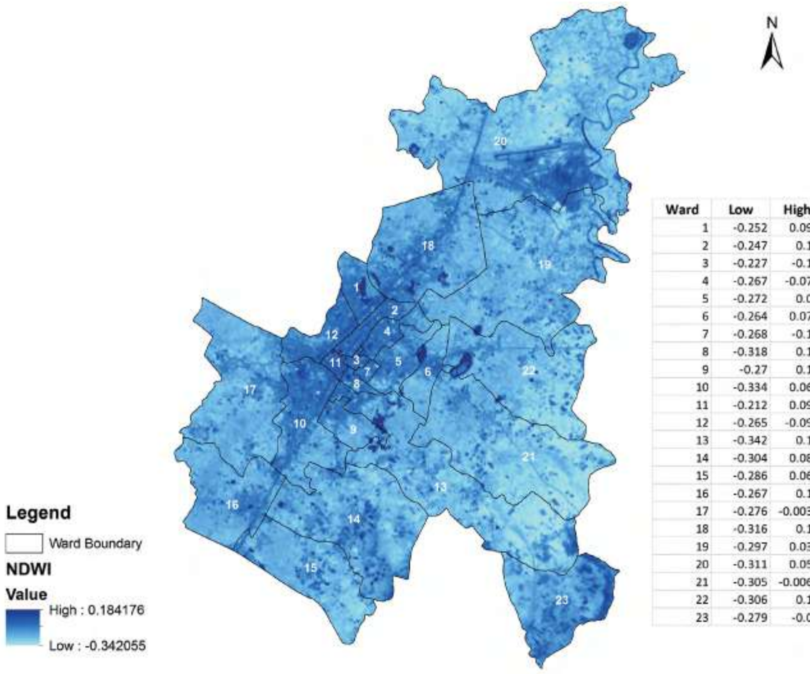


Figure 12. NDWI

Source: Author's illustration based on data obtained from Landsat satellite images

Ward	Low	High
1	-0.252	0.0977
2	-0.247	0.131
3	-0.227	-0.105
4	-0.267	-0.0784
5	-0.272	0.038
6	-0.264	0.0792
7	-0.268	-0.133
8	-0.318	0.105
9	-0.27	0.126
10	-0.334	0.0663
11	-0.212	0.0959
12	-0.265	-0.0906
13	-0.342	0.126
14	-0.304	0.0874
15	-0.286	0.0684
16	-0.267	0.131
17	-0.276	-0.00393
18	-0.316	0.137
19	-0.297	0.0309
20	-0.311	0.0593
21	-0.305	-0.00615
22	-0.306	0.184
23	-0.279	-0.077

The high NDWI value is observed in ward 22, which indicates ward 22 has more water and vegetation surface content compared to other wards, while the lowest NDWI is found in ward 13, indicating the built-up area and bare land are more in this ward. Unlike other wards, there are no water surfaces.

Although the western part of the city (such as ward two) consists of highly populated regions, the temperature is still noticeably lower as the lower LST values are found in the western parts of the city. The NDWI study confirms that this is because of the high vegetation water content in the city's western side.

The NDVI is a measure of surface reflectance which gives a quantitative estimation of vegetation growth and biomass. Here, low values of NDVI (0.1 and less) correspond to vegetation free regions and stony and sandy areas. Moderate index values (0.2–0.5) show sparse vegetation such as shrubs and grasslands or senescing crops.

Photo 3: Water body in ward two in Nepalgunj

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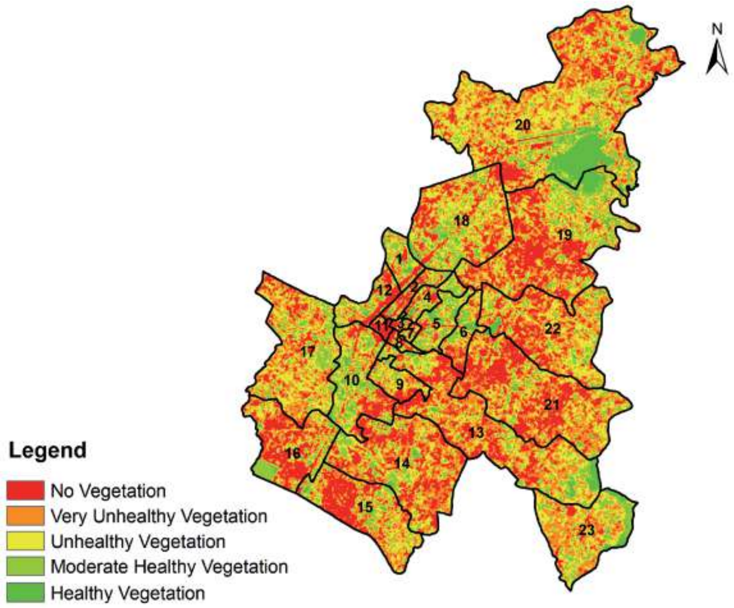
Figure 13. NDVI

Source: Author's illustration based on data obtained from Landsat satellite images



Ward 20 of Nepalgunj City has the highest NDVI. However, as seen in Figure 13, Nepalgunj City has very little healthy vegetation. This might be another reason for the temperature increase in the city. As we know, trees and vegetation have lower surface and air temperatures resulting from the shade they provide and through evapotranspiration (Akbari *et al.*, 1997). Summer peak temperatures can be reduced by 1–5°C when evapotranspiration is used alone or in combination with shading (Huang *et al.*, 1990; Kurn *et al.*, 1994).

3.2 Urban heat island (UHI) effect

The UHI effect makes one neighborhood hotter than another. It was found that surface temperature is higher in urban areas than the surrounding rural areas (BDRCS, 2021). UHI can be detected by taking temperature readings on the ground or in the air. Surface temperatures influence air temperatures in an indirect but critical way. Parks and vegetated spaces, for example, contribute to cooler air temperatures since they have cooler surface temperatures (Wong & Yu, 2005). Densely populated places on the other hand, tend to have warmer air temperatures. The relationship between surface and air temperatures is not constant because air mixes within the atmosphere (Wong & Yu, 2005; Ngie *et al.*, 2017). Due to impervious surface and or higher reflection of the roof, the temperature starts rising as it is trapped in those areas. Consequently, in summer, the roof and pavement surface temperatures can be higher than the air temperature (BDRCS, 2021). People who work outside or on the ground, roof, or road, as well as those who live in slums or on the street, are most vulnerable to UHI effects (BDRCS, 2021). The measurement of UHI is done at various levels (surface level and atmospheric level) and by different tools.

