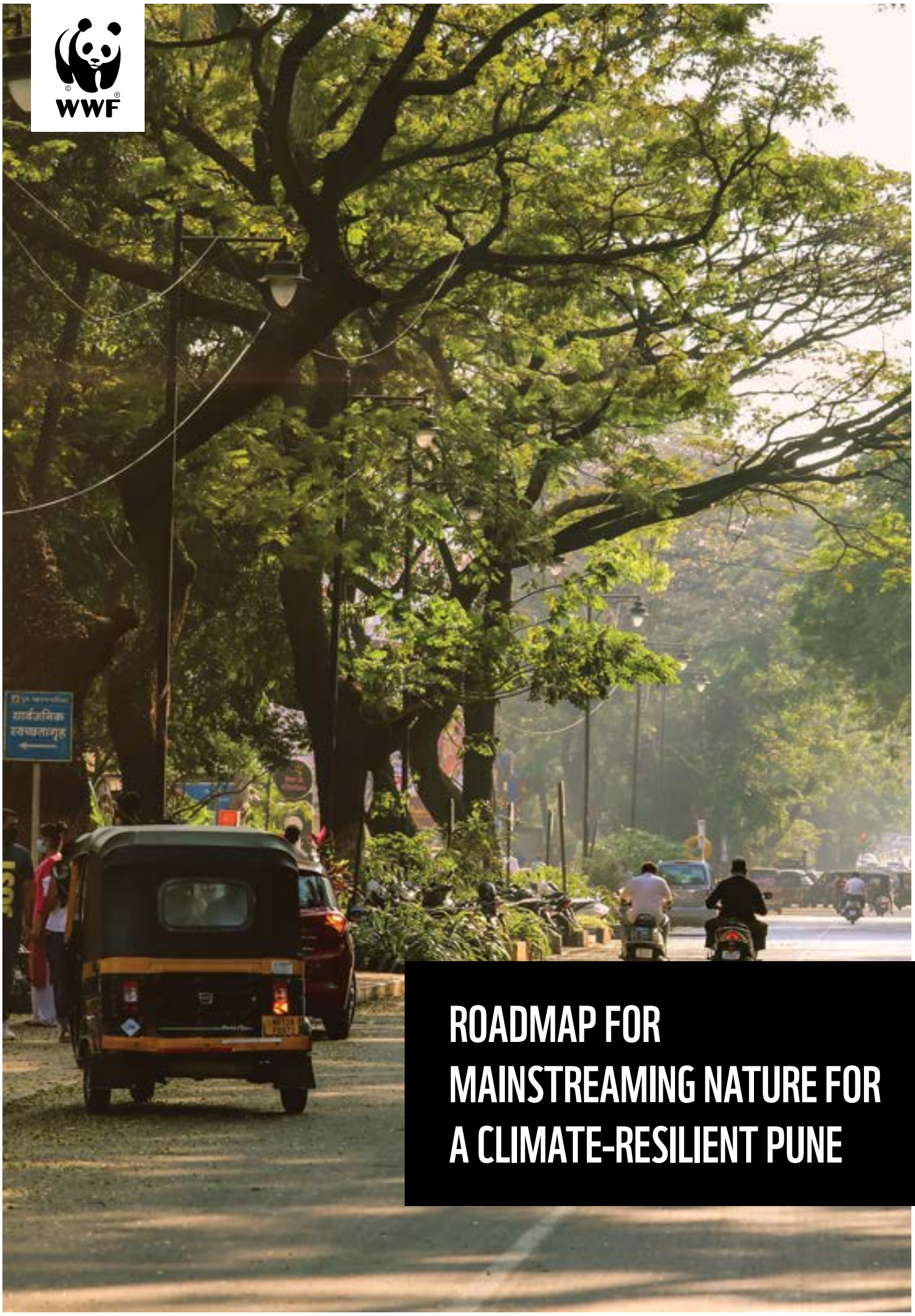

ROADMAP FOR MAINSTREAMING NATURE FOR A CLIMATE-RESILIENT PUNE

CONTENTS

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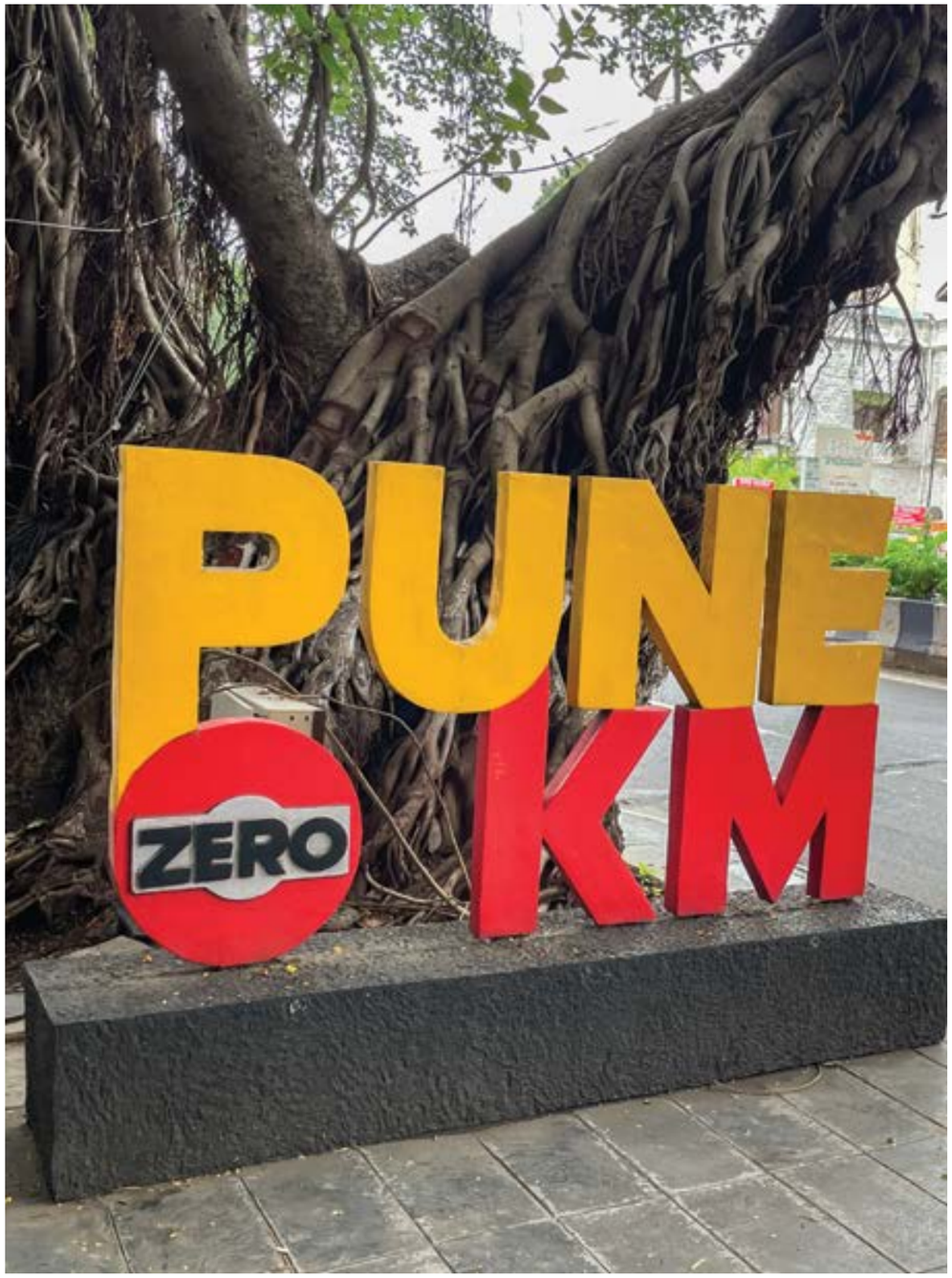

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EXECUTIVE SUMMARY

Cities globally are currently home to approximately 54 percent of the population and account for approximately 75 per cent of global green house gas emissions.

Once known for its pleasant climate, Pune city grabbed attention for economic development making it one of the most urbanised and economically forward cities in the country. However, climate change has substantially affected the climatic characteristics of the city.

Over the past three decades, Pune city has undergone a transformational change resulting in an vibrant and diverse urban agglomeration. The economy is supported by robust sectors like service and manufacturing.

However, the rapid urbanization has come at the cost of depletion in ecological resources, not only in the urban but also the peri-urban areas.

The continuing decline of natural resources like wetlands and green tree cover over the past few decades have further exacerbated the impacts of climate change, that are now more frequently observed as incidences of flash floods and heat waves in the city.

Impacts of climate change like flash floods and heat waves are quite evident in the city making it essential for adapting to a 'Climate-resilient Plan". A Strategic Roadmap has been developed for tackling climate changes issues in the city. It is derived through an ecological approach wherein the suggested interventions utilize ecosystem services to for benefiting the urban environment.

The study broadly touches on three major aspects, viz., climate profile of the study area, vulnerability of the city to climate change and associated impacts, and assessment of the feasibility of NbS in the city. Several tools and techniques were used in the development of the baseline and climate vulnerability assessment. Secondary and primary data was collected through literature review, site visits, and stakeholder engagement. The collected data was analysed for climate change trends using a linear regression model; a vulnerability matrix was developed based on the data collected and stakeholders' perceptions. Further, Driver-Pressure-State-Impact-Response analysis was undertaken to understand influencing factors towards climate change and NbS that can be developed to address the issues.

Pune city is vulnerable to extreme climate events, viz. extreme precipitation, heatwaves, and landslides. The city experiences climate change not only due to its micro-climate but also due to external factors like an increase in western disturbances (WDs) and ocean warming leading to an increase in cyclone events along the coasts.

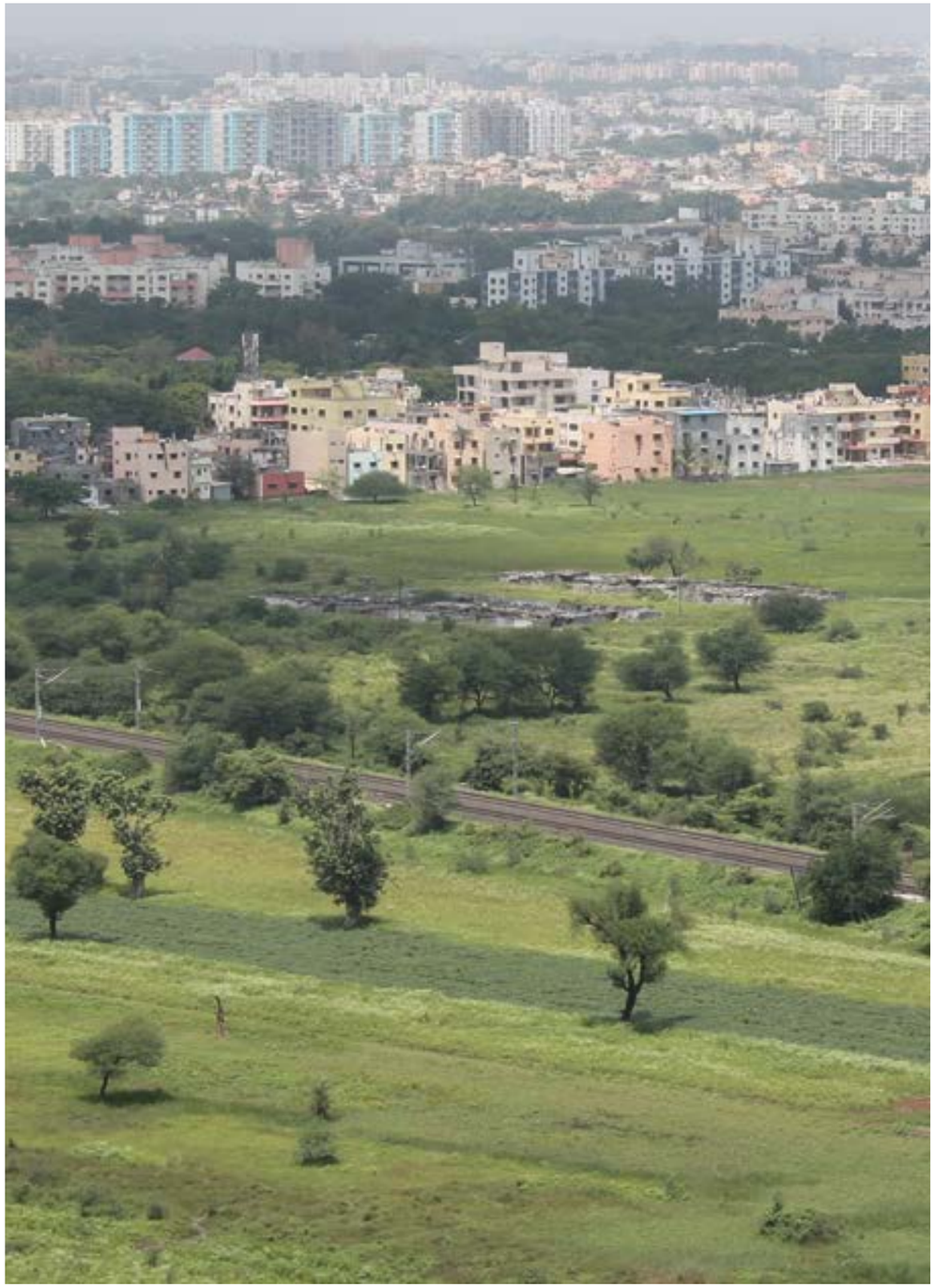
Trend analysis study highlight that the temperature in the city is increasing, creating an influence on precipitation and humidity. Pre-monsoon droughts are predicted to be an additional issue in the city.

Also, the issues of flash floods and non-seasonal monsoon are common events in the city. Reduced green cover, increased built-up area, water-logging, flooding of rivers, and extreme temperature are few barriers to developing climate resilience in the city.

Pune city is enriched with terrestrial and aquatic ecosystems, but currently, these ecosystems are in a polluted and degraded form. Issues such as reduced green cover, increased built-up area, waterlogging, flooding or rivers, and extreme heat needs to be addressed to build climate resilience in the city. Considering these issues, several NbS initiatives, such as restoration of habitat, development of green spaces, and increasing blue-green infrastructures are proposed in the document. The proposed solutions can contribute to reducing the vulnerability of the city to climate change through a participatory approach and strategic implementation plan.

NbS has been proved as an effective adoption strategy to tackle climate change issues. It provides a dual benefit wherein Ecosystems are conserved and the services provided by these ecosystems are exploitedfor developing climate resilience. Pune city is enriched with terrestrial and aquatic ecosystems, however, the state of these ecosystem needs further restoration and conservation measures. The reduced green cover due to an increase in infrastructure can be addressed through the implementation of blue-green infrastructures like green-roofs, facades, hedges, vertical gardening, etc. Additionally, creating permeable footpaths and parking areas, and bio-swales along roads can reduce issues of increased water run-offs and flooding. Pergolas and pocket parks can provide resilience towards extreme temperatures by decreasing micro-climate along streets.

NbS needs to be complimented with other strategies like solid waste management, use of renewable resources, and awareness among citizens for their effective utilization.



1. INTRODUCTION

1.1 Climate Issues and Need for Resilience

1.1.1 Climate Scenario

Global climate, a climatic condition measured over 30 years or longer, is changing as a result of human activities, specifically to the one leading to an increase of greenhouse gases from fossil fuels (McMichael,

et al., n.d.). Emissions of greenhouse gases (GHGs), aerosols, and changes in land use and land cover (LULC) during the industrial period have substantially altered the atmospheric composition, and consequently the planetary energy balance, and are thus primarily responsible for the present-day climate change. Global warming since the 1950s has significantly contributed to an increase in extreme weather and climate globally (for example heat waves, droughts, heavy precipitation, and severe cyclones); changes in precipitation and wind patterns (including shifts in the global monsoon systems; warming and acidification of the global oceans, melting of sea ice and glaciers, rising sea levels, and changes in marine and terrestrial ecosystems.

Urban areas are currently home to 54 per cent of the world's population accounting for approximately 75 per cent of global carbon dioxide emissions and 60-80 per cent of total energy consumption. With world population increasing rapidly, it is predicted that cities will accommodate 67 per cent of the total population by 2050.

Urban climate often differs from the surrounding rural areas as it is comparatively more polluted, warmer, rainier, and less windy. These characteristics in turn highlight that the impacts of climate change with increasing temperature and rain will be more extreme in urban areas. Urban population is already prone to other issues like air pollution, Urban Heat Island, storm water management, etc. These issues will cumulatively enhance the impacts of climate change. There are possibilities that the changing climate may exaggerate the current negative effects that urban populations are already experiencing (Emilsson & Ode, 2017). Pollution is associated as a by-product of mostly urban landscapes, is directly linked with climate change as both the events are exaggerated with the burning of fossil fuel and emissions (United Nation, n.d.). In India, out of the total 102 cities, 43 cities are already facing issues of poor air quality. (Climate Smart Cities Assessment Framework, 2021).

In India, according to IMD data released by the Ministry of Statistics and Programme Implementation, average temperatures have increased by 0.6 degrees Celsius (°C) between 1901-10 and 2009-18. At an annual level, this

may seem trivial, but projections deeper into the future paint a more alarming picture (Arindam, et al., 2020).