The UHI effect can be calculated by comparing the difference in the ambient temperature (DHM observed data) and the land surface temperature (LST). Although the two temperatures have different physical meanings and responses to atmospheric conditions, there is a link between LST and near-surface air temperature (Ngie *et al.*, 2017). The parameter 'delta T' defines the difference between LST and air temperature.

Delta T

Delta T is calculated by computing the following equation:

$$\Delta t \text{ (UHI Effect)} = \Delta\mu - \Delta\sigma/2$$

Here, Δμ is the mean of the differences and Δσ is the Standard Deviation (SD) of the differences.

Method to compute Delta T for Nepalgunj City: All raster images were taken or sensed by the sensor around 9:45 am of the respective day. We calculated the LST for each of the images. Since the hourly temperature was not available, the maximum air temperature from DHM was subtracted by 3°C. This was done to get the temperature around 10am. 3°C was used because the average difference between maximum temperature and temperature around 10 am is around 3-4°C. The air temperatures were then subtracted from LST and the mean and SD of the differences were calculated. To get a higher level of accuracy, UHI was calculated by adding the full SD with mean and here, and half of SD was subtracted from the mean of differences between LST and air temperature.

According to computations, on average, the surface temperature is 1.01°C greater than the air temperature in Nepalgunj. Therefore, this temperature difference value or 1.01°C, which is recognised as UHI effect or delta (t), needs to be added up with the air temperature to calculate the heat index (HI) and further risk assessment.

Chapter 4: Heat Impact Limit Analysis

4.1 Heatwave impact

The critical aim of heatwave impact analysis is to identify the maximum temperature condition and its impacts on the residents of the city and accordingly, to identify the respective year and days when heatwave impacts were at their maximum. This impact analysis is meant to give an indication when the residents of the city were impacted by the extreme heat. It facilitates setting thresholds for anticipatory actions.

The heatwave impact analysis has been undertaken through investigation of newspaper articles for roughly the last 20 years. Given the dearth of public healthcare data in the city and limitations on undertaking community level extensive heatwave impact surveys; due to restrictions associated with the Covid-19 pandemic, this alternative approach has been undertaken to identify the respective years when heatwave impacts were maximum. Moreover, a detailed impact analysis requires substantial resources and time, which is beyond the scope of this study.

The analysis suggests the most severe heatwaves to strike Nepalgunj in the last two decades occurred in 2015, 2016, 2017 and 2019, with impacts reported as maximum in these four years. Based on newspaper articles from 2015, 2016 and 2019 and later substantiated by the daily temperature data collected from DHM, it has been observed that the maximum temperature mainly occurs from mid-April to June. These two and half months tend to be the hottest months in Nepalgunj. The average maximum air temperature for these four years varies from 37°C to 39°C. The humidity value ranges from 20 per cent and rises to 80 per cent.

As reported in news articles, typical heatwave impacts included an increase in the number of patients at hospitals with ailments such as headache, typhoid, diarrhea, constipation, nausea and other heat-related illnesses (Rastriya Samachar Samiti, 2016; The Kathmandu Post, 2016). The scorching weather primarily impacted daily wage earners and low-income groups who could not use electric appliances to stay cool due to prolonged power outages (The Himalayan Times, 2016; The Kathmandu Post, 2016). The majority of people stayed in their houses most of the time, and marketplaces were shut during the afternoon for nearly two weeks due to severe heat conditions (The Kathmandu Post, 2015a, 2015b). The number of patients coming to hospitals with communicable diseases also increased. The Bheri Zonal Hospital, Nepalgunj, received 35 to 40 such patients daily (The Himalayan Times, 2017). Similarly, heat impacts also placed stress on farmers and street vendors (Nepal24Hours, 2019; Nepalgunj News, 2019).

4.2 Heat Index

The heat index (HI), commonly known as the apparent temperature, is the temperature that the human body perceives when combining relative humidity and air temperature. This has significant implications for the comfort of the human body. The HI analysis helps to understand how hot current weather conditions feel to the average individual.

The temperature and humidity analysis in Nepalgunj from 1996 to 2020 indicates a slight decrease in maximum temperature (by 0.02°C), but an increased trend in relative humidity over the last 25 years (DHM, 1996-2020). The air temperature and relative humidity directly correlate with the heat index, which means that when the air temperature and relative humidity increase, the heat index also increases and vice versa.

The National Oceanic and Atmospheric Administration (NOAA) has categorised the HI into four different classes linked to severity of health effects for practical application, as shown in Table 2 below:

Table 2: Health risks to various heat index categories adapted from NOAA

Heat Index	Categories	Health Risk
27 – 32	Caution	Fatigue is possible with prolonged exposure and activity. Continuing activity could result in heat cramps.
32 – 41	Extreme caution	Heat cramps and heat exhaustion are possible. Continuing activity could result in heat stroke.
41 – 54	Danger	Heat cramps and heat exhaustion are likely; heat stroke is probable with continued activity.
> 54	Extreme danger	Heat stroke is imminent.

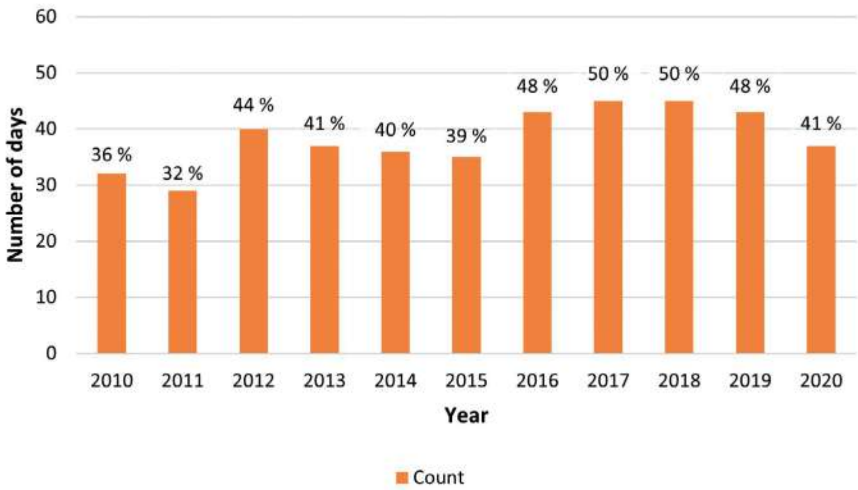
Source: NOAA, 2009

The analysis of long-term climate records reveals evidence of a rise in the frequency and length of extreme temperature events across Nepalgunj, particularly during the summer (DHM, 1996-2020). As it has been recognised from the literature review and daily temperature analysis in the above sections – April, May and June are the peak summer months in Nepalgunj. So, the HI analysis has been calculated for these three months from 2010 to 2020, for the last 11 years, to identify those years when HI or apparent temperature exceeds extreme danger level i.e. above 54.

The UHI is one of the critical factors for the heat risk assessment. To get a higher level of accuracy and to calculate the heat threshold in Nepalgunj City, the HI was calculated incorporating UHI effect (1.01°C) in air temperature.

Figure 14. Number of days with HI at extreme danger level (i.e. 54°C) during the peak summer months from April to June, 2010-2020

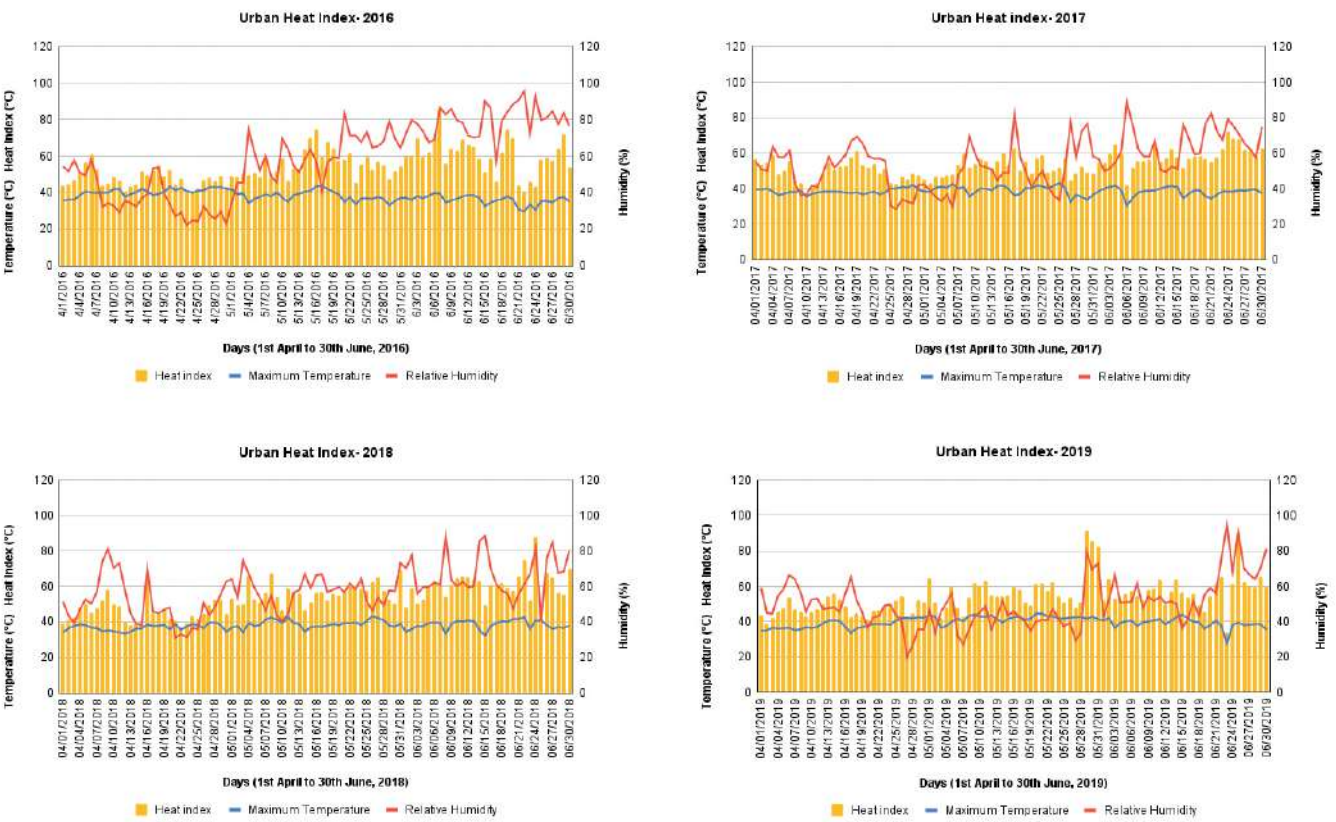
Source: Author's Illustration based on data obtained from DHM



The above chart shows that in 2016, 2017, 2018 and 2019, over 45 per cent of days in the entire three months i.e. April to June, recorded temperatures or HI above the extreme danger level. The HI of these four years has further been examined (Figure 15 – below) to recognise the months and days when the HI was maximum. The analysis of newspaper articles also corroborates that the heatwaves in 2016, 2017 and 2019 were severe, and their impacts were extreme, although not many news articles have reported about the heat-health impacts in 2018. However, it facilitates to set the impact limit for setting up thresholds and anticipatory actions.

Figure 15. Urban heat index 2016, 2017, 2018 and 2019

Source: Author's Illustration based on data obtained from DHM



In these four years, during the heatwave period, the minimum temperature, humidity, and heat index were 39.21°C, 20 and 40.85 respectively. Similarly, the maximum temperature, humidity, and heat index were 44.51°C, 79.5 per cent, and 91.67 respectively (shown in Table 3). The maximum heat index is observed when both temperature and humidity are high.

Newspaper articles have indicated significant impacts during those days when HI was above extreme danger level or above 54. For instance, on 26 April 2019, the HI was above 54 and in a newspaper article on 27 April 2019 (Nepalgunjnews), it was published that people were feeling exhausted and sick due to hot wind and extreme heat. Similarly, from 9 to 17 May 2019, there was a spell when the HI was above extreme danger. Newspaper articles on 10 May 2019 (Nepal24Hours) and 12 May, 2019 (Nepalgunjnews), reported that children were falling ill and the livelihoods of daily wage earners were being affected. At local hospitals, a growing number of people were suffering from rashes, dysentery, fever, and diarrhea. Typhoid had also been reported in news articles. No news articles were found during the days when HI was maximum, such as on 25 June 2019 when the HI touched 90.