In India, vulnerability has contributed more to overall risk than hazard and exposure, the country lacks adequate provisions to tackle changing climatic condition. The current pattern of urbanisation in India has resulted in the transformation of cities into "hotspots" of vulnerability. This is why Indian cities need to adapt to the expected changes on time to protect inhabitants, assets, and elements of critical infrastructures (Cortekar, Bender, & Groth, 2016).

Given this background, it is understood that cities are at the forefront of climate vulnerabilities and need to develop with a climate resilience approach. Situated at the crossroads of extensive urbanisation, unequal development, and high climate vulnerability, Indian cities face an urgent imperative to adapt to current and projected climate change impacts (Singh, 2021).

1.1.2 Climate Resilience in Cities

The term "Climate Resilience" refers to the ability of ecological, social, or socio-ecological systems and their components to predict, reduce, accommodate, and recover from the effects caused due to a hazardous event in a timely and efficient manner (Denton, et al., 2014).

Natural climatic phenomena related to climate change are accelerating with time. Despite the several tools developed to predict these, it is impossible to gauge their exact impact. Hence, it is necessary to adapt to a strategy that protects the community and businesses against climate change shocks. The strategy to develop a climate-resilient city needs a local approach while considering the external influences as climate change phenomena is a global and hyper-local issues. Climate Resilience strategies are comprehensive and their execution is required not only in the neighbourhood but also on an individual scale. (C2ES, 2019). Climate resilience is not solely related to adapting new development patterns but also the inclusion of a planning and development framework that considers a long-term preparedness plan towards climate change. Resilience-building entails working on two aspects, viz., strengthening of city systems (infrastructure, services, and sectors) and city planning (land distribution, policies, norms). Climate Resilience Strategies can fit along with other planning efforts like solid waste management, wastewater management, improved transportation, infrastructure, economic development, etc. (TERI, n.d.).

To address issues arising due to climate change, two-pronged approaches, i.e., adaptation & mitigation are widely considered. (Fig. 2). Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "the process of adjustment to actual or expected climate and its effects." It means acting in all possible ways to minimize the destruction and suffering due to climate change. IPCC describes mitigation as "human intervention to reduce the sources or enhance the sinks of greenhouse gases" (Elizabeth & Donald, 2019).

Adaptation deals with the impacts of climate change whereas, mitigation aims at reducing the cause of climate change, which is GHG emissions.

Extreme Heat

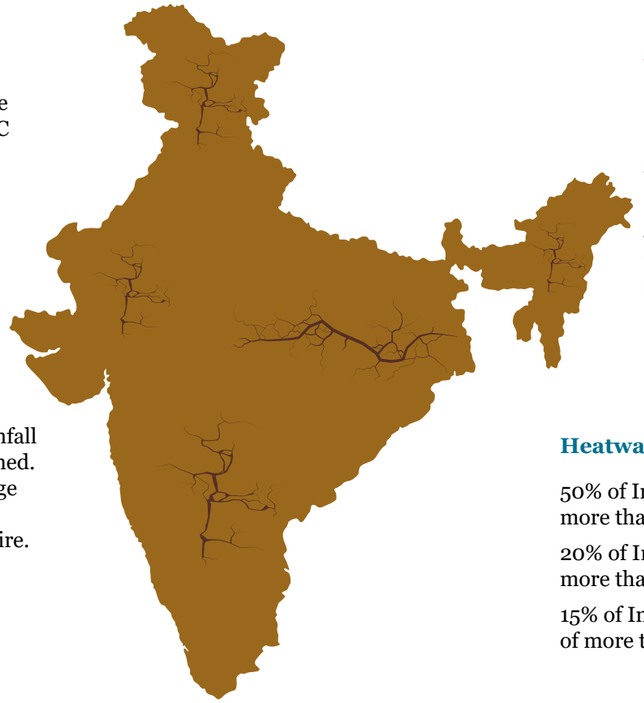
What we know

Annual mean temperature of India has risen by 0.6°C in the past 114 years west coast and southern India are projected to shift to neww, high-temperature climatic regions.

Rainfall

What we know

A decline in monsoon rainfall since the 1950 has happened. A 2°C rise in global average temperature will make India's monsoon go haywire.



Droughts

What we know

In 1987, 2002-2003 and 2009, 2012 droughts gripped more than half of India's sown area. Western States, Jharkhand, Orissa and Chattisgarh will be very drought-prone.

Heatwaves

50% of India to get heatwaves of more than 3 degrees.

20% of India to get heatwaves of more than 2 degrees

15% of India to witness heatwaves of more than 1.5 degree.

* In the absense of climate change solution
Source: (Narayan V. , 2020)

Fig 1. Extreme Weather Events faced in Indian Cities
According to the Global Climate Risk Index released by Germany-based think tank, German watch, India is the 14th most climate change-affected country in the world

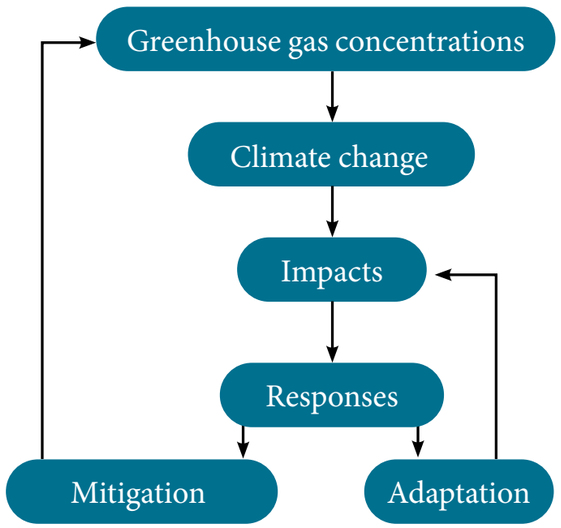


Fig 2. Adaptation & Mitigation
Source: (Locatelli, 2011)

Adaptive Measures	Mitigative Measures
• Urban greening and green infrastructure practices • Passive cooling • Flood protection measures such as walls, bunds, etc. • Urban wetlands	• Urban Planning • Forested Catchment • Renewable Energy • Rainwater Harvesting • Public Transport system

Source: (Stelios, et al., 2018)

1.2 Nature-based Solutions

1.2.1 Introduction to Nature-based Solutions (NbS)

NbS are defined by IUCN as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits". It is an umbrella term used to cover all the technologies which support sustainable societies while supporting biodiversity.

NbS concept relates to nature and enhances it to help address societal challenges. The concept is rooted in the knowledge that a stable ecosystem can provide several benefits to humans. NbS can be implemented through several approaches (Fig. 4) depending on the need, availability of space, and ecosystem.

In a natural environment, ecosystems offer services through interdependent functioning cycles. These chains are fragmented in urban environments when development is not taken sustainably. Well-implemented NbS offer multiple benefits, they offer resilience and long-term gains, in terms of avoiding losses and ecosystem services. NbS technologies have to be applied at various scales in the urban environment to enhance their effectiveness. Adaptive and mitigative efforts, especially the one planned during the initial phase will provide maximum benefits. With increase in urban landscape, adaptive and mitigation efforts are not well-considered resulting in narrow space, high carbon footprint and low resilience to climate change. The health of humans is directly related to that of the environment and incorporating NbS will significantly help in achieving both.

1.2.2 NbS as a Strategy for Climate Resilience

NbS have been identified and developed across the world as part of sustainable development and climate-resilient strategies. NbS deliver important ecosystem services

to urban dwellers. Examples of NbS include forests, wetlands, green belts, and parks in and around cities as well as green infrastructures such as natural wastewater plants, green roofs, green walls, combined non-motorised transport and ecosystem corridors, and other green, blue and hybrid infrastructure. Such NbS help in building resilience by reducing disaster risk and delivering many other benefits: climate adaptation and mitigation; clean water and air; cooler streets; and access to green public spaces for recreation and physical, mental, and spiritual well-being. Table 1 details some NbS that can be deployed to address the vulnerabilities to climate change.

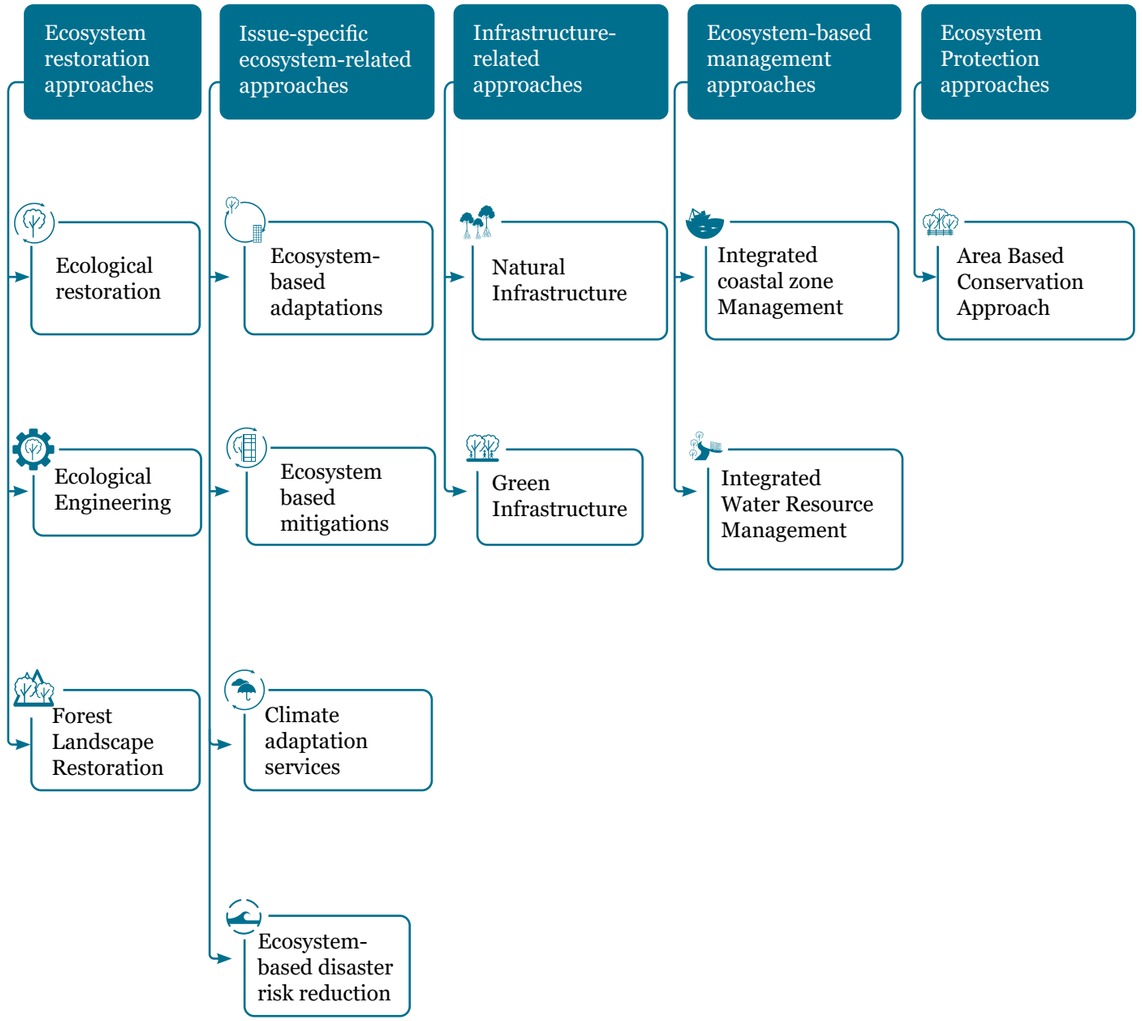


Fig 3. Approaches for Adoption of Nature-based Solutions
Source: (IUCN, Commission on Ecosystem Management, n.d.)

Table 1: Internationally implemented NbS

Type	Name	Description
Greening interventions	Boulevard Trees	Plantation of trees along roads should be undertaken with consideration of the surrounding habitat and species. It provides microclimate regulation, habitat provision, improves aesthetics, and offers rainwater regulation (delayed runoff)
	Arboretum	Group of trees may be an option for the design of shaded squares or as contrasting green element in densely built-up areas or for courtyard design.
	Public Parks	Public parks act like an oasis in an urban environment, with positive effects for urban climate, recreation, and biodiversity in the neighbouring residential areas.
	Green Corridors	Linear natural infrastructure, such as trees and plants, that link up other green and open spaces to form a green urban network is a green corridor. It can be constructed along with certain infrastructure like railways and rivers to connect smaller fragments of habitat.
Vertical Greening	Green Facades	The facade-bound greening uses the facade for fixing panels and containers to it, usually uses intensive technologies for irrigation as the plants are not directly rooted in soil.
	Ground-based Green facades	Ground-based green facades are made of climbing plants. The climber plants get planted in the ground and grow directly on the wall, or climb on a frame that is connected to the wall and keeps a distance to it. These often have lesser maintenance.
	Free-standing Green wall	Natural soil with vegetation cover (perennials and shrubs/trees) is the model for living walls. These are placed near bus stands or in public spaces which reduce dust and air pollution.
Green Roof	Intensive	Intensive green vegetation is often established on roofs that are accessible for public or recreation purposes and also for regular maintenance measures. The growth media of intensive green roofs needs to be relatively deep and nutrient-rich.
	Extensive	Extensive green roofs are basic, lightweight systems characterized by a low vegetation surface that covers the surface of the building.
Water Sensitive Design	Bioswales	Bioswales absorb, store, and convey surface water runoff and also remove pollutants and sediments when the water trickles through the vegetation and soil layer. It is a linear, sloped system built along roads to control run-off and also improves the quality of run-off water which drains into other water bodies.
	Permeable Pavement	Permeable paving systems are known as surfaces that can absorb stormwater and thus, minimising surface water runoff.
	Constructed Wetlands	Constructed wetlands represent artificial wetlands with the main objective to harvest, treat and store storm- /greywater runoff in urban areas.
River Restoration	Natural Restoration	Opening closed channels and natural development of the riparian zone can establish a natural system, which helps in purifying the water and streamlining the flow.
	River Space Expansion	Extending flood plain areas can be undertaken at locations that are not surrounded by infrastructure. It is useful for flood/water control and management.
	Riparian buffers	Replication of natural conditions (vegetation at the riverside), that stabilizes the soil protects the river zone from erosion, and slowdowns water velocity along with supporting biodiversity.
	Planted embankment mat	Natural protection against erosion; reduced erosion risk compared to bare hillsides with a high risk of water, wind, and soil erosion can be achieved by placing jute and coir mats with plantation of native flora.

Fig 4. Case Study- Urban Forestry, Milan

Heat mapping surveys have enabled the city to focus its tree-planting efforts in the hottest neighborhoods, and the local administration has committed to plant three million trees by 2030. In 2019 the city inaugurated the “Tree Library”, a large park developed in what was previously a concrete square in the business district and which is now home to hundreds of trees.

Source: (UNEP, 2021)

Fig 5. Case Study – Sponge city, China

Sponge cities are a context-specific urban approach to integrated water resource management that use grey-green infrastructure like waterways and greenways, green roofs, porous design and water-saving approaches to control urban flooding, limit water pollution, recycle rainwater and reinstate degraded environments.

Source: (Maciejewska, 2020)

NbS are often cost-effective as they aid in addressing multi-faceted issues. To sustain the efficiency of NbS, it has to be integrated into the infrastructure planning process at the earliest stage (upstream planning stage) and tailored to local contexts.

Based on selection criteria and suitability, NbS for Pune City are proposed and detailed in Chapter 6.

1.2.3 Benefits of Nature-based Solutions

Nature-based solutions have an advantage over other solutions as they collaborate with other abiotic components in the environment, influencing climatic attributes. Climate change and degradation of ecosystems are linked and both impacts health, well-being, and social and economic stability.

Fig 6. Benefits of NbS
Source: (IUCN, Commission on Ecosystem Management, n.d.)

Nature-based solutions provide economic, social, and environmental benefits. Some of the economic benefits are creation of jobs, protection against extreme weather events, increased water and food security. Through the implementation of nature-based solutions, reduced energy demand also helps in saving costs. Apart from these some social and environmental benefits include improved quality of air and water, increased habitat for supporting biodiversity, carbon sequestration, and better quality of life for the people.

Application of NbS can protect and utilize ecosystems and contribute to mitigating the impact of climate change. It will lead to the development of strategic plans that enhance and conserve the local ecosystem. NbS can prove advantageous in regulating the percolation of water and increasing the recharge of groundwater resources. Additionally, NbS also provide other ecosystem services, for example, providing clean air and water, food, fuel, medicines and genetic resource, recreational centres, etc., that contribute towards a stable human-nature system.

1.2.4 Challenges/ Limits of NbS

The purpose of NbS is to provide multiple benefits. However, it is difficult to choose a plan that meets all the requirements.

Measuring the deliverables is a challenge as many interactions occur within natural processes within thecreated ecosystems. For instance, biomass may change with changing climatic conditions, leading to a change in the frequency and intensity of weather events. In that case, the intervention may not have expected outcomes. It might become economically challenging in such cases to maintain or upgrade such systems. Implementing a plan which accounts for only a part of the problem may cause trade-offs in the later stages. For example, a mono-culture afforestation project will not provide the anticipated resilience, nor will support much biodiversity. Consideration of nativity, use, and vulnerability to current and anticipated weather scenarios is required to ensure desired results.