The signs of rising heat index on a particular day and its impacts reported in newspaper articles the following day facilitate to set the impact limits, the impact limits projects an indication to set a threshold for anticipatory actions in the city by the respective authorities. From the HI and primary heat impacts analysis, the limit of the following impact can be drawn:

Table 3: Impact Limits

Heatwave days	Impact Based Rank	Temp max. range °C	Humidity (%)	Heat Index
2016 (5 April-11 April; 18 April-1 May; 13 May- 19 May)	Low	39.21-43.21	22.05 – 53.7	40.85-54.77
2017 (25 April-30 April; 3 May-8 May; 19 May-26 May)	Medium	39.31-43.01	28.35-52.3	42.43-59
2018 (7 May-12 May; 17 June-22 June)	High	39.21-42.51	40.4-61.62	46.75-74.86
2019 (25 April-2 May; 5 May-2 June; 13 June-18 June)	Very High	39.51- 44.51	20 – 79.5	42.44- 91.67

Source: Author's Illustration based on data obtained from DHM and newspaper articles

It is important to note here that the impact assessment based on newspaper articles analysis gives an overall indication of the heat-health impacts. A detailed investigation using public health data and a community-level impact survey is necessary for an in-depth analysis on heat-health impacts and adverse impacts of extreme temperature events on livelihoods.

Chapter 5: Heat Hotspots Identification in Nepalgunj

A combined exposure map along with a vulnerability index is critical to understand heatwave risk. A set of eight indicators have been used in assessing exposure and vulnerability to heatwaves in Nepalgunj City. The below table presents a list of indicators along with the rationale behind their inclusion in the assessment.

Table 4: List of indicators, their dimensions and category, and rationale for the selection

Indicators	Dimension	Category	Rationale for selection
Population density	Sensitivity (Positive)	Exposure	Increased population density, population growth, and dispersal increase heat susceptibility.
Built-up area	Sensitivity (Positive)	Exposure	Increasing built-up surfaces, means of transport, and industrial activities are major factors towards increasing temperatures in the city area as compared to other areas.
Heat hotspot areas	Sensitivity (Positive)	Exposure	This gives information about the area with high temperatures.
Low income status	Sensitivity (Positive)	Socioeconomic vulnerability	People with low incomes are among the most vulnerable: they have little to no financial capital and hence have the least ability to combat the impact of heatwaves and the effects of climate change (Rothfusz, 1990).
Age group population (below 5 years and above 65 years)	Sensitivity (Positive)	Socioeconomic vulnerability	This age group population is sensitive to the effects of extreme heat, less aware of the impacts of extreme heat and must rely on others to keep them cool and hydrated during a heatwave.
Education	Adaptive Capacity (Negative)	Socioeconomic vulnerability	Literacy rates have a direct correlation towards reducing vulnerability. As the literate population increases, better livelihoods will be adopted. High literacy rates also have a significant positive connection with low infant mortality rates and better sanitation facilities.
Housing Materials	Sensitivity (Positive)	Physical vulnerability	People living in tin houses where metal roofs absorb heat when directly exposed to the sun; impact the resident population.
Hospital	Adaptive Capacity (Negative)	Adaptive Capacity	As access to functional healthcare facilities increases, the opportunities for communities' overall health and well-being and access to first aid/treatment for heat illness also increases.[1]

Source: Author's illustration

1 Here, access to functional healthcare facilities refers to only medical infrastructures, availability of doctors and other medical staff. However, other factors that can impact adaptive capacity, such as cost, availability of free medicines in the hospital, health insurance, stigma, kinds of treatment, health staff to-patient ratio, etc., also need to be assessed for in-depth analysis on heatwave and health.

Furthermore, all the parameters are normalised to compute normalised heat index scores. The normalisation process has been explained in Table 5 below:

Table 5: Normalisation of indicators for exposure, vulnerability and capacity

Normalisation is based on the indicator's functional relationship with vulnerability.
For positively related indicators, i.e. where vulnerability increases with an increase in the value of the indicator, the following formula has been used. $N_P = ((P - Pmin) / (Pmax - Pmin)) \times 100$ Where P is the value of the respective indicator; Pmax is the maximum value of the indicator; Pmin is the minimum value of the indicator. Here, positive indicators are population, hotspots, built-up areas, age group, low socioeconomic status and physical structures.
For negatively related indicators, i.e. where vulnerability decreases with an increase in the value of the indicator, the following formula has been used: $N_N = ((Pmax - P) / (Pmax - Pmin)) \times 100$ Where P is the value of the respective indicator; Pmax is the maximum value of the indicator; Pmin is the minimum value of the indicator. Here, negative indicators are education and health capacity as their vulnerability decreases with an increase in the value of the indicator.
The **higher value of normalisation** refers to the region or ward with **maximum vulnerability** and the lower **value of normalisation** corresponds to the ward with **minimum vulnerability** with respect to a particular indicator.

Source: Author's illustration

5.1 Exposure

Exposure is the location, attributes, and value of assets critical to communities (people, buildings, factories, farmland, etc.) which could be affected by a hazard. Due to the predominance of concrete surfaces in the city, temperatures in built-up areas and densely populated parts, tend to be hotter than those in the surrounding countryside. The heatwave exposures indicators used in this study are population density, heat hotspot areas and built-up areas.

Parameters to calculate the following indicators:

Population density: ward-level population density data has been analysed.

Hotspots: the year 2012 has been selected because every ward has a higher temperature than the 90th percentile value i.e. 38°C. The mean value of 2012 is 40.4.

Built-up area: to construct the heatwave exposure index, ward-level built-up area data has been extracted from land cover (ArcGIS).

5.1.1 Exposure analysis

The exposure analysis has been conducted by using normalised scores of population density, hotspots, and built-up. The sensitivity for all these indicators is positive, which indicates the higher the normalisation value, the greater the exposure.

The formula for the combined exposure:

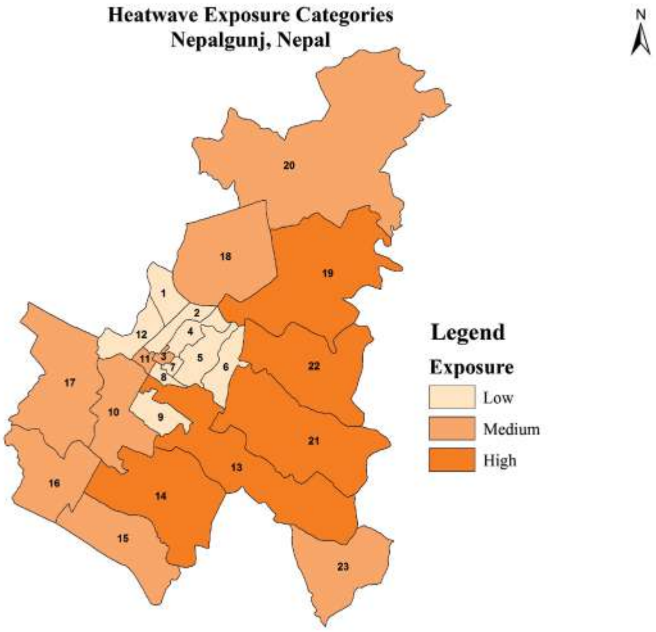
$$E = W_{t1} \times \text{Population} + W_{t2} \times \text{Hot spots} + W_{t3} \times \text{Built-up}$$

After the normalisation process, the individual parameters have been transformed by scaling so that all the parameters come in a similar range. Each normalised value of population density, heat island, and built-up has been multiplied with equal weights, i.e. 0.33. This individual weighted value was selected on the basis of socio-economic context through expert judgments.

Figure 16.

Heatwave exposure

Source: Author's illustration based on data obtained from CBS and Landsat satellite images



The exposure analysis suggests that wards 13, 14, 19, 21 and 22 are highly exposed and could be more affected by heatwave effects. More specifically, wards 13,19 and 21 are highly exposed because urban growth is happening significantly in these wards. Built-up areas are also expanding. In wards 14 and 22, the maximum temperature value is observed making these wards highly exposed to heatwave events. Furthermore, in these wards, the NDWI value is significantly low. NDVI analysis also suggests that there is very little to no vegetation in these wards.

Photo 4: Street vendor under the scorching sun in ward 12

© Ashma Subedi, Climate Centre

5.2 Vulnerability

Vulnerability can be defined as a person's or a group's inability to predict, cope with, resist and recover from the effects of a climatic disaster. Vulnerability has been categorised into three different types and each type has further been classified into sub-categories as presented in Figure 17 below:

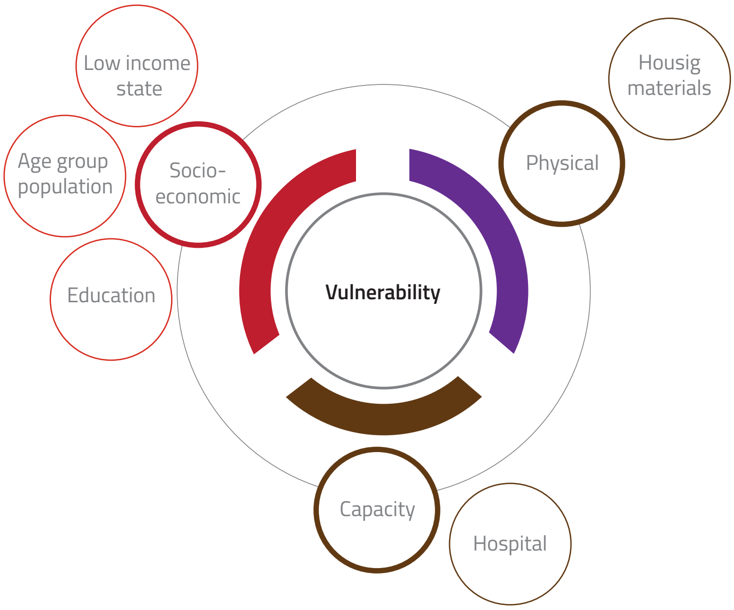


Figure 17. Vulnerability Indicators

Source: Author's Illustrations

Weightage: Each normalised value is multiplied with a weighted scale. The individual weighted score for all the parameters has been determined through expert judgments, considering the socioeconomic and anthropological context of the city. This scaling has been done so that all the parameters are brought to a similar range.

5.2.1 Socioeconomic vulnerability analysis

Socioeconomic vulnerability is defined as a set of social, economic and demographic factors that unite together to influence people's ability to cope with stress. People living in tin houses with low financial status, daily workers like auto and rickshaw drivers, construction workers, street hawkers, etc., are the populations most vulnerable to heatwaves. These groups are more likely to become dehydrated and suffer from different ailments like headaches, diarrhea, fever, skin diseases and other heat-related illnesses.

Nepalgunj's socioeconomic and demographic characteristics (age groups) directly impact the city's social vulnerability. Individual factors such as well-being ranking, education and age group have been analysed to understand socioeconomic vulnerability.

After calculating the normalisation score, the socioeconomic vulnerability score has been calculated. Higher normalisation shows populations living in those areas are more vulnerable to heat stress in all three cases.

The formula for socioeconomic vulnerability is:

$$VSE = W_{t1} \times \text{Well-being} + W_{t2} \times \text{Age group} + W_{t3} \times \text{Education}$$

After the normalisation process, the individual parameters are transformed by scaling so that all the parameters are in a similar range. For this, the obtained normalised value of well-being, age group and education have been multiplied with 0.6 (Wt1), 0.3 (Wt2), 0.1 (Wt3), respectively. This individual weighted value has been selected through expert judgments.

The socioeconomic vulnerability index is shown below:

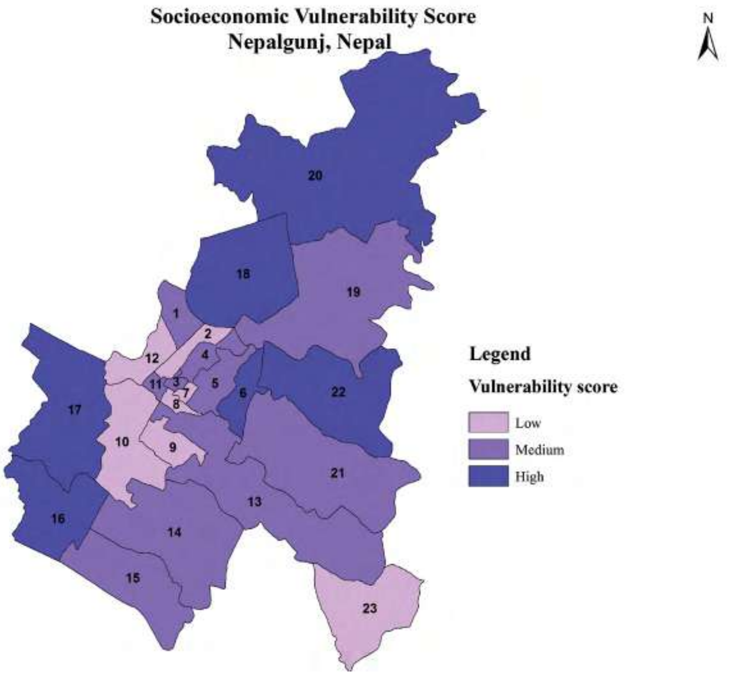


Figure 18. Socioeconomic vulnerability

Source: Author's illustration based on data obtained from Nepalgunj Sub-Metropolitan City office

Socioeconomic vulnerability is high in wards 6, 16, 17, 18, 20 and 22. The lowest is in wards 2, 7, 8, 9, 10 and 12. Wards 6, 17 and 22 are highly vulnerable because these wards have a high number of low-income population groups, whereas wards 16, 18 and 20 have a high age group population.