There is limited funding available for implementing NbS, as various countries have their definitions of technologies that may be categorized under it, which may or may not be covered under existing schemes. Governance is another challenge while

implementing NbS. Any new blue-green intervention is well received by multiple stakeholder groups in the initial setting-up phase, but its ownership and budget of maintenance in the long run, remains an unaddressed issue. Public funding is limited, and often long-term measures are not given weightage in the urban planning process (Narayan & Dhindaw, 2021). NbS governance requires active cooperation and coordinated action between multiple actors whose priorities, interests, or values may not be coordinated, and may even conflict. At times, different aspects of NbS are covered by international funding agencies and under national/ regional policies. Hence, coming up with a comprehensive plan to address issues may be a challenge faced by Urban Local Bodies (ULB)s (Morita & Matsumo, 2021).

1.3 Objective and Expected Outcomes

Considering the importance of NbS to regulate climate change, the proposed study was undertaken with an objective (Fig. 8) to develop a Strategy Roadmap for Nature-based climate resilience in Pune with an understanding of climate vulnerability, and related risks and hazards; additionally developing a framework for implementation of NbS with the participation of associated stakeholders. developing a framework for implementation of NbS with the participation of associated stakeholders. developing a framework for implementation of NbS with the participation of associated stakeholders.

Fig 7. Green Facade in a building

Source: Report: Global Living 2021 (Part 1)

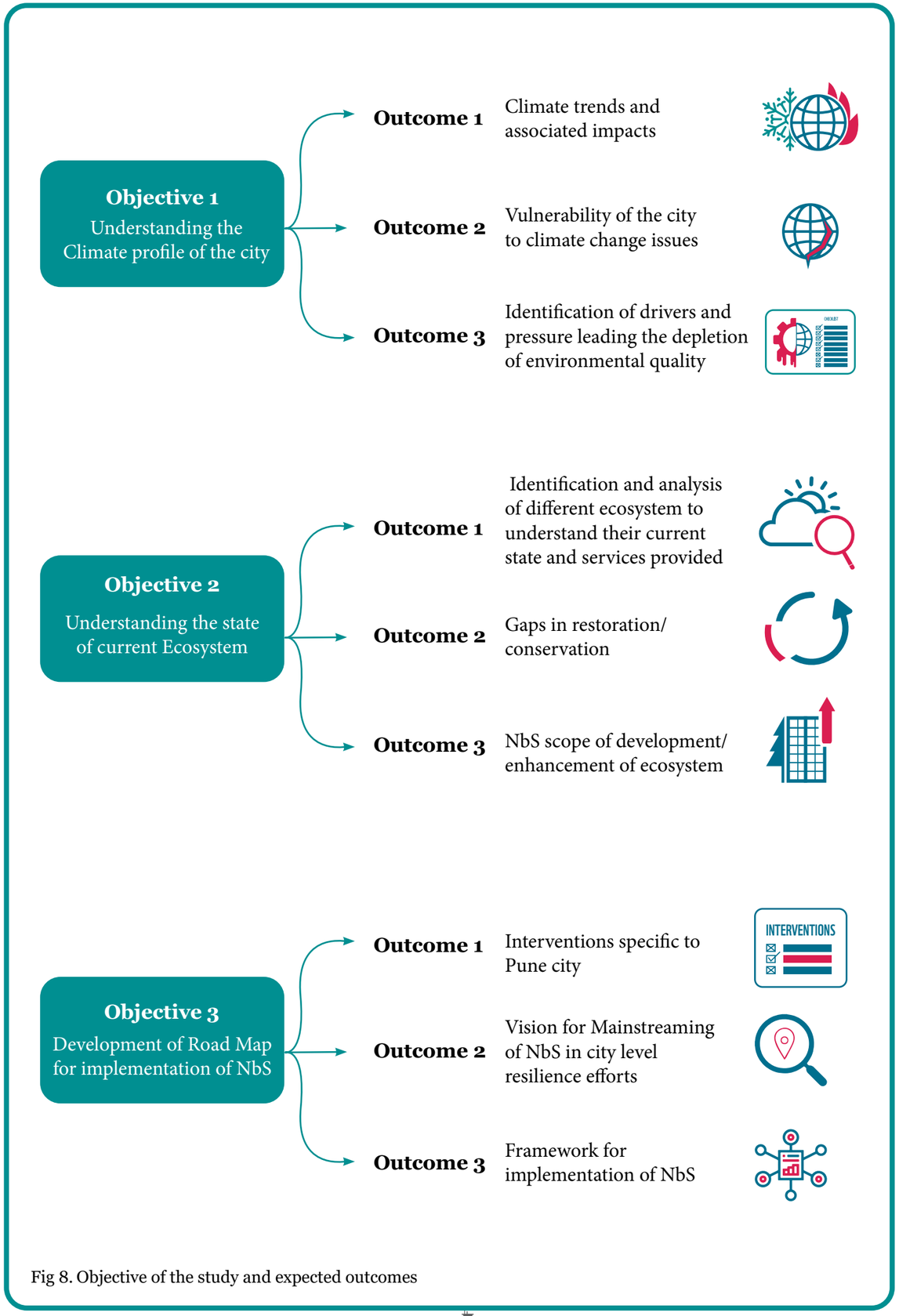


Fig 8. Objective of the study and expected outcomes

2. STUDY AREA

2.1 History and Geographical Location of Pune

Pune, once called “Punnakka” was a small agricultural settlement that has emerged as the cultural capital of Maharashtra. The city of Pune was governed by Pune City Municipality and Pune Suburban Municipality up to 1950 after which the population increased considerably. The Pune Municipal Corporation (PMC) was constituted by the state government on 15th February 1950. It is governed under the Bombay Provincial Municipal Corporation Act, 1949. Pune has been evolving, from being a historical centre of pre-colonial urbanism, then an important military centre, further an industrial and educational hub, and now being identified as a metropolis (Mundhe, 2017).

Geographically, PMC is located in the Pune district of Maharashtra state, South-east of Mumbai city (Fig. 9). It is situated on the leeward side of Deccan Plateau (Sahyadri Hills/Western Ghats) between 18o 32’ North latitude and 720 51’ East longitudes at an elevation of 560 m. Pune city comprises 144 wards spread over an area of 243.84 sq. km. Bio-geographically, it is located near the margin of the Deccan Plateau, surrounded by hills on all three sides and stands at the confluence of Mula and Mutha rivers, which are tributaries of the Bhima River. The city is bounded by Thane district to the north-west, Raigad district to the west, Satara district to the south, Solapur district to the south-east, and Ahmednagar district to the north and north-east (PMC, 2012).

Entire area of Pune city is underlain by basaltic lava flows of Upper Cretaceous to lower Eocene age. The Basaltic lava flows are horizontally disposed over a wide stretch giving it a plateau-like topography. The shallow alluvial formation of recent age also occurs in small areas along the banks and floods plains of the rivers. Pune is also a part of the seismically active zone of the Koyna Region, about 100km south of the city in Zone IV (Mishra, 2009).

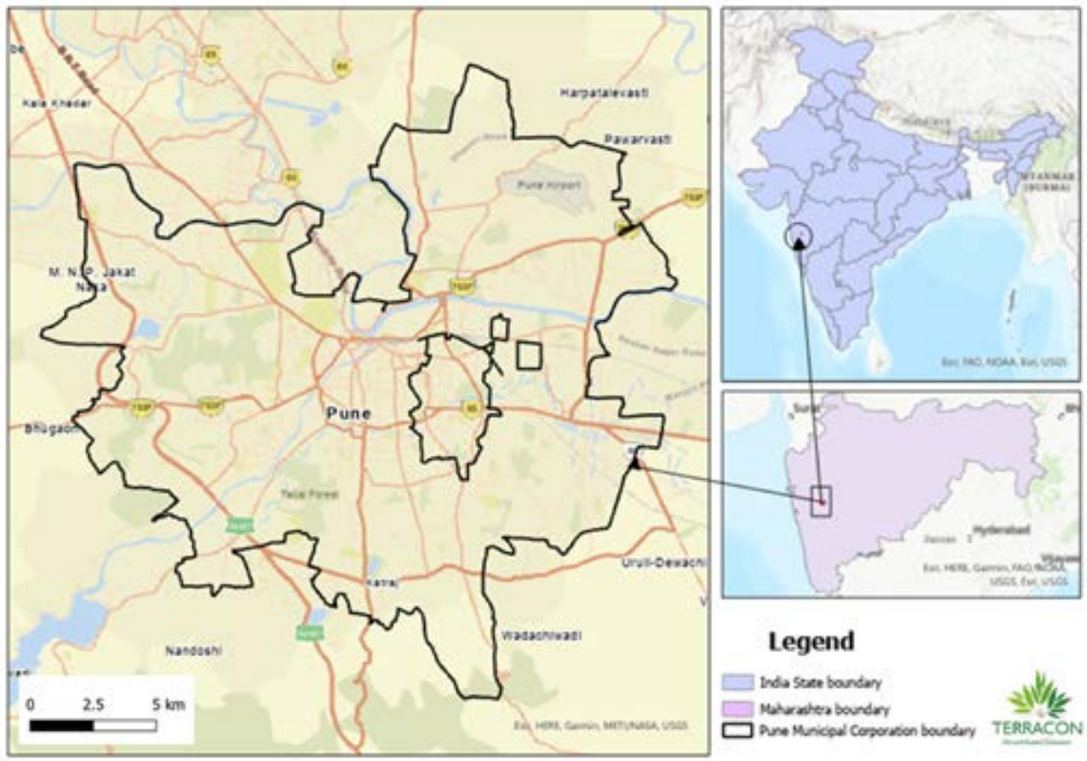


Fig 9. Pune Municipal Corporation Boundary Map

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Fig 10. Dhanori Tekad

2.2 Forest Resources

Pune is located close to the Sahayadri Hills, a part of the Western Ghats, comprising of several green patches in form of natural hillocks, gardens, and avenue trees. As per the land use distribution of Pune city, 1245ha, i.e., 5.10 per cent of the total land is under hills and hill slopes. Parvati Hill, ARAI and Malwadi Hill, Fergusson College Hill, Vetal Hill, Ram Hill, Baner Hill, Taljai Hill, and Katraj, Dhanori Hill (Fig. 10) are a few of the well-known green patches in the city. Pune is also well known for its gardens, with 204 gardens at present and more fourteen gardens proposed for development (Garden Department, 2021). These hills and gardens are a major focus for recreational activities for the citizens and also provide other ecosystem services to the city. The total trees in Pune city count up to 47,13,791. (PMC, 2021).

2.3 Water Resources

Pune city is also further divided into 23 basins or watersheds which form the drainage channel of the city. Each basin comprises a network of natural drains discharging stormwater into Mutha and Mula rivers. (PMC, 2012) The drainage map (Fig. 12) of the study area was developed using QGIS software. From the map it is understood that there are rivers, small streams and other water bodies in the study area and water flow is from the North West direction to South East Direction in the city. Mula-Mutha River system is 4 Demography of the Region.

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Fig 11. Mula- Mutha River

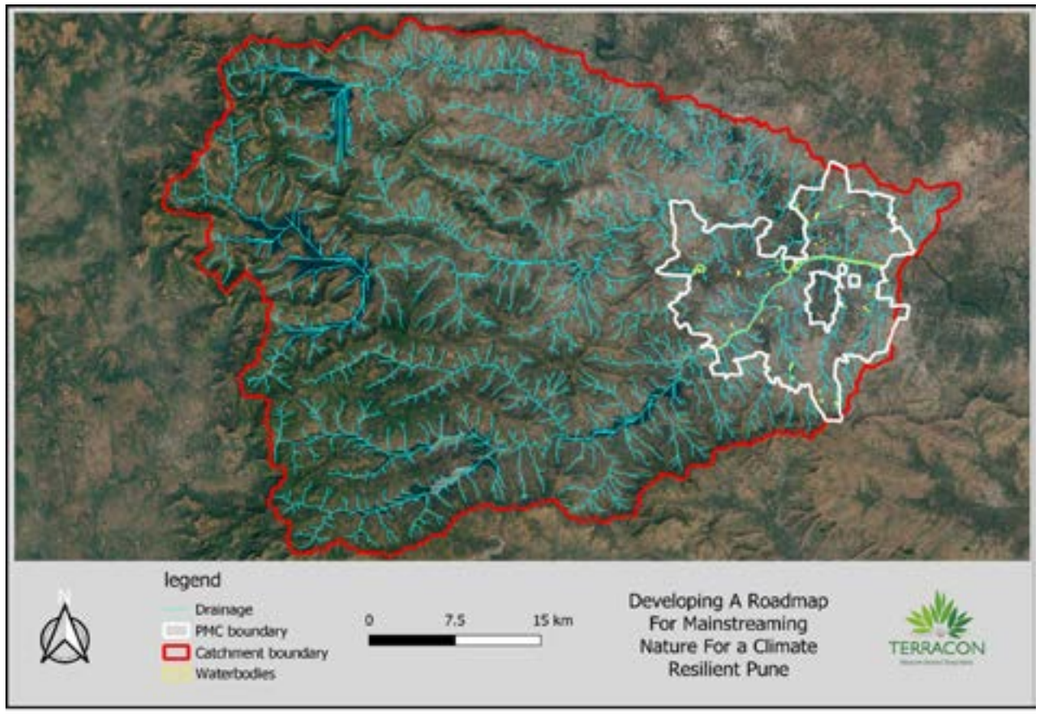

Fig 12. Drainage Pattern Map

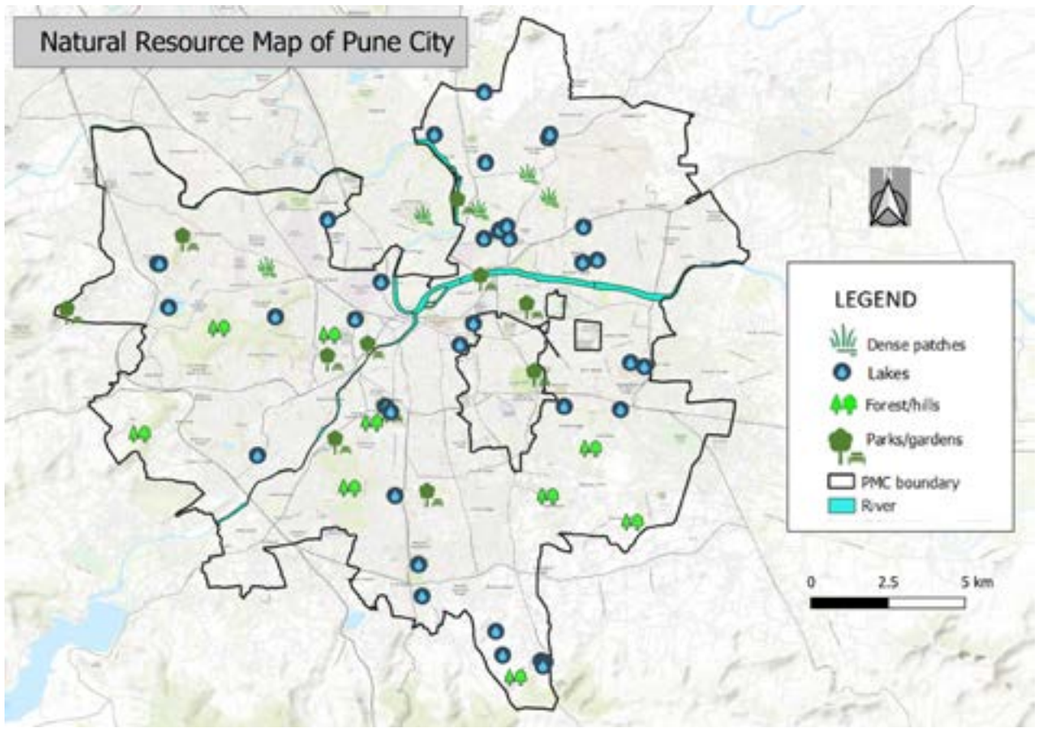

Fig 13. Natural Resource Map of Pune City

2.4 Demography of the Region

The population of Pune city has a population of more than 3 million as per census 2011. There has been a rapid increase in the population of Pune city by six times due to industrial and economic growth in the last 60 years (PMC, 2012).

Pune's population is expected to rise due to economic development and increase in the total area. Projected population for Pune City highlights that the population in the city for the years 2021, 2031, and 2041 will be 4,487,573, 6,211,404, and 8,597,417 respectively. (PMC, 2012). Urban sprawl has taken place in all directions but more significantly in the eastern, southern, and south-western directions. The reason for an increase in the population of Pune is due to the development of several commercial sectors with migration of population increasing from 3.7 lakhs in 2001 to 6.6 lakhs in 2011 (PMC, 2012) .

Total Population: 3,124,458

1,520,783 **1,603,675**

Sex Ratio: 948

Children: 337,062

Literacy rate: 89.56%

Population Density: 5,600 people/ Sq.Km.