Photo 5: House of a low-income population family in ward 20

© Ashma Subedi, Climate Centre

5.2.2 Physical vulnerability analysis

There are many indicators that can be used for analysing physical vulnerability such as house types, density, and materials. Here, rooftop materials data has been analysed to construct the physical vulnerability score. People living in houses with tin thatched roofs are impacted significantly by heatwaves, as metal roofs absorb heat when directly exposed to the sun.

Figure 19.

Physical vulnerability

Source: Author's illustration based on data obtained from Nepalgunj Sub-Metropolitan City office

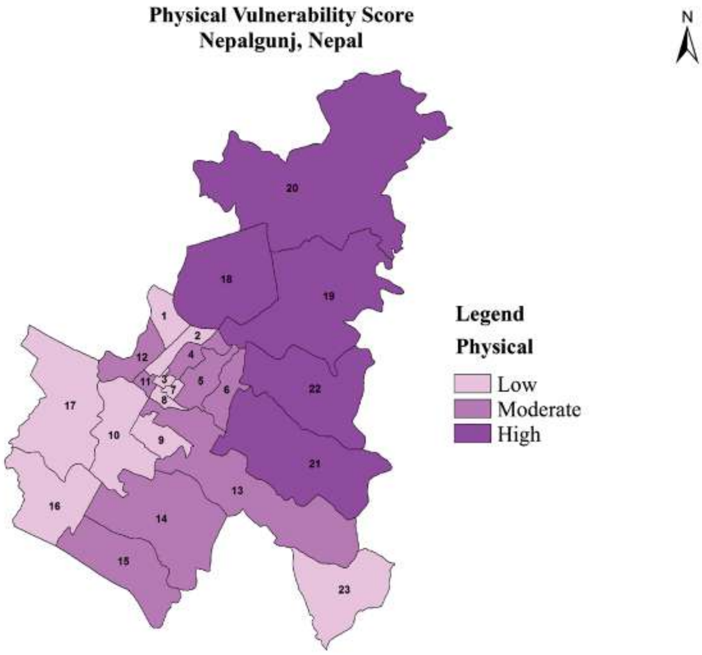


Photo 6: Tin roofed houses in ward 4

© Ashma Subedi, Climate Centre

Physical vulnerability is high in wards 18, 19, 20, 21 and 22. These wards are located on the northeast side of the city. Most low-income groups habitations with tin or thatched houses are situated in these areas.

5.2.3 Infrastructure/capacity

Health services facilities are considered when analysing vulnerability capacity. The higher the health services facilities in a particular ward, the fewer people are vulnerable to heat.

There are four different health facilities in Nepalgunj City: hospitals, clinics, health posts and health centres. Since details related to the treatment of the number of patients monthly or yearly are not available, a normalisation process has been adopted for this analysis. To get the normalised value of individual health services (hospitals, clinics, health posts and health centres) have been multiplied by 1, 0.7, 0.4 and 0.15 respectively. The weighted value is selected through expert judgments. This normalisation has been done with respect to the capacity equivalent of hospital services.

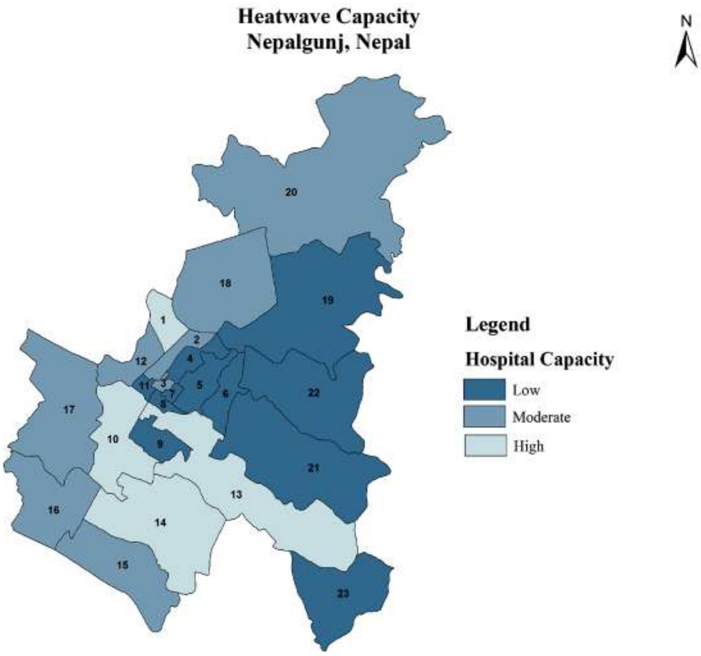


Figure 20. Capacity

Source: Author's illustration based on data obtained from Nepalgunj Sub-Metropolitan City Office

There are 11 wards, or almost 50 per cent of wards, with minimal health services, which indicates the population of these wards is less able to access health care facilities to recover from heat illnesses than other wards. The highly vulnerable areas are primarily located on the city's eastern side with very few in the city centre.

5.2.4 Vulnerability index

To obtain the overall vulnerability index, each normalised socioeconomic, physical, and capacity value has been multiplied with the predetermined weightage values 0.6, 0.4 and 0.1. This scaling is done so that all the parameters are in a similar range.

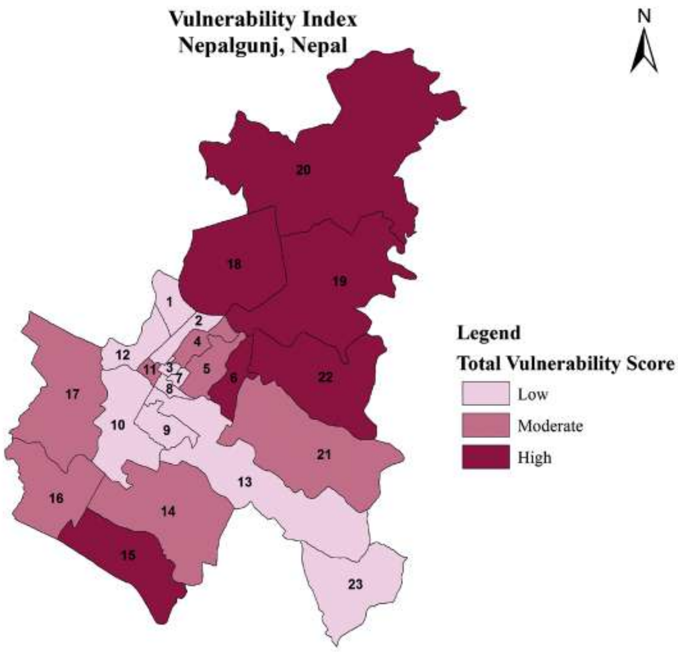


Figure 21.
Vulnerability index
Source: Author's illustration based on data obtained from Nepalgunj Sub-Metropolitan City office

The ward-level vulnerability map embedding the socioeconomic and physical vulnerability and capacity factors, exhibits six highly vulnerable wards. Seven are moderately vulnerable and 10 are less vulnerable. The most susceptible wards are 6, 15, 18, 19, 20 and 22. These wards are located mainly in the north to the central part of Nepalgunj. One of the most vulnerable wards is situated south of the city.

5.2.5 Vulnerable groups

Heatwave impacts in this socioeconomic context relate mainly to loss of income (loss of working hours) and increase in expenditures (illness and other) facing the exposed, vulnerable population. Some people most vulnerable to heatwave impacts are individuals with low socioeconomic status, people living in tin roofed houses, daily workers like auto and rickshaw drivers, construction workers, street hawkers and vendors, etc.

Among these vulnerable groups, the most impacted are rickshaw pullers and auto drivers. The survey results indicate they lose 23% and 20% of their income respectively, if they reduce their working day by four hours over six consecutive days during peak heatwave periods. Medium impacts are observed among construction workers and people living in tin roof houses, whereas street hawkers are less affected compared to other vulnerable groups.

Photo 7: Rickshaw puller in a busy street near Ranitalau-8, Nepalgunj City

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Chapter 6: Conclusion: Heat Threshold and Hotspots in Nepalgunj

6.1 Heat threshold in Nepalgunj

Two thresholds are important for triggering early action for heatwaves: (a) threshold to define an extreme event and (b) setting the impact limit.

The extreme event threshold has been defined by the DHM as the 90th percentile of the historical maximum daily temperature data set, when the daily maximum temperature becomes extreme and remains above six days or more. The analysis in the above sections suggest that 38°C is the maximum daily temperature, becoming an extreme event in Nepalgunj Sub-Metropolitan City.

During an extreme heatwave period, the temperature ranges from 39.21°C to 44.51°C. Humidity ranges from 20 per cent to 80 per cent and HI ranges from 40.85 to 90. Ideally, the least impact limit or HI 40.85 should be considered for setting up the threshold for anticipatory actions. However, in one survey, it has been found that the income of vulnerable people such as rickshaw pullers and auto drivers reduced by 20 per cent when the heat index was 47. Hence, heat index 47 is proposed as the impact threshold in Nepalgunj.

6.2 Heat hotspots in Nepalgunj

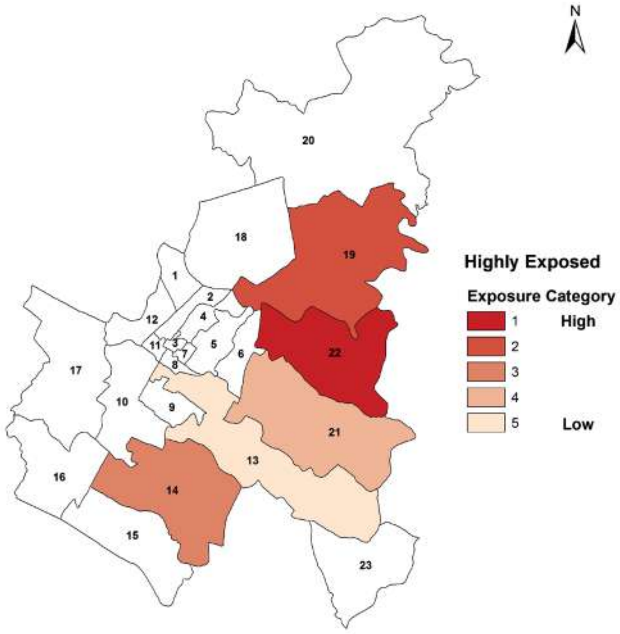
After the activation threshold is reached, it is necessary to know where to act. Identification of heat hotspots and most vulnerable groups (which may or may not overlap and not necessarily be geographically defined) based on exposure and vulnerability to heatwaves helps to understand where and for whom, early action or preparedness measures by the city authority and other emergency service providers needs to be considered.

The wards are classified into three categories of heat exposure: high, moderate, and low. There are five highly exposed wards, nine wards are moderately exposed and the rest of the nine wards hold low exposure (shown in Figure 16). The highly exposed five wards are 13, 14, 19, 21 and 22. The heatwave exposure in these wards is high primarily due to unplanned, rapid and high-density urban growth, low vegetation and water bodies in these areas, presence of industrial belt, airports, and significantly busy highways (blacktopped road surface, intense vehicular movements).

These five highly exposed wards have been further ranked with the vulnerability index score (shown in Figure 22) to recognise their degree of vulnerability. As a result, depending on available resources and capacity, the respective city authority and other emergency service providers can prioritise where early actions before or during a heatwave are indispensable, should the heatwave reach the threshold in Nepalgunj.

Figure 22. Highly exposed wards with vulnerability ranking

Source: Author's illustration



The analysis interprets that ward 22 is highly vulnerable, followed by ward 19, 14, 21 and 13. It suggests that in addition to preparedness measures for an imminent heatwave or actions taken during a heatwave, long-term and policy-level interventions to reduce urban heat risks are also critical, especially in wards 22, 19 and 14.