Fig 14. Population growth curve and future projection
Source: (PMC, 2012)

2.5 Climate

Pune is known for its pleasant climate which has been one of the major reasons for the increase in the economic development of the city. The city has a hot semi-arid climate bordering with tropical wet and dry climate and the micro-climate of the city is influenced by surrounding hills and physical features. Pune experiences three seasons: summer, monsoon, and winter. The summer season is experienced from March to June, the rainy season from June to September, and the winter from October to February. (PMC, 2021). The warmest month in Pune is April and the city often receives heavy thundershowers in May with high humidity. Though the summer climate is hot, night temperature is usually cool due to high altitudes. Even during the hottest months, nights are usually cool due to Pune's high altitude. Most of the annual rainfall is experienced from June to September and July is the wettest month

Maximum Temperature: 38.80C

Minimum Temperature: 13.30C

Total Percipitation: 1152.10mm

75-100% Relative Humidity in Rainy Season

50-75% Relative Humidity in winter

25-50% Relativity in Summer

Fig 15. Details of Climate Parameters for Year 2020

2.6 Infrastructure Development

Pune has witnessed tremendous growth in the last decade. As one of India's foremost industrial and IT hubs, it has attracted professionals from all over the country with the automotive industry already having a conspicuous presence in Pune. Pune, also known as "Oxford of India" is dotted with many research institutions. The infrastructure in Pune is rapidly extending towards the areas of Mahalunge, Kirkatadi, Lohegaon, Shivane, Dhayari, and Shiwalewadi. Hadapsar, in Pune, is pinned with two special economic zones– Magarpatta City and Fursunghi IT Park. About 11 km from the city centre, many industries and corporations are based in the city including IBM, Mphasis, Aviva, and Honeywell. Magarpatta City was envisioned as a well-planned township with all modern amenities (PMC, 2012).

The proposed draft development plan, 2041 (DP) for the Pune Metropolitan Region (PMR) which also includes parts of the Pimpri Chinchwad Municipal Corporation (PCMC) targets making the city India's most liveable habitat. It is also planned to develop the city as a premium international investment destination, over the coming 20 years. To house the increasing population, PMC has incorporated 23 villages into its jurisdiction intending to become one of the largest urban areas (Fig. 16) (PMC, 2012).

The DP aims to integrate and consolidate growth to facilitate convenient mobility, efficient infrastructure, self-sufficient housing and amenities, prudent employment and economic growth, and a resilient environment. There are 26 town planning schemes, two ring roads, 59 public housing projects, 9 truck terminals, 12 logistical hubs along with the 152.19-km Pune-Nashik semi high-speed rail and 89.65-km crescent railway that constitute this draft plan (PMC, 2012).

Fig 16. New Villages added in PMC region

Pune also has a developing metro network under construction comprising 30 stations spread over two corridors, which run over a total length of approximately 33.1 km (Fig. 17) (Pune Metro, n.d.).

Fig 17. Proposed Metro development Plan for PMR

Pune is among the 109 cities shortlisted in India's Smart Cities Mission, and the city has been allocated an estimated USD 5.2 billion for its smart city development plan and has been ranked as the eighth-fastest city by India's Urban Development Ministry (India Focus, 2017).

2.7 Urban Environmental Quality

2.7.1 Land

Pune has observed rapid urbanisation due to increased economic growth. This has led to substantial land use/ land cover (LULC) changes. The city has witnessed considerable growth in the built-up area due to developing residential areas and infrastructure facilities. Additionally, an increase in the utilisation of land for commercial setups has also contributed to the land-use change in the city (Parishwad & Shinkar, 2017). The map in Fig. 18 highlights that there has been a considerable change in the green cover of the city with a difference of 12 per cent from 2013 to 2020. This has led to the

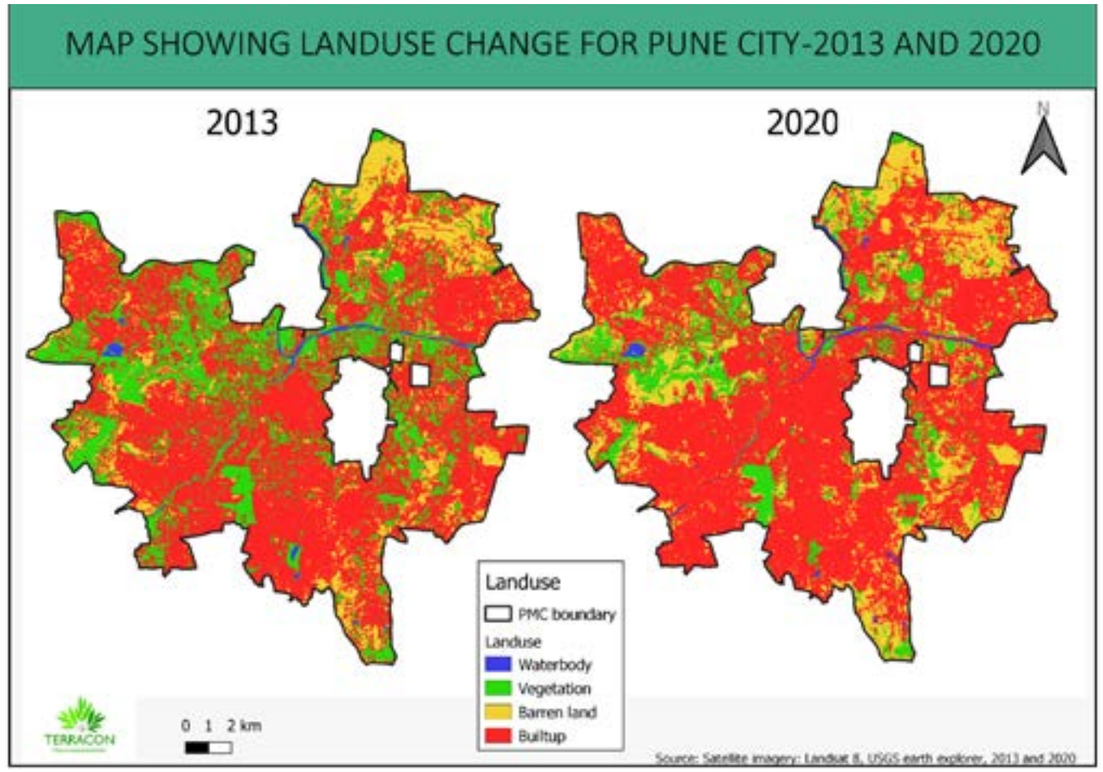

Fig 18. Change in Land Use Pattern (2013-2020)

depletion of the ecosystem and its services. Hilly areas in Pune have been encroached by slums and several hill-cutting activities have taken place in the region which have promoted an increase in soil erosion and reduced run-off control.

Restoration of the hills is being carried out by PMC in coordination with the forest department under the Joint Forest Management project. Approximately 1826 acres of forest cover and/or hillocks are under development for soil and water conservation through tree plantation and construction of protective walls. (PMC, 2012).

2.7.2 Air

Air quality is deteriorating in Pune city primarily due to vehicular emissions with further addition from wind-blown re-suspended dust, industrial operations, use of electricity for residential purposes, solid fuel combustion, etc. (Vijay, 2019; PMC, 2012).

Air quality parameters highlights the situation before and during lockdown wherein the level of air pollution during lockdown was observed to be comparatively less as the major contributors of air pollution were non-functional or in low function during that phase (PMC, 2021).

Pune has seen an increase in the number of two-wheelers from 24.97 lakh in 2016-17 to 27.03 lakh in 2017-18, while, the number of four-wheelers increased from 5.89 lakh to 6.45 lakh (Dharwadkar, 2018). There has been a rise in demand for cabs due to the growinginflux of people in the city for business and education, an increasing number of industries, and the IT sector. This contributed to a rise of 18% in 2018 in the auto-rickshaw segment. Before this, in 2017 highest growth in vehicle registration of about 25% was observed in the taxi cab segment (Dharwadkar, 2018).

Newsly registered vehicles per year

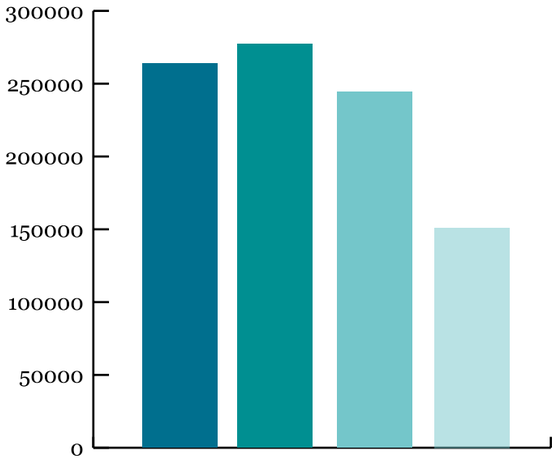

Fig 19. Vehicle Registration in Pune
Source: (PMC, 2021)

Particulate matter levels (PM10 and PM2.5) in the air are higher than National Ambient Air Quality Standards (NAAQ) set by Central Pollution Control Board (CPCB). It was found that the concentration of PM2.5 was 53.70µg/m3 in 2019 and 39.92 µg/m3 in 2020 (PMC, 2021). Also, the concentration of PM10 was 79.30 µg/m3 in 2019 and 63.94 µg/m3 in 2020; wherein the permissible limit for PM2.5 is 40 µg/m3 and PM10 is 60 µg/m3. The concentration of NOx, SOx, CO, and O3 has decreased in the year 2019 and 2020 compared to the past three years (PMC, 2021). The emergence of Covid-19 can be one of the reasons for a reduction in the level of these pollutants as several industrial activities were under less operation and transportation was prohibited (PMC, 2021).

In the year 2010-11, the Carbon Emission in Pune was about 4,661,064.20 tCO2e which is 1.50 tCO2e emissions per capita. The maximum emission of CO2 is from the residential (31.6%) due to the consumption of electricity and petroleum, followed by HT electricity than the transport sector (TERI, 2012). The emission value reached 1.64 tCO2e in the year 2017 (PMC, 2021).

2.7.3 Noise

The Environmental Status Report published in 2021 states that the reason for noise in Pune city is due to increasing vehicular traffic and other commercial reasons. The report mentions that since 2019, levels of noise pollution in residential areas is lower than the permissible limit, whereas the commercial areas show a slightly higher noise level than the limit for both years. In silent zones within 100 m of the court, hospital, and education institute the noise level was also found to be within the permissible limit (PMC, 2021).

2.7.4 Water

The Mula-Mutha River has been through several transformations due to changes in land-use patterns and encroachments along the riverside leading to the reduced width of rivers. Also, solid waste and debris are dumped in the rivers deteriorating the water quality and health of the ecosystem (PMC, 2016). The Mula-Mutha River pollution is also influenced by the pollution load from industries located in Pune-Chinchwad Municipal Corporation that release effluents into Pavana River and Mula River. The nallahs in the city covers a stretch of362.11 km of which 15.93 km have been completely encroached whereas 51.89 km have been partially encroached. Additionally, at several places retaining walls have been constructed, obstructing the normal flow of the water bodies (PMC, 2016).

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Groundwater in Pune city is extracted through 399 dug wells and 4820 bore wells (TERI, 2013). No specific data on the state of groundwater level specific to the city is available limiting the understanding of its criticality and stress on the resources. Though studies mention that the quality of groundwater in the region is contaminated due to discharge of industrial effluent and hazardous industrial and residential solid waste on the surface soil and rivers, which perhaps percolated and contaminated the groundwater (Absar & Deepali, 2018). Groundwater level in Pune is depleting at an alarming rate due to the rapid expansion of the city and the disturbance of the surrounding hills (Himanshu, Manoj, & Vivek, 2019).

2.8 Schemes and Policies

The PMC has adopted several policies and schemes for the environment, social and economic development. The list of the same is presented in Table 2.

Scheme	Purpose & Area
Nagar Van Scheme	Nagar Van scheme is planning to grow about 200 Urban Forests pan India over the next five years. The Warje Urban forest located in Pune at Maharashtra will be considered as a role model for this.
Rooftop Rainwater Harvesting	Mandatory for new buildings post-2007 in PMC
Green Rating for Integrated Habitat Assessment (GRIHA)	GRIHA is a rating tool that helps people assess the performance of their building against certain nationally acceptable benchmarks.
Solar Mission	It targets for 100 GW installed capacity of solar electricity by 2022.
National Clean Air Program	To prepare clean air action plans to reduce PM2.5 pollution by 20–30% by 2024 as compared to 2017, in 122 cities
Green Highways Policy	The policy aims to promote greening of Highway corridors to reduce the impact of air pollution and dust by planting trees and shrubs along the National Highways. They will act as a natural sink for air pollutants and arrest soil erosion at the embankment slopes.
India Cooling Action Plan	To provide an integrated vision towards cooling across sectors encompassing inter alia reduction of cooling demand, refrigerant transition, enhancing energy efficiency, and better technology options with a 20-year time horizon.
Atal Mission for Rejuvenation and Urban Transformation (AMRUT)	To focus on upgrading urban centres and providing public utility services like waste and water management
Pradhan Mantri Ujjwala Yojana	To safeguard the health of women and children by providing them with a clean cooking fuel - LPG

Warje Urban Forest: A Case Study

Warje Hill was once 16 hectares of barren land belonging to the Forest Department and encroached by slums. Technology, Education, Research, and Rehabilitation for the Environment (TERRE) in collaboration with TATA Motors and Persistent Foundations planted about 9500 saplings of 23 indigenous species on the hill as part of CSR activity.

In 2-3 years, the hill has flourished and is now supporting about 29 local bird species, 15 butterfly species, 10 reptile species, and 3 mammal species. This was the first urban forestry project in the state and is now serving as a role model for urban forestry projects all over India. (Warje Urban Forestry, 2018).

Fig 20. Restoration of Warje Hill
Source: (PMC, 2021)

3. APPROACH AND METHODOLOGY

3.1 Approach

Our approach for the study is comprehensive and holistic. It considers sustainable development of the city while making it climate-resilient through NbS. The study focuses on three broad aspects, viz. climate profile of the study area, its vulnerability to climate change and impacts, and local feasibility of the NbS. The overall approach focuses on providing a roadmap for the implementation of the solutions in Pune City.

3.2 Methodology

The study was undertaken in three phases:

Phase I: Preparatory Phase

Phase II: Data Analysis

Phase III: Road Map Development

The overview of the methodology is presented in Fig. 20, while detailed methodology is explained in the further sections of the chapter.

3.2.1 Literature review and secondary data collection

Secondary data is a valuable source as it can supplement with primary data and form a baseline of the project. Secondary data for the proposed project was collected from government statistics, Municipal Corporation published reports, NGO reports, newspaper articles, and research studies. As this project needed an understanding of the historical timeline of the city profile and climate considering environmental and social aspects, secondary data collection was a crucial step in analysis and prediction.

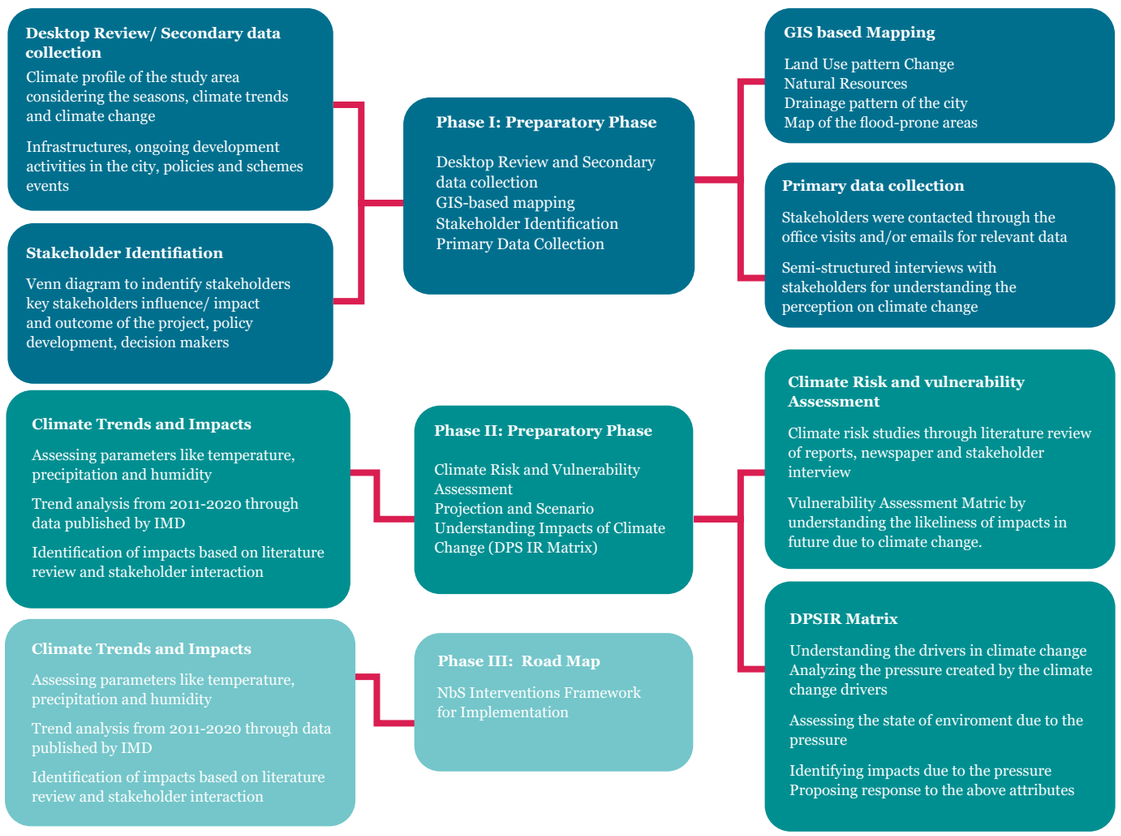

Fig 21. Methodology for Development of NbS for Pune City

3.2.2 Resource Mapping

Climate change is a geographical issue, implementation of GIS technology helps in developing a clear state of the environmental aspects and its correlation with the climate change scenario. For the proposed project, GIS was used for the development of maps to understand the physio-biological profile of the city, which was also used by the experts during the site visit for primary data collection.

3.2.3 Stakeholder Identification

Stakeholders play a critical role in any project development as they bring different perspectives, values, and expectations to any plan. Stakeholders were identified based on the following questions:

- Who is affected by the current climate trends?
- Who deals with the impacts associated with climate change?
- Who maintains a database of the ongoing climate change hazards and also the climatic condition?
- Which groups could be impacted or have an interest/ stake in the project?
- Who approves the sanction of activities within the PMC?

Fig. 22 highlights the possible stakeholders that can be associated with the projects.

Further key stakeholders were identified that can influence and impact the outcome of the project. The following questions were considered while selecting the key stakeholders depending upon their power and interest in the project:

- Who sets the vision/goals for the city?
- Who is already working on climate-related interventions in the city?
- Who will play a major role during the implementation phase of this project?
- Who will have to change their systems or processes because of this project?
- Who represents organizational policies governing this project?

A list of stakeholders connected for the development of the project is provided in Annexures. The stakeholders were contacted through interacting with them in person and through e-mails for obtaining data concerning the project and understanding their perception of climate change in the city.

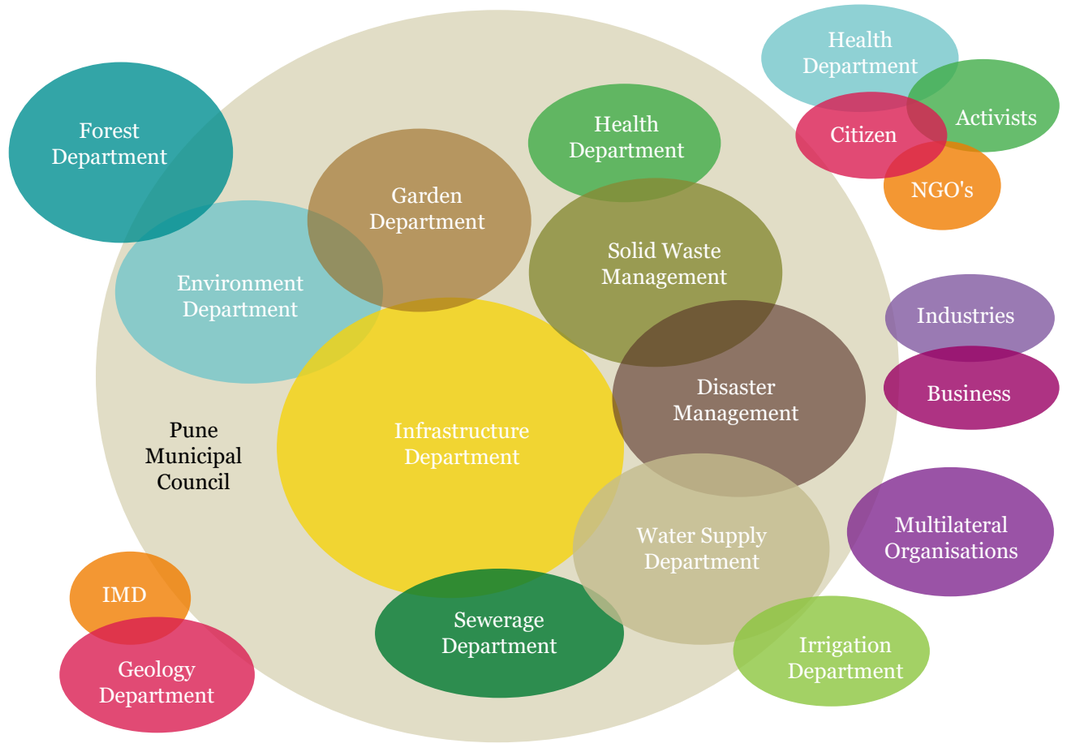

Fig 22. Figure Venn Diagram identifying Possible Stakeholders

3.2.4 Primary data collection

Primary data collection was undertaken through two approaches:

a. Situation analysis:

- A team of experts visited several sites in Pune City that are prone to climatic events like flooding and also to understand the current development activities taking place in the city (Fig. 23). Additional ecosystems like rivers and hills were also visited by the experts to understand their current state as well as opportunities and challenges for their inclusion in NbS development. During the visit, data were also recorded in form of photographs.

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Fig 23. Field visit by experts

b. Semi-structured interviews:

- Interviews are common tools used in planning, monitoring, and evaluation. For the proposed project, semi-structured interviews were undertaken through personal interaction and emails. The interview included open-ended questions to broadly understand the perception of the audience related to the climate change scenario in the city and target audience for the interview included identified stakeholders, viz., officials from Pune Municipal Corporation, members of NGOs, and activists. The interviews were conducted through personal interaction, e-mails, and stakeholder consultation meetings.

The following pre-determined questions were asked to proceed with the discussion:

- How do you consider the climate change issue in the city? : High/ Medium/Low
- What are the climate change events that you have observed in the city?
- What are the issues according to you that are leading to climate change?
- What are the impacts of climate change observed by you in the city? How critical do you find these issues?
- Does development/ management plans include measures/ precautions to tackle climate change issues?
- What all measures do you think are required to tackle climate change issues in the city?

The secondary and primary data were further collated and analysed to understand trends in climatic parameters, vulnerability to several climatic events, and factors influencing climate change in the city.

3.3 Analysis

3.3.1 Trends in Climatic parameters

Research studies mention that global warming has a direct influence on several climatic factors like temperature, precipitation, and relative humidity (Gunawardhana, Al-Rawas, & Kazama, 2016). Hence, these three parameters were studied to understand the impact of climate change on the trends in the city. Data for daily mean temperature and relative humidity were collected from the weather underground website from the year 2011 to 2020. Using the daily mean data, mean monthly temperature and relative humidity were calculated and further plotted on a graph to understand their trends in 10 years. For precipitation, data on yearly mean rainfall from the year 2009 to 2020 was assembled from Environmental Status Reports published by PMC.

Using the forecast tool on Microsoft Excel, a prediction of all three parameters for the year 2021-2030 was derived. The forecast predicts linear value based on the approach of linear regression. In linear regression, modelling of the relationship between a dependent variable (y) and an independent variable (x). Forecast calculates the x and y values based on current x and y values (Nadler & Kros, 2007).

Formula,

- Predictions = FORECAST (x, known_y's, known_x's)
- Where, X (required argument) – This is a numeric x-value for which we want to forecast a new y-value
- Known_y's (required argument) – The dependent array or range of data
- Known_x's (required argument) – This is the independent array or range of data that is known to us

3.3.2 Vulnerability Assessment

Inter-governmental Panel on Climate Change (IPCC) defines vulnerability as "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 capacity." (IPCC, 2001).

A report by the Council of Environmental and Water mentions that Maharashtra is highly vulnerable to extreme climate events such as floods, droughts, and cyclones, according to the Climate Vulnerability Index (CVI). Also, the Pune district is stated to be moderately vulnerable to floods and droughts with an index value of 0.3901 (Mohanty & Wadhawan, 2021). Hence, the study was undertaken to assess the vulnerability at the niche level for Pune city towards four extreme climate events, viz., floods, droughts, landslides, and heatwaves.

The vulnerability assessment was undertaken through the integration of two approaches:

a. **Literature review:** The literature review study explored the exposure of the city to different climate events, associated impacts, and adaptive capacity of the city.

b. **Perception of stakeholders:** During stakeholder interaction, a semi-structured interview was conducted to understand their perception of the climate-related issues and vulnerability in the region.

Here,

- **Sensitivity** is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli.
- **Adaptive Capacity** is the efficiency of adjusting to current/ predicted climate changes and their effects.

Table 3: Vulnerability Assessment Matrix

Hazard		Adaptive Capacity		
		Good	Average	Poor
Sensitivity	Extreme	Low	Medium	High
	Moderate	Low	Low	Medium
	Negligible	Low	Low	Low

3.3.3 DPSIR Analysis

The study employs DPSIR (Drivers- pressure-state-impact-response) framework to describe the relationships between the origins and consequences of climate change issues. According to the DPSIR framework, there is a chain of causal links starting with 'driving forces' (economic sectors, human activities) through 'pressures' (emissions, waste) to 'states' (physical, chemical, and biological) and 'impacts' on ecosystems, human health, and functions, eventually leading to political 'responses' (prioritisation, target setting, indicators) (IEA Training Manual, 2009). In the context of Pune city, the DPSIR matrix is an outcome of studies undertaken as part of the preparatory phase and climate vulnerability studies through literature review, GIS-based analysis, primary observations, and interaction with stakeholders.

This framework was used in decision-making by assessing the driving forces, their pressures, the consequences on state variables, and their ultimate impact. From the assessment of the impacts, appropriate responses (i.e., NbS) to direct the final effects in the desired directions were proposed (Giupponi, 2002).

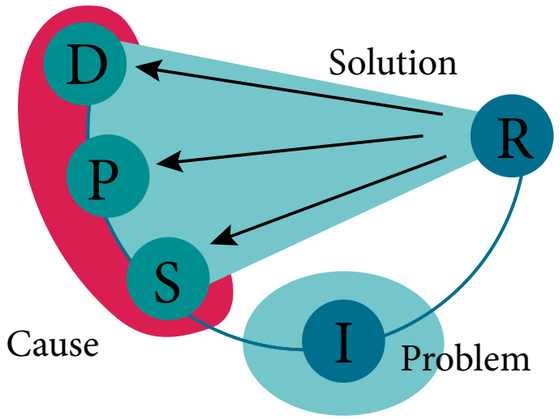


Fig 24. A DPSIR Framework Source: (Giupponi, 2002)

4. CLIMATE VARIATIONS AND VULNERABILITY ASSESSMENT

4.1 Trends in Climatic Variation and future predictions

Trend analysis was carried out for three climate parameters, i.e., temperature, precipitation, and humidity for a decade (2011-2020) to understand the trends in their characteristics due to climate change. Also, future projection models were developed for the same parameters.

4.1.1 Temperature

Temperature is one of the most obvious and immediate effects of global warming around the world. The average temperature is rising as the amount of greenhouse gases in the atmosphere is increasing and it is leading to the trapping of more heat in the Earth's atmosphere (EPA, 2017). An increase in temperature also influences other parameters such as precipitation and humidity, hence, playing a vital role in climate change.

To understand the trends in temperature for Pune city, the month of May was considered a representative month for summer, and January was considered as a representative month for winter. From the graph (Fig. 25) it is understood that for the winter season, from 2011 to 2020 there is a 1.8°C rise in temperature in the year 2020 compared to 2011. According to the forecasted values, an increasing trend in temperature is observed from the year 2021 to 2030 wherein a 2.16°C rise in temperature is predicted by the end of 2030 for the winter month. This indicates that the rate of increase in temperature is rising by almost half-degree Celsius. For the summer season, the temperature has risen by 2.8°C in the past decade (2011-2020). It is predicted that in 2030 there will be a rise of 2.17°C in average monthly temperature. Predictions also highlight that Pune's winter temperature may show a decreasing trend in minimum temperature at night while the day temperature may drastically rise. A similar situation was faced in 2020 (Madan, 2020). The projected increase in temperature can be considered as one of the driving forces influencing the alteration in the hydrological cycle by influencing the air moisture and precipitation.

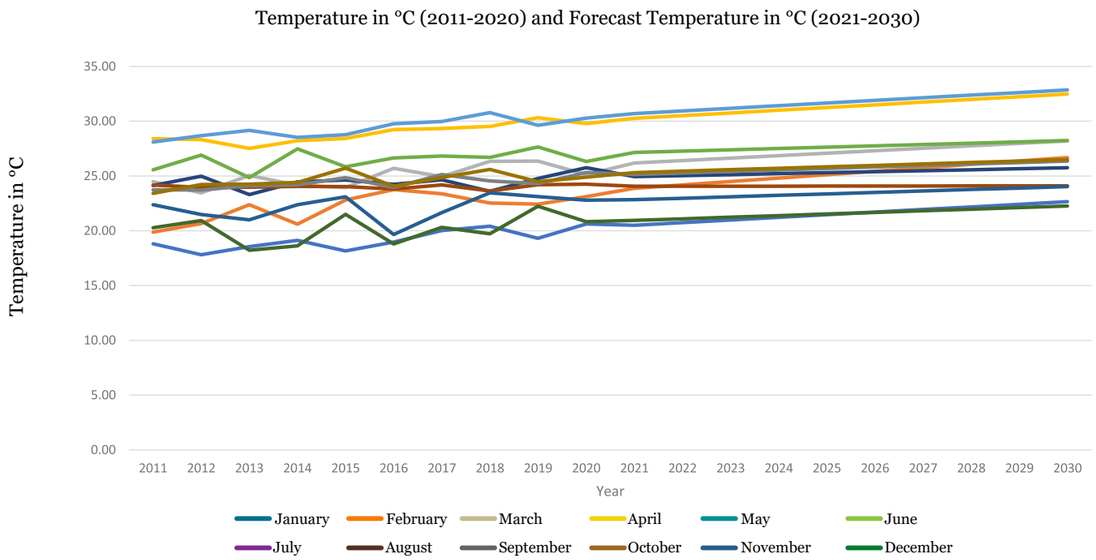
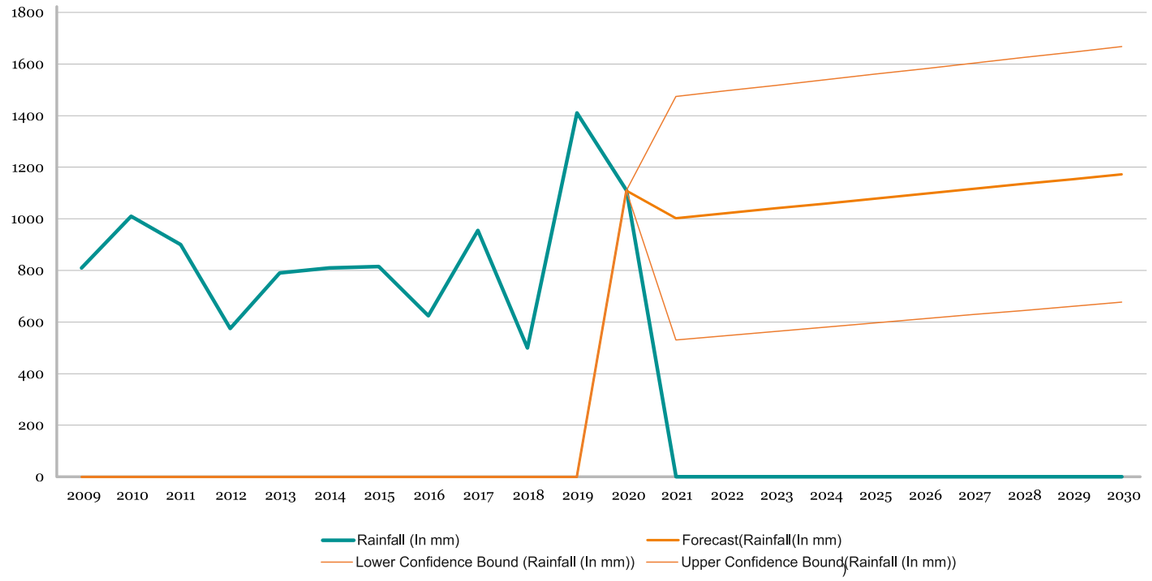


Fig 25. Temperature-Trend Analysis (2011-2020) and Forecast (2021-2030)

Source: (Underground.com, n.d.)



Source: (Environment Status Reports from 2011-20, PMC)

Fig 26. Precipitation Trend (2011-2020) and Forecast (2021-2030)

4.1.2 Precipitation

Precipitation is directly influenced by global warming. Due to global warming, there is an increase in heat in the atmosphere leading to greater evaporation and surface drying, thereby causing pre-monsoon drought. Also, due to evaporation, the water holding capacity of air increases by 7 per cent per 1oC warming. This leads to the abundance of water vapour in the atmosphere causing extreme precipitation (Trenberth, 2011).

From the graph (Fig.26), it can be seen that the mean yearly rainfall has been irregular with extreme precipitation in the year 2019 and 2020, and lowest precipitation in 2018. The prediction model illustrates that the precipitation shows an increasing trend for the years 2021-2030. This means rainfall would be above 1000mm from 2020 onwards with possibilities of extreme rainfall of more than 1600mm after the year 2026 and possibilities of drought-like events every year. The projected increase in temperature can be considered as one of the driving forces toward such a situation.

4.1.3 Relative Humidity

The relative humidity is influenced by factors like evapotranspiration that is induced through changes in land surface temperature and moisture content of air (Byrne & O'Gorman, 2016).

Studies also assume that Relative Humidity distributions remain constant in the atmosphere over long time scales and no specific quantification of change in relative humidity due to climate change has been studied (UEA, 2007).

The graph exhibits a higher relative humidity in August (monsoon), while the lowest in April (summer). In the year 2018, the monsoon season showed a reduced level of relative humidity, this can be correlated with a lower level of precipitation (Fig. 26).

The graph shows a slightly increasing trend for August whereas other monsoon months show a negligible to no change in relative humidity. A decreasing trend is observed in the months of January, February, April, and May wherein the latter two months exhibit a comparatively more decreasing trend in relative humidity than other months. These months are typically hotter in Pune and the increased surface temperature, which has been predicted in the temperature trends in Fig. 25 can be a reason for the decreasing relative humidity.

The source contributing to irregularities of the precipitation, temperatures, and other extreme conditions needs to be studied for effective planning of the solutions addressing climate change.

The extreme events that Pune faced since 2012 are listed in Table 4.

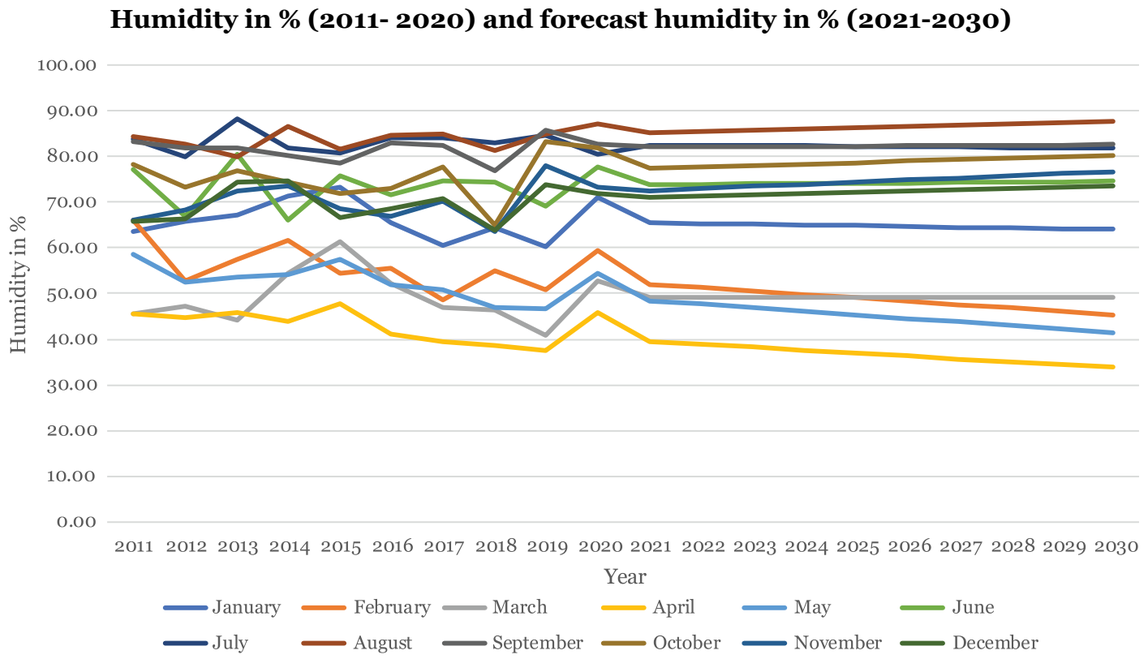


Fig 27. Relative Humidity Trend Analysis (2011-2020) and Forecast (2021-2030) Source: (Underground.com, n.d.)

Table 4: Chronological Extreme Events in Pune City

Date	Event
February 10, 2012	Pune city recorded the third lowest temperature (4.6°C) in the past 78 years (Nambiar, n.d.).
November 17, 2012	Pune recorded the first-lowest temperature (7.9°C) (Skymet weather, 2016).
December 13, 2014	Pune recorded the highest rainfall in one day (55.6mm), making it one day the highest rainfall in the decade (Diwekar, 2021).
March 29, 2015	Pune observed the highest rainfall of 55.6mm in March as compared to record rain in 1954 (34.5mm of rainfall) in the same month (TOI, 2015).
November 21, 2016	Pune recorded the second-lowest temperature of 9.6°C (Skymet weather, 2016).
April 27, 2019	Pune recorded 42.9°C, the highest recorded temperature for the city in the last 36 years (Skymet Weather, 2019).
September 26, 2019	The city witnessed flooding and wall collapse incidents after heavy rains, causing loss of lives, cattle, and materialistic damages (TOI, 2019).
December 13, 2019	Pune recorded 13.7°C at night making it the warmest night of the decade (Madan, 2019).
July 2, 2020	Pune city recorded more than 100mm of rainfall in a span of just 2-3 days (TOI, 2020).
October 15, 2020	Pune city recorded 96mm of rainfall in Shivaji Nagar alone, breaking the records of the heaviest rainfall in the decade (Punekar News, 2020).
November 11, 2020	Pune city slipped to an unusually low temperature (10.60C) early in the morning and the day temperature was also at 29, one of the lowest November temperatures in the decade (Madan, 2020).
January 9, 2021	32.5 mm rainfall at Shivaji Nagar, Pune in just 24 hours which was the highest rainfall in 52 years (Marar, 2021).
December 1, 2021	Pune observed unusually thick fog and light rains for most of the day and the 76.6 mm of rainfall at night making it the wettest December night in the past 25 years (Dighe, 2021).
December 17, 2021	Pune city has reported rainfall every month in the year 2021 starting from January, with more rainy days as compared to past years (Devikar, 2021).

4.2 Impacts

Pune city is currently prone to three climate events, i.e., floods, heatwaves, and landslides. The prediction models in the above sections highlight an increase in these events due to changing climate parameters. Same assumptions have been also stated in one of the reports published by IPCC in 2017 wherein an increase in the frequency and intensity of such climatic events has been stated on a global scale (Hossein, et al., 2016).

4.2.1 Heat Waves

Pune city has developed a micro-climate different from the surrounding environment leading to the phenomenon of 'Urban Heat Island (UHI)'. The effect occurs when cities replace the natural land cover with

dense concentrations of pavement, buildings, and other surfaces that absorb and retain heat. This effect increases energy costs (for uses such as for air conditioning), air pollution levels, and heat-related illness and mortality (EPA, n.d.). Apart from the temperature influences, the welfare and health of inhabitants could also be affected by local heat waves. A study conducted from 2004 to 2012 identified that non-linear temperature is one of the reasons for the mortality rate in Pune city. It was also found that cold temperature attributes to more mortality risks than heat waves (Vijendra, Scott, Sanjay, Hicham, & Paula, 2022). Heat waves can lead to physical distress like tiredness, fever, dry skin, lack of appetite, dizziness, nausea, headache, hypertension, anxiety and, unconsciousness (Aruna Rastogi, 2016). No statistical data on such issues is available for exactly quantifying the impacts.

Studies also indicate the global urban population (which is over 50 per cent of the total population) per capita energy usage for operating cooling systems, to be over three times than the rural dwellers (Parishwad & Shinkar, 2017). This overconsumption of resources has caused serious concerns for energy as well as the environment sector. The use of air conditioners increased in Pune city in 2016 due to UHI, which was reflected through energy consumption data (PMC, 2016). Such situations not only increase the economic expenditure for an individual but also contribute to increased emission levels.

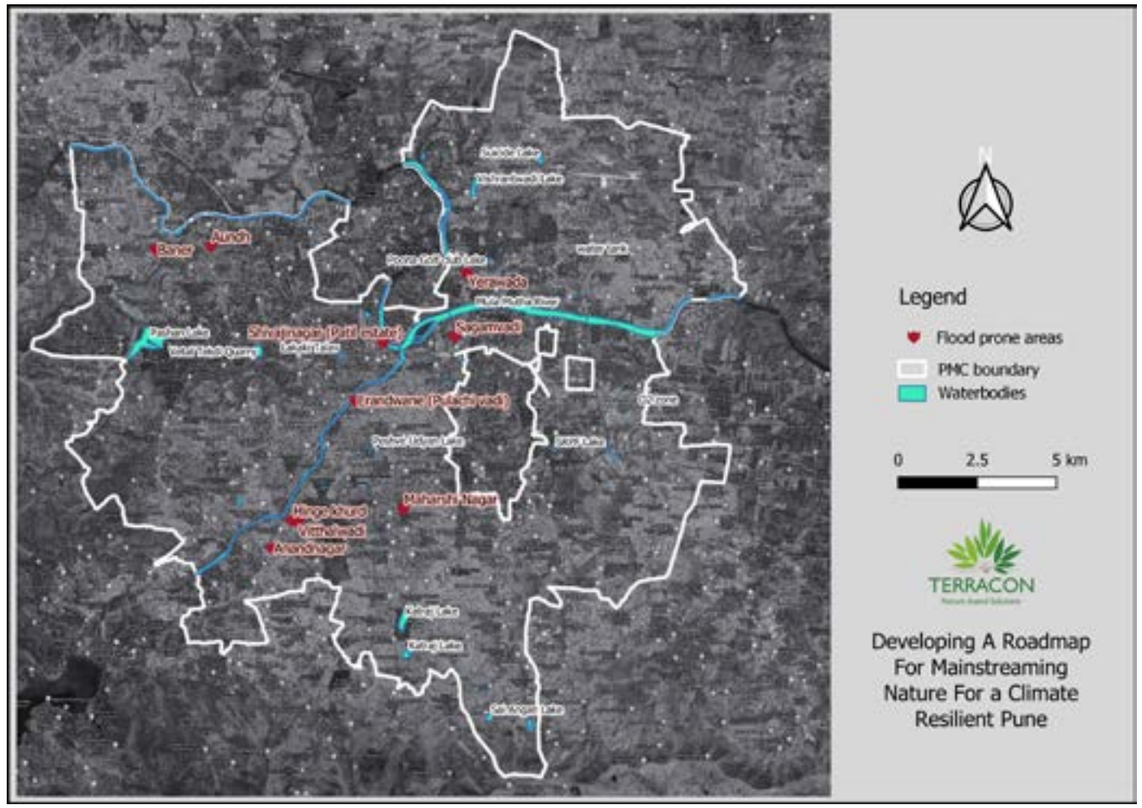


Fig 28. Flood-prone Areas in Pune City

Increased temperature also leads to reduced agricultural produce, reduced forests, and ecosystem functions, drying of water bodies, availability of resources, economic losses due to lack of raw material, reduced working capacity, etc. No published data was obtained for the same in context to Pune city.

4.2.2 Flood/ Flash Floods

The rainfall in Pune is characterised by extreme and off-season precipitation, leading to increase events of flooding. Experts have stated that urban flooding will be a normal rather than an exceptional event in the city (Hindustan Times, 2016). A map presenting the flood prone areas in PMC is given in Fig. 28.

During the heavy precipitation, the 12 nallahs in the city get flooded and affect the localities and slums along their side (PMC, 2012). The slum areas are rehabilitated to a different place during extreme conditions. Flood and lightning events in Pune city have led to loss of lives and injury during several events (Economic Times, 2019).

Property damage is another impact specific to flooding activities. Pune has been facing issues like collapse of walls, damage of roads, loss/ damage to vehicles, loss of other infrastructure like electricity poles, pipelines, paver blocks, etc. (Environment Department, 2021) Floods in Pune also disrupt the water supply and electricity supply in the city (Banerjee, 2019).

In Pune, water pollution is the main source of the rise in cases of typhoid, gastroenteritis, diarrhoea, dysentery, and jaundice in the city. Water logging due to heavy rains and flash floods has led to an increase in leptospirosis cases and the number of people suffering from dengue, chikungunya, and malaria has increased during the monsoon season. (PMC, 2012).

4.2.3 Landslides

Floods not only cause human and economic losses during the event but also lead to utilising a huge expenditure for recovery.

Landslides in the city are an outcome of human-induced hill cutting and construction activities. These landslides are further influenced by heavy rainfall in the region. The Khadki hills landslides lead to blockage of vehicle movement on the Mumbai- Bangalore Highway (Puri, 2016). No appropriate data is available on the exact impacts due to the events but such events can lead to loss of lives, personal property, infrastructure, economic activities, and environmental valuables.

4.3 Vulnerability Assessment

A vulnerability assessment was undertaken for four climate events, viz., floods, heatwaves, landslides, and draughts based on the predictions and impacts studied in the above sections. The vulnerability assessment is gauged on the sensitivity of our well-being to climate change and on the cost of adapting to climate change.

Pune is exposed to climate events like heatwaves and flash flood events due to lack in adaptive measures (PMC, 2015). Additionally, the climate of the city is also influenced by other climate events like an increase in the number of Western Disturbances (WDs) that arise from the Mediterranean during December-February (Devikar, The Bridge Cronicle, 2019). Also, the increase in humidity and surface temperature of the ocean has given rise to more cyclonic events along the coast of Maharashtra that influence the climatic condition of Pune leading to increased precipitation and storms (Deshpande, Singh, Ganadhi, & Roxy, 2021).

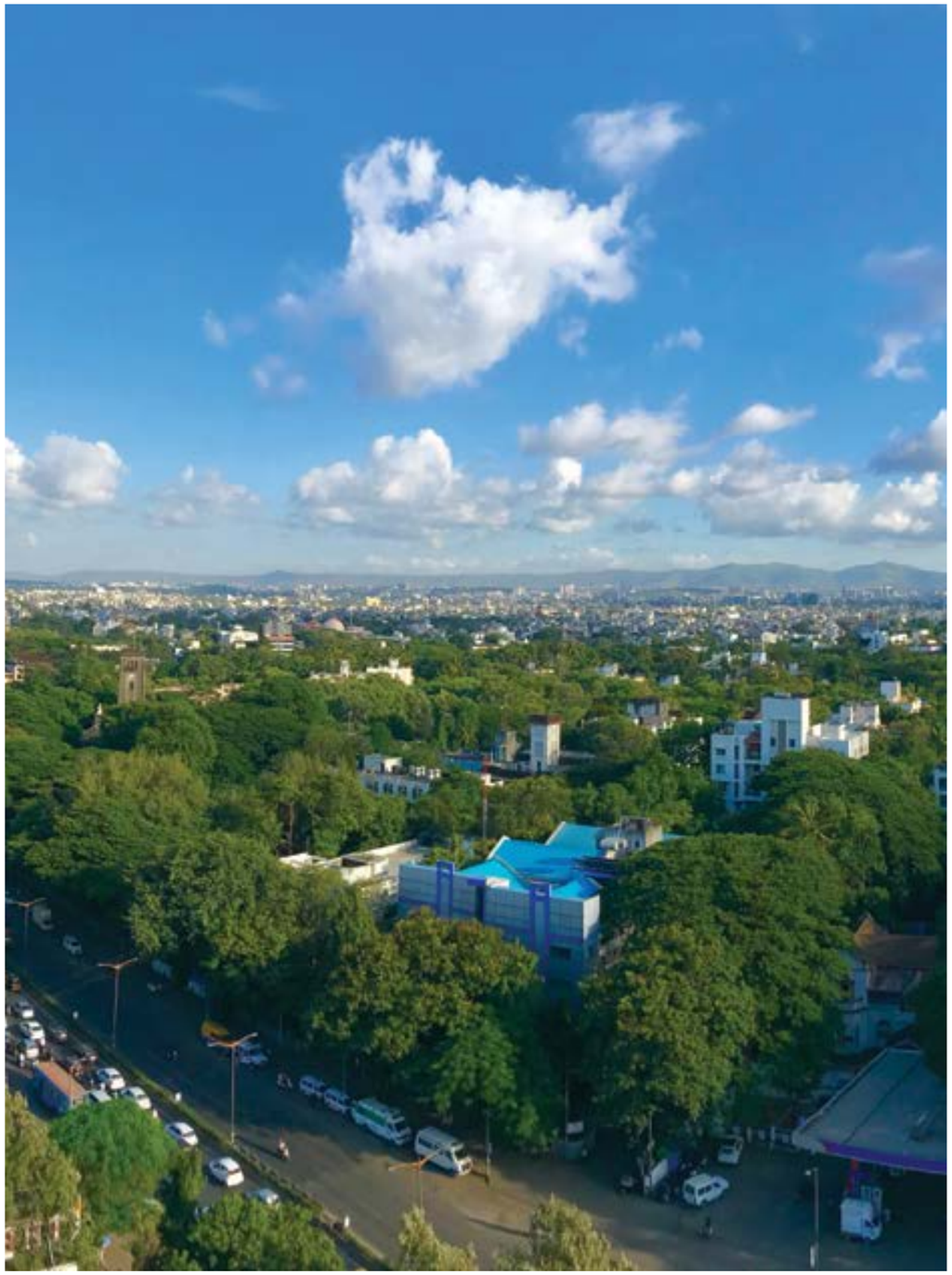
Land Use in the city has already led to an increase in surface temperature disturbing the micro-climate of the city. Land surface temperature is inversely proportional to the Normalized Difference Vegetative Index (NDVI), this highlights that Pune needs more green cover to reduce heat stresses (Parishwad & Shinkar, 2017). Also, the condition of water bodies in the city is poor, reducing its contribution towards lowering city temperature and also water flow control during flood events. This has escalated the sensitivity of the city to extreme events with increased magnitude of the impacts.

The vulnerability of the city to flood, temperature, and landslide events is 'medium' and may increase if no further adaptive measures are taken towards controlling the present condition and planning for future consequences.

Table 5: Vulnerability Matrix

Climate Event	Illustration of Exposure	Hazard	Sensitivity	Adaptive Capacity	Vulnerability
Flood/ Flash Floods	**Literature review:** • Pune city is prone to several flood events. • Hingne Khurd, Vitthalwadi, Erandwane (Pulachi vadi), Shivajinagar (Patil estate), Yerawada (Shantinagar, Indiranagar), Sangamwadi, Aundh, Baner have been declared as flood prone locations in the city with high susceptibility to flood. • The DMP for Pune city also mentions choking of drains, construction near nallahs, encroachments on natural waterways and nallahs, debris dumping in nallahs as the reason for flash floods • The occurrences of flash floods are evident in almost all the wards. • Slums are temporarily rehabbed during flood events **Stakeholder's perception:** • The flood events in Pune are an outcome of the cloud burst in the city. Khadakwasla dam which is built on Pavana is responsible for flooding the city. • Dumping of waste in the water bodies is an additional aspect contributing to flooding in the region. • Flooding from the nallahs is uncontrollable in the region.	Loss of life and property, impacts low-income groups, infra-structure damage	Moderate	Poor	Medium
Heat Waves	**Literature review:** • In Pune, there is an increase in temperature due to Urban Heat Island Effect. • High urbanization and population growth is the reason for the increase in temperature. **Stakeholder's perception:** • Increase of heatwaves in Winter Season • More hot summer in 3-4 years compared to past climatic conditions	Increase in health issues and water shortage	Moderate	Poor	Medium

Climate Event	Illustration of Exposure	Hazard	Sensitivity	Adaptive Capacity	Vulnerability
Landslides	**Literature review:** • Pune is surrounded by hills and there are landslide issues in wards in Aundh, Kothrud, Ghole road, Warjemalewadi, Bibwewadi, Kondhwa Wanowarie and Yerwada, Sangamwadi. Also, Dhanakwadi ward is highly susceptible to landslides. • Landslides occur due to the cutting of hills for road construction and quarrying. • No strategy was implemented to prevent the disaster, by either relocating the populations, banning constructions and road construction, or mining. There is no strategy to make people aware of the risk. **Stakeholder's perception** • Landslides occur in hilly areas where encroachments are located, the landslide issues only occur in the rainy season and events are low in the region.	Loss of life and property, impacts low-income groups, infrastructure damage	Moderate	Poor	Medium
Droughts	**Literature review:** • No drought reported in Pune city. • Surrounding talukas, viz., Daund, Baramati, Indapur, Shirur, Purandar, Velhe, and Ambegaon are prone to moderate drought. • Stakeholder's perception: • No drought condition has been observed in Pune city.		Negligible	Poor	Low



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5. DPSIR ANALYSIS

In the context of Pune city, the DPSIR matrix is an outcome of a study that overlays the baseline condition of the city and vulnerability assessment. The responses proposed will help in controlling most of the influencing parameters to develop resilience to climate change. The analysis is detailed in Table 6.

Table 6: DPSIR Analysis

Drivers	Pressures	State	Impacts	Responses
1. Population: The population of Pune city as per Census 2011 is more than 3 million which has grown by more than six times in the last 60 years. The population density has increased from 10405.28 persons per Sq.km in 2001 to 12,770.25 persons per Sq.km.	**1. Change in land use pattern:** Increased economic growth leads to an increase in demand for land **2. Increased demand for resources:** Increased demand for resources leads to its over-utilisation than its availability **3. Increased economic growth:** Increased standard of living leads to increased utilisation of electric appliances and private vehicles, which are major causes of carbon dioxide emission in the city.	**1. Reduced green cover:** Decreased green cover is quite evident in the city wherein the green areas have been replaced by infrastructure to facilitate the existing population **2. Increased exploitation of resources:** The increase in population has led to overuse of resources like food and water. **3. Reduced percolation of Water:** Due to concretization, the normal percolation of the water has been hindered and hence, the flow rate has increased. **4. Change in normal flow of river:** The river flow has been changed due to increased solid waste and the release of industrial and domestic discharge.	**1. Reduced Ecosystem Functions:** Loss of native flora can reduce the ecosystem services like water flow management, filtration of pollutants, sequestration of carbons **2. Depletion of resources:** Scarcity of resources due to increased demand reducing its availability **3. Prone to extreme climate events** Pune city is prone to UHI effect due to reduced natural resources and an increase in gray infrastructure. The city is experiencing more than usual events of extreme temperature, flooding, landslides, etc.	a. Restoration of existing green and blue resources b. Increase in Blue-Green Infrastructure c. Green Policies for Infrastructure Development d. Heat action plans for extreme climate events e. Use of renewable energy
2. Increasing economic activities: Pune has been declared as an economic centre. It is one of the strongest economically growing city with triggered work force and industrialisation. The city is potentially growing to become the biggest city.	**1. Change in land use pattern:** Increased economic growth leads to increase in demand for land **2. Increased demand for resources:** Increased demand for resources leads to its over utilisation than its availability. **3. Increased economic growth:** Increased standard of living leads to increased utilisation of electric appliances and private vehicles, which are major causes of carbon dioxide emission in the city.	**1. Reduced green cover:** Decreased green cover is quite evident in the city wherein the green areas have been replaced by infrastructure to facilitate the existing population. **2. Increased exploitation of resources:** The increase in population has led to the overuse of resources like food and water. **3. Increase in Green House Gases and Pollution:** Increased levels of pollution due to vehicular movements and release of greenhouse gases into the atmosphere.	**1. Reduced Ecosystem Functions:** Loss of native flora can reduce ecosystem services like water flow management, filtration of pollutants, and sequestration of carbons. **2. Depletion of resources:** Scarcity of resources due to increased demand reduces its availability.	a. Retaining the health of the environment through the restoration of existing ecosystems and creation of a new ecosystem that will help infiltration of pollutants through the increased green cover. b. Increase in blue-green infrastructure. c. Use of renewable energy.
3. Lack of Awareness Lack of understanding and awareness about the ecosystem has led to development of green infrastructure that are built with an aesthetic approach rather than ecosystem functioning.	**1. Increase in invasive/ exotic species:** Most of the species used for aesthetic purpose are exotic species, this has increased their population and replaced native flora. **2. Improper waste management:** Dumping of waste on land and in water bodies.	**1. Loss of native flora:** The local biodiversity is under loss and depleting due to natural invasion from surrounding and human-induced plantations. **2. Pollution of land/ waterbodies:** Increased pollution of natural resources like land and water and chocking of the sewerage system.	**1. Reduced Ecosystem Functions:** Loss of native flora can reduce the ecosystem services like water flow management, filtration of pollutants, sequestration of carbons. **2. Increase events of flooding in the city:** Increased solid waste dumping in the water bodies, issue acts as an indirect driver of flooding.	a. Development of green policies for citizens. b. Developing a Local Biodiversity Strategy and Action Plan (LBSAP), and CBI. c. Awareness among citizens and increasing the relationship between humans and the ecosystem. d. Students and teachers' participation in climate change mitigation projects and ecosystem conservation.

6. STRATEGIES WITH NBS AND ROAD MAP

6.1 Vision

The vision of this study is to develop Pune as a climate-resilient city through NbS by focusing on three interdependent factors, i.e., climate, ecosystem and community.

Following goals are proposed for developing climate-resilience in Pune City:

Vision 1: Increase climate resilience in City by decreasing Urban Stress

Vision 2: To conserve the ecosystem and enhance its functions

Vision 3: Increase people's participation in developing climate-resilient Pune City

6.2 Strategies for mainstreaming NbS

6.2.1 Conservation and Restoration of Terrestrial Ecosystem

The terrestrial ecosystem is under degradation due to encroachments, hill cutting, and infrastructure growth. Also, several green patches are covered by invasive species impacting the native floral composition and ecological function.

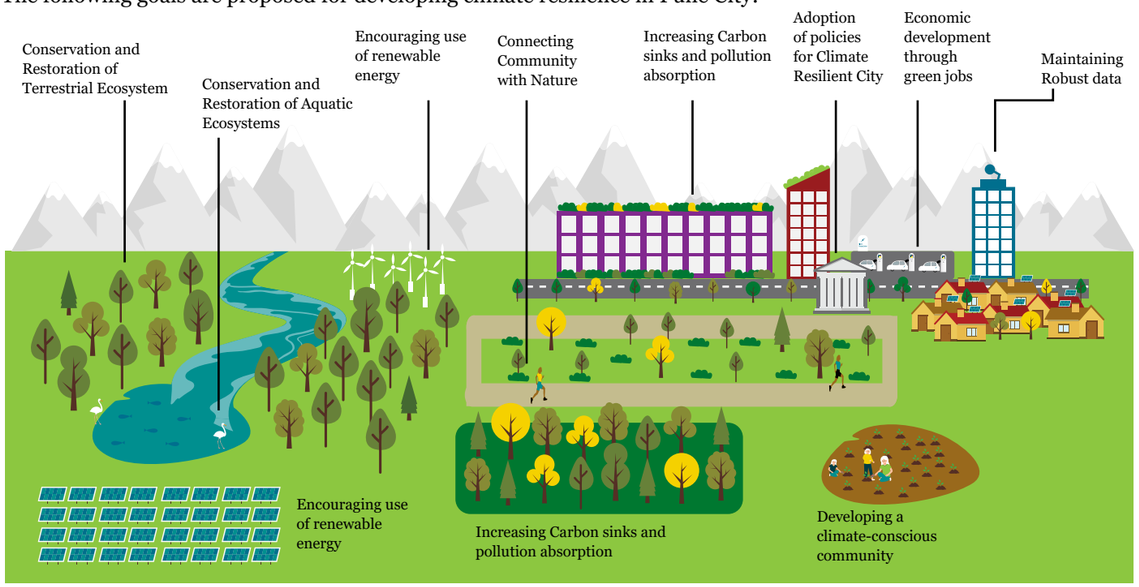
Adaptive Measure(s): Following adaptive measures are suggested for the restoration of the ecosystem.

a. Reforestation of degraded land using native species
b. Creating an Urban forest
c. Restoration of land covered with invasive species and promoting the growth of native species

a. Reforestation of degraded land

Understanding the need to increase green cover in the city, PMC along with the forest department has proposed plans for the restoration of hills (1826 Ha) in the city.

The following goals are proposed for developing climate resilience in Pune City:



Also, PMC has undertaken tree plantation activities under the roadside. It was observed that some species like *Plumeria alba, Terminali mantaly, Hymenocallis littoralis, Duranta erecta, etc.* which are exotic are used for plantation. Also, at places, monoculture plantations have been undertaken. Forests offer several benefits like carbon storage and climate regulation, nutrient cycle, water quality and quantity, soil formation, control of pests and human diseases, etc. (Liu, Kuchma, & Krutovsky, 2018). Hence, the plantation must be undertaken through an ecosystem-based approach wherein native tree species are used for plantation and mono-culture plantation is avoided.

b. Creating urban forests

PMC has initiated the creation of biodiversity parks in the city for which 221.24 Ha has been proposed in different parts of the city area around hills and water bodies. It is recommended to develop biodiversity parks as urban forests. Urban forests are the backbone of the green infrastructure, bridging rural and urban areas and improving a city's environmental footprint. They offer crucial ecosystem services such as improving air and water quality, reducing cooling requirements by offering shade, and supporting biodiversity. And also, mitigation measures by capturing and sequestering carbon. They control UHI effect in built-up areas, as well as manage the run-off from precipitation. Active urban forest management for climate change strengthens community resilience to climate change impacts (as well as other potential disasters), and creates more liveable, desirable places to live, work and play (Safford, Larry, McPherson, & Nowak, 2013). Urban forests are also supported under the Nagar Van project by MoEFCC. Well-maintained, healthy urban forests are one of the few municipal investments that appreciate over time – because the economic benefits increase as trees grow and require less maintenance.

Fig 29. Proposed Urban forest (Source: PMC)

c. Restoration of land covered with invasive species and promoting growth of native species

Fig 30. Cosmos sulphurous, Taljai hill Source: (HT, 2021)

Species such as *Cosmos sulphurous* are invasive species reported on Taljai hill of the city (Christopher, 2017; HT, 2021). Also, an old plantation of *Gliricidia* sp. was observed near the hills. Although initiatives have been taken for the removal of Cosmos, it is important to regularly check the growth in all parts of the city. Also, to restore lands covered by invasive species, the initial step required is mapping the locations where such species are observed and further phase-wise developing a plan for restoration of these lands.

Fig 31. Udaan Biodiversity Park (Source: PMC)

6.2.2 Restoration of Polluted water bodies

The state of water bodies in the city is poor due to the dumping of waste, sewage, and improper maintenance. Due to extreme climate conditions, rivers and nallahs overflow leading to flooding in the surrounding areas.

Adaptive Measure(s): Following measures are suggested for reducing flooding due to rivers and other water bodies:

a. Restoration of the water body to its original form by adopting an Ecosystem-based approach
b. Development of wetlands in surrounding gardens to collect stormwater before it reaches the river
c. Developing the quality of the existing garden and creating new gardens along the river bank

a. Eco-restoration of Waterbodies and Wetlands

The Mula, Mutha, and Mula-mutha rivers in the city are in poor condition due to increased urbanisation along the river, releasing of untreated sewage, lack of accessibility,

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Fig 32. Mula-Mutha River lined with concrete wall and a poor riparian zone

and poor bank connectivity. To avoid flooding issues, the banks of the rivers have been concretised leading to reverse effects.

The management and conservation of riparian zones of the river are crucial as they are significant in maintaining water quality, flood, and soil erosion (Olokeogun, Ayanlade, & Popoola, 2020). These zones also provide a range of ecosystem functions and services, e.g., bank stabilisation and protection, water purification, reservoirs of biodiversity, wetland products, as well asrecreation and tourism. Riparian zones perform a variety of biophysical functions that can be managed to reduce the effects of land use on instream habitat and water quality. Concretisation of the riparian zone reduces its productivity and efficiency to regulate the flow of water.

PMC has proposed a river rejuvenation project for the development of these three rivers and the connecting nallahs to increase the water quality, improve green cover, and control floods. It was understood that the project will include concretisation in the riparian habitat, this may obstruct the function of the riparian habitat and promote more flooding in the area. It is recommended to restore the river to its natural state wherein the banks of the river are not developed using solid structures but are in the form of natural riparian habitat. Also, during the restoration of the banks care must be taken that the flow of stormwater entering the river should not get restricted. To maintain the quality of riparian habitat measures such as discharge of treated water as per the norms should be promoted, avoiding dumping of waste and debris, and reducing the load of runoff in the river. It is also recommended to use native floral species to promote the increase of local floral species and enhance the ecosystem of the region.

The same approach shall be applicable to all the nallahs in the city as they contribute towards the water level and quality of the river. It is also important to study the carrying capacities of the water bodies and measures to promote the capacity. Inventorisation and monitoring of all the water bodies for physio-chemical and biological health should be undertaken and measures should be adapted to maintain them.

Fig 33. Before and after phase of implementation of ABC Waters Program in transformation of Kallang River at Bishan-Ang Mo Kio Park with bioengineering technique the transformation of Kallang River at Bishan-Ang Mo Kio Park has produced meaningful and valuable outcomes
Source: Singapore National Water Agency

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Fig 34. Constructed Wetlands (Representative image)

b. Development of Constructed Wetlands

Constructed wetlands have been widely discussed in the context of NbS with a focus on stormwater management, nutrient load, pollution retention, and providing multiple ecological functions and benefits (Dhyani, Karki, & Gupta, 2018). Also, constructed wetlands on catchment hydrology indicate an overall reduction of 23 per cent in flood adjacent areas (Satish, et al., 2021).

In Pune, there are several gardens located along the bank of all three rivers, development of constructed wetlands can be promoted within the gardens, wherein stormwater from surrounding areas can be diverted to the wetlands leading to less load on the river. In cases where the gardens are of small size, pocket wetlands can be a solution. It is necessary to study the groundwater tables and carrying capacity studies for the development of constructed wetlands.

c. Increasing number and distribution of gardens

Deployment of NbS in cities through the creation of green space has been promoted as a sustainable approach to help in effectively dealing with climate change. Through this ecosystem functions like regulating the urban hydrological cycle, reducing the risk of flooding, and recharging groundwater.

6.2.3 Increasing Blue-Green Infrastructure

Pune city has undergone tremendous land-use changes, wherein most of the land is used for residential and infrastructure development purposes. Though currently there are green spaces in Pune, adequate space for increasing more green cover is not available in the core areas of the city.

Adaptive measure: Increasing green infrastructure in the city through the following NbS:

a. Green roof
b. Green Facades
c. Vertical Gardening

Fig 35. Porto's largest green roof located on Praça de Lisboa (Portugal)
Source: associação nacional de coberturas verdes

Green-roof can act as a very significant component of a sustainable urban drainage system as it can shift peak discharge by 20-30 minutes and also reduce the runoff volume. The calculation is based on assumptions that a 114 mm thick green roof can retain 55 per cent of annual average water precipitation and a 365 mm thick intensive green roof can retain 70 per cent. (Dubey & Gajraj, 2017). Additionally, hedges and green facades are other solutions for concretized walls/ metal fences wherein

Fig 36. Green facades Source: edeni stories; medium.com

the plant species are grown close to the wall, which acts as a boundary to the property or covers the complete wall. Green roofs and facades can be developed for new residential buildings, commercial parks, petrol pumps, malls, schools, hospitals municipal buildings, small shops, bus stops, and garden boundary walls.

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Fig 37. Vertical Gardening using felt pockets

To address the issues of decreasing green space in urbanised areas with a high density of the built-up area

with no space for creating gardens. Vertical gardens can promote filtration of air, reduce the UBI effect and also act as sinks for carbon sequestration.

PMC metro corridor, Sky Walkways, residential and commercial sector compound walls, and concrete garden walls are suitable locations for Blue-green infrastructure development.

An area for the development of green walls along the metro corridor has already been proposed. Here, vertical gardening can be done through the use of felt pockets.

Currently, the species used for vertical gardening are exotic and no studies have been undertaken on the usage of the native ones. Experiments can be undertaken at a pilot scale to understand the efficiency of nature species in vertical gardening.

The study can be implemented with the aim to understand the efficiency of the species at different pollution levels.

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Fig 38. Permeable footpath

6.2.4 Increasing percolation of water along roads

Roads and pavements are concretised, which decreases water percolation, leading to flooding.

Adaptive and mitigative measures: To promote the usage of plants in developing permeable surfaces for increasing water percolation and check runoff, the following NbS are proposed:

a. Permeable pavement for footpath and parking area

b. Bioswales/ Bioretention

c. Plantation on median/ multi utility zone

a. Permeable pavement for footpath and parking area

Currently, the parking area and footpaths in Pune are mostly concretised and the new street development plan proposes permeable pavement for footpaths. The same pavement should be used for parking areas as well. Permeable pavements are made of permeable asphalt, permeable concrete, concrete grid pavers, loose gravel or stone chippings, resin-bound paving, and porous plastic structures, designed to have grass growing in the pores. Permeable pavement requires an analysis of the system's retention capacity and underlying reservoir to determine its required depth.

b. Bioswales/Bioretention

Bioswales along the footpath in the street development plan have been proposed by PMC. Additionally, places like refuge islands, and medians can also be converted into bio-retention. This will promote control of run-off from the street and also enhance the local biodiversity.

c. Plantation on Median, Refuge Islands, and Multi Utility Zones

- The street development plan mentions the construction of a median along roads. Currently, the medians used in the city are also utilised for the plantation of shrub and herbs species, but the species are exotic and need to be replaced by native species and the same shall be considered in new road development plans.
- The ground of the multi-utility zone should be covered with vegetation and solid concrete paving structure should be avoided.
- Wherever plantation of trees is not possible, plantation of small herbs and shrub species should be promoted.

It is recommended to mark the blue and red lines in the drainage system and study if the planning in development has been undertaken accordingly.

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Fig 39. Current plantation on Refuge Island (left) and footpath (right) can be converted to bioswales/ bioretention and also the refuge to control run off from roads and footpath.
Source: (PMC, n.d.)

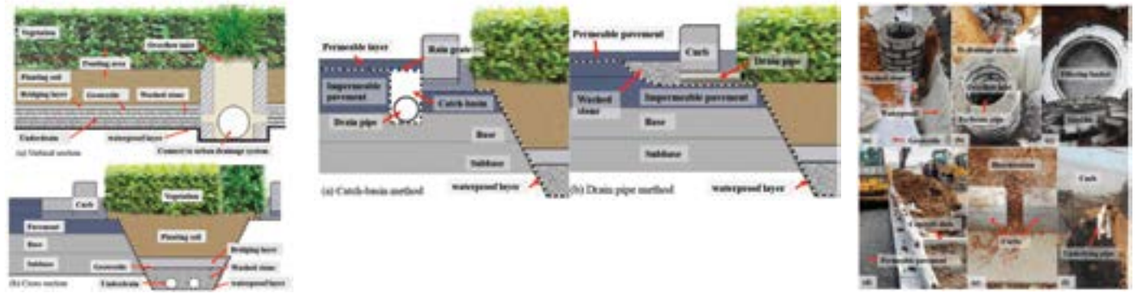

Fig 40. Street-side plantations and medians converted to bio-retention in China
Source: (Li, et al., 2018)

6.2.5 Increasing green areas to reduce the impact of extreme temperature

Lack of shade leads to prolonged exposure to heat increasing discomfort and health issues.

Adaptive Measures:

Tree plantation along the footpath and other locations is already being undertaken by the PMC. In addition to that, the following measures are suggested:

a. Pocket parks

b. Pergola along footpath/ green urban furniture

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Fig 41. Corner (Pocket) Parks

a. Pocket Parks

Pocket parks are simple parks developed in urban areas in small places. They help in lowering the temperature, can be used as shelter in extreme heat, reduce pollution, can act as corridors for faunal species, and are easily accessible to communities.

Pocket parks being small in size can be created at several locations in the city, especially in areas of dense traffic and urbanised areas that lack space for gardens.

b. Pergola along footpath/ Green urban furniture

A pergola is an outdoor feature forming a shaded passageway, walkway, or sitting area. Pergolas made up of metal structures with climbers can help in reducing the intensity of direct sunlight. Installation of such infrastructure along streets lacking space and trees can help in reducing the impact of extreme weather conditions. They can be used in multi-utility zones where a sitting place is provided.

6.2.6 Developing Local Biodiversity Strategy and Action Plan (LBSAP)

A Local Biodiversity Strategy and Action Plan (LBSAP) is a guiding strategy, complemented by specific actions and adopted by local governments to achieve optimal and realistic governance and management of biodiversity and ecosystem services. The tool helps in understanding how biodiversity and ecosystem services can be employed to address issues like storm-water regulation, mitigation of urban heat island effect, and also engage citizens. City Biodiversity Index (CBI) serves as a self-assessment tool for cities to benchmark and monitor the progress of their biodiversity conservation efforts against their baselines. It consists of 23 indicators grouped into 3 broad components viz. native biodiversity, ecosystem services, and governance and management (Avlonitis, Doll, Galt, & Mader, 2012). Additionally, PBR needs to be referred while implementing NbS with the involvement of Biodiversity Management Committee (BMC). Case study of CBI & LBSAP-PCMC

Terracon Ecotech Pvt. Ltd. prepared CBI & LBSAP for PCMC in 2019 in conformity with the guidelines of CBD, National Biodiversity Strategy and Action Plan (NBSAP) and Aichi target 2020. PCMC was found to have 30.2 per cent of its land cover as natural areas and about 166 ha of gardens and parks during its City Biodiversity Index. Primary and Secondary surveys with spatial analysis tool (GIS) was undertaken for calculations of the index. PCMC attained 58 out of 92 points.

Taxa	No. of Species
Birds	136
Butterflies	50
Freshwater fishes	47
Mammals	06
Trees	184
Shrubs	50
Herbs	182

Based upon a baseline study conducted for CBI, literature review and discussions with various government and non-governmental stakeholders, the following strategies for PCMC were finalised:

Awareness and capacity building

Streamlining the biodiversity park and creationof biodiversity information centre

Conservation of natural habitats in the city

Creation of ecological network

Management of invasive species

Development of alternative livelihood from biodiversity

Incorporating ecological perspective in development projects

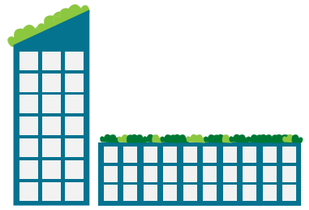
Conservation of rare and native species

Restoration of degraded ecosystem

The report sums up with action plan of each strategy described in detail with implementation areas, responsible agencies, cost estimates, and expertise required. (PCMC, 2019)

Pune city is already taking measures to reduce the sources of GHGs and several schemes and policies have been developed by the PMC to promote the use of clean energy, conserve resources and reduce pollution. The proposed NbS should be implemented in addition to the existing schemes and policies to develop efficient adaptive measures.

6.3 Policy Development



Promoting Blue-Green Infrastructure

Along with the Eco-housing policy, an additional policy should be developed that will include all tools and procedures for shaping and assessing development proposals to include green infrastructure in the plan. Town development for the current area and new villages should include procedures that apply green infrastructure in planning. The same shall be applicable for large commercial sectors like IT Parks and also industries operating in the city.

Additionally, the policy should include generating a list of floral species that should be included in the development of green infrastructure. The floral species shall be native to the region and should consider not only trees but also, herbs, shrubs, and climber species. To incorporate the policy efficiently, tax benefits to the citizens can be provided.

Financing NbS in the City

Green infrastructure needs to be funded/ subsidised as part of the city's core infrastructure with long-term maintenance along with other services and should have a yearly budget allocation. Since Pune is developing as an economic sector with several top-notch commercial brands being set up in Pune and a few already established in the city, funding can be initiated from these private sector corporates. These corporates can be asked to fund and incorporate ecosystem conservation and climate resilience Nature-based Strategies as a price for benefiting from Ecosystem services. For the same purpose, it is necessary to undertake an economic valuation of resources.

6.4 Awareness and Behavioural Changes

Up to two-thirds of the total global emission is linked with both direct and indirect forms of human consumption (Williamson, Satre-Meloy, Velasco, & Green, 2018). Awareness about climate change phenomena and their impacts can help in significant behavioural changes, especially when aware of climate change impacts on health (Indrani & Purba, 2010). Communities most vulnerable to climate change should be made aware of the drivers leading to such events. Awareness activities should focus on adaptive and mitigative measures to tackle climate change; engaging in climate resilience approaches and development of policies and their appropriate utilisation.

Awareness activities can be undertaken through the following approaches:

- Rallies, workshops, training courses, camps
- Audio and video
- Meetings, exhibitions, cultural and recreational events

The involvement of activities addressing climate change issues through NbS can be included as a part of the curriculum. Education related to the environment can help in developing a sense of responsibility among students. The city is dotted with several academic institutes, involvement of the students for data collection purposes and in experimenting with newly proposed ideas within the city can add value to developing a climate-resilient city.

7. INSTITUTIONAL CAPACITY BUILDING

Nature-based solutions are gaining popularity of late due to the increasing need for climate resilience in the city. Successful implementation of NbS in development plans requires a rigid system to obtain the proposed objectives. (Land, 2000). Capacity-building activities must focus on equipping individuals, organisations, and communities with abilities, resources, and opportunities to understand the applicability of NbS in tackling climate change issues.

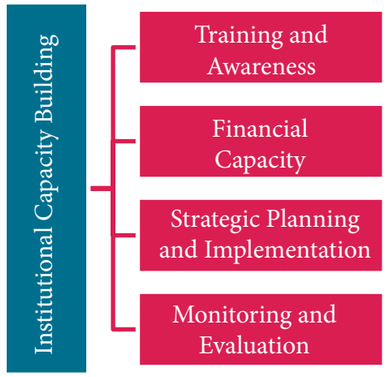


Fig 42. Components of Institutional Capacity Building

7.1 Training and Awareness

To develop a feeling of ownership, capacity-building activities will focus on targeting all stakeholders that are related to the development and execution of the projects.

The stakeholders for the training will include but are not limited to:

- Decision and Policymakers
- On-field working staff
- Maintenance and monitoring staff
- Communities
- NGOs
- Educational and research Institutes

Modules developed for the training should cover the following aspects of NbS and climate resilience:

- The current climate scenario in Pune and impacts associated
- Nature-based solutions and how they can contribute to tackling climate change impacts
- Case studies of successful implementations of NbS
- Role of individuals, organisations, and communities contribute to NbS
- Environmental, social and economic benefits of NbS
- Available policies, their benefits, and techniques to avail them
- NbS solutions combined with existing development and schemes
- Governance strategies for NbS
- Maintenance and monitoring of NbS

The training can be undertaken through workplace learning, e-learning, peer-to-peer learning, communities of practice, mentoring, and the provision of material for self-directed learning.

7.2 Financial Capacity

Nature-based Solutions restore and utilize ecosystems to address challenges such as climate change. Compared to engineering techniques, NbS approach tends to be economical and delivers multiple additional benefits for people and nature.

Leveraging nature-based solutions has been recognised as a crucial aid in combating climate change globally.

Fig 43. Training and Awareness Process

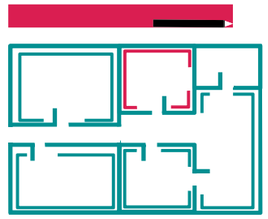
Subsequently, many funds have been mobilised on that front, especially for developing countries. Technical and financial assistance can be received through these grants. The state and regional level policies are drawn from national plans. Benefits such as tax exemptions and subsidies can be accessed through these funds as well.

7.3 Strategic Planning and Implementation

Strategic planning and implementation define the future performance of the proposed NbS and hence is a crucial step in overall project development. Following are the components of strategic planning and implementation:

a. Site Selection

Site selection is necessary to limit the geographical boundaries as the project will be implemented in phases and site selection for each phase will depend on factors like resources, time availability, season, and delivery deadlines, among others. The site selection should be done through a feasibility study with the involvement of stakeholders and on the basis of a thorough understanding of external players, such as policies, economic, political, and environmental aspects that will impact the implementation process.



b. Designing Implementation Plan

The implementation plan requires human resources and infrastructure planning for the development and maintenance phase. This stage also includes estimating the budget and preparation of proposals for internal implementation or selection of an agency.

c. Selection of Implementation Agency

Implementation agencies can be selected directly or through a tendering process. It is necessary to scrutinise the capability of the implementation agency on the basis of their capability to form the proposed task considering the expertise, experience and projected cost of delivery. The agency should possess a sound understanding of the subject through a research perspective than just a technical one.

d. Supervision of Implementation

During the implementation phase, regular monitoring is required to improve project performance. This can be done through regular site visits, understanding the proposed timeline, taking regular updates, and maintenance of data.

The roles and responsibilities of stakeholders in the implementation phase and monitoring of the project are detailed in Table 8.

Table 8: Roles and Responsibilities of Stakeholders in NbS Implementation and Monitoring

S. no.	Intervention	Responsible Department(s)	Implementation Agency/ Department(s)	Maintenance and Monitoring Department(s)
1	Restoration of Forest and Hilly Areas	• Forest Department • Garden Department • Solid Waste Department • Encroachment Department	• Forest Department • Garden Department	• Forest Department
2	Restoration of Waterbodies	• Environment Department • Building Construction Department • Solid Waste Department • Drainage Department • Encroachment Department	• External agency with expertise in the environmental sector, biodiversity, architecture designs, and civil work	• Environment Department
3	Green Roof for Government Property	• Building Construction Department	• External agency with expertise in biodiversity sector and civil work	• Building Construction Department • PMC gardeners
4	Green Roof for Private Property	• Private Builders		• Gardeners • Private owners
5	Green facades for Government Property	• Garden Department • Building Construction Department	• External agency with expertise in biodiversity sector and civil work	• Construction Department • PMC gardeners
	Green facades for Private Property	• Private Builders		• Gardeners • Private owners
6	Gardens	• Garden Department • Tree Department • Building Construction Department	• Garden Department • External agency with expertise in the environmental sector, biodiversity sector, architecture designs, and civil work	• Garden Department
7	City Corner Parks	• Garden Department • Tree Department • Building Construction Department • Encroachment Department	• Garden Department • External agency with expertise in the environmental sector, biodiversity sector, architecture designs and civil work	• Garden Department
8	Plantation along medians and footpath	• Tree Department • Road Department	• Garden Department • External agency with expertise in the environmental sector, biodiversity sector, architecture designs and civil work	• Road Department
9	Vertical Gardening	• Garden Department • Pune Metro Department (Metro specific) • Road Department (Bridges and along the roadside)	• Garden Department • External agency with expertise in the environmental sector, biodiversity sector, architecture designs and civil work	• Pune Metro Department (Metro specific) • Road Department (Bridges and along the roadside)
10	Constructed Wetlands	• Garden Department • Environment Department • Building Construction Department • Drainage Department	• Garden Department • External agency with expertise in the environmental sector, biodiversity sector, architecture designs and civil work	• Environment Department • Building Construction Department
11	Bio swales/ Bio retention	• Garden Department • Road Department • Drainage Department	• Garden Department • External agency with expertise in the environmental sector, biodiversity sector, architecture designs and civil work	• Environment Department • Building Construction Department
12	Paved footpath/ Park area	• Road Department • Drainage Department	• External agency with expertise in biodiversity sector, architecture designs and civil work	• Road Department

7.4 Monitoring

Monitoring is important to reveal the wider benefits and impacts of the interventions. No single method exists to monitor the performance of NBS but tools and technologies developed for monitoring individual parameters or a complete impact can be employed for measuring the impact (Prashant, 2021). The monitoring of the project can be undertaken through the use of indicators, a list of the same is detailed in Table 9.

Table 9: Indicators for Monitoring NbS Interventions

Category	Indicator	Method
Environment	Local micro-temperature at locations where interventions are proposed	Daily or weekly monitoring
	Land Surface Temperature at locations where interventions are proposed	Daily or weekly monitoring / GIS mapping
	Reduction in level of GHGs	Monitoring data
	Reduction in pollution level	Assessing the level of pollution at different stations
	Green Cover	LULC