Photo 8: Street vendor and daily wage earner near Ranitalau-8, Nepalgunj City

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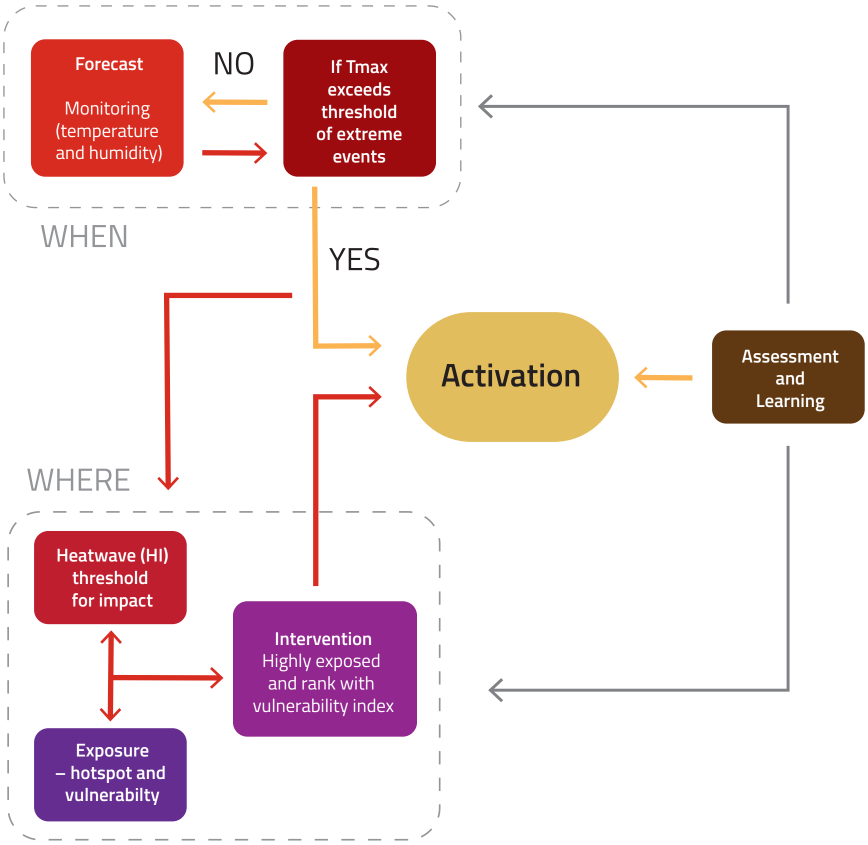
Chapter 7: Way Forward

The heat threshold and hotspots help to understand when and where to act during heatwave days. It is also determined that heatwave risk (Heat Index) is high enough to impact the health and livelihoods of vulnerable groups in the hotspots of Nepalgunj City. As a next step, the local city authority and other emergency service providers need to take stewardship and anticipatory actions to reduce heatwave impacts and related losses in the city. The aim of anticipatory action for a heatwave is to reduce human suffering and impacts on livelihoods, which means not waiting for disaster to occur but acting before by using skilled heatwave forecasts. Formal engagement with DHM, the respective authority in the case of Nepalgunj, would need to take place. A forecast service that included temperature and humidity could be set up (subject to the availability of resources), with the extreme event used as the trigger threshold. Alongside this, there would need to be the establishment of effective coordination with the Nepalgunj Sub-Metropolitan Municipality and emergency response authorities to provide heat index forecast information and or issuing heat warnings for short-term and long-term responses. The Municipality, DHM and NRCS could make reference to the following schematic diagram that shows the steps and criteria of the activation action for heatwave risk:

Figure 23.
Workflow of activation action for heatwave
Source: Author's Illustration



There would be a requirement for a forecast lead time of up to 10 days to enable anticipatory measures to be put in place.

7.1 Future directions:

The future direction of work for the city authority and other emergency service providers involves:

- Initiating stakeholder engagement on heatwave preparedness and response using existing materials and through consultation with relevant stakeholders such as DHM, city officials, health officials and the District Disaster Management Committee (DDMC).
- Relevant stakeholders focusing on extending support for heatwave management planning to priority wards, monitoring the process and its effectiveness, and updating the plan accordingly.
- A community-level in-depth impacts analysis and capacity assessment.
- Rolling out awareness and capacity-building programmes.
- In-depth analysis and validation of the heatwave impact analysis by investigating public health data.
- Formulation of a trigger model and simulation in the city, particularly in the vulnerable wards and, development of an early warning early action standard operating procedure (SOP).

7.2 Key roles and stakeholders in the city

This section intends to give an overview on the different critical roles for the heat actions in the city and the list of potential stakeholders in Nepalgunj.

Table 6: Roles of different stakeholders in the city for heat actions

Roles	Potential Departments and partners
Developing a heat action plan	- Nepalgunj Upamahannagar Palika (all the lead departments) - Banke district branch, Nepal Red Cross Society (NRCS) - Bheri Zonal Hospital, - Bheri Environmental Excellence (BEE) Group, - Bageshwori Asal Shasan Club (BAS) - Nepalgunj Chamber of Commerce and Industry
Developing and issuing heat early warnings	- DHM - Department of Health Services, Nepal
Leading emergency response	- Disaster management division, Nepal Police - Disaster management department, NRCS - Banke district branch, NRCS - Nepalgunj Upamahannagar Palika
Liaising with the media	- Nepalgunj Upamahannagar Palika
Liaising with city residents	- Nepalgunj Upamahannagar Palika - Banke district branch, Nepal Red Cross Society (NRCS) - Bheri Zonal Hospital, - Bheri Environmental Excellence (BEE) Group, - Bageshwori Asal Shasan Club (BAS)
Strengthening health systems	- Department of Health Services, Nepal - Bheri Zonal Hospital
Mainstreaming heat into city planning	- Nepalgunj Upamahannagar Palika

7.3 Simple actions to reduce heat risks:

Some of the simple city level actions that the Nepalgunj Upamahannagar Palika in collaboration with other city stakeholders can plan to undertake are:

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Annex I: Glossary

The climatic terms used in this report are derived from the Intergovernmental Panel on Climate Change's (IPCC) reports. According to IPCC, definition of the climatic terminologies are as follows:

Adaptation: Adaptation is an adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Adaptive Capacity: It is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, take advantage of opportunities, or cope with the consequences.

Climate Change: Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer).

Disaster: A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its resources.

Exposure: The nature and degree to which a system is exposed to significant climatic variations. In this document, exposure is considered as the characteristics and magnitudes of climate change, climate variability, and associated hazards including the extreme events to which a system is exposed

Hazard: A dangerous phenomenon, substance, human activity, or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Heat Index: Heat index is a measurement of perceived temperature in the human body indicating how hot it feels when the relative temperature is added to the actual air temperature.

Land Surface Temperature: The Land Surface Temperature is the radiative skin temperature of the land surface, as measured in the direction of the remote sensor.

Lead Time: It is the length of time between the issuance of a forecast and the occurrence of the phenomena that were predicted.

Percentile: A percentile is a number where a certain percentage of scores fall below that number. Example: If a value of X is 90th percentile, this means that the value of X is higher than 90% of the total dataset.

Risk: Risk is the combination of the probability of an event and its negative consequences. The degree of risk is expressed in terms of monetary value in this document.

Resilience: The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change.

Susceptibility: The state or fact of being likely or liable of a system or an element to be influenced or harmed by a particular thing or hazard.

Variability: It is the state or characteristic of a system of being variable, in this case, that of the climate. In this document, variability will be mostly associated with climate.

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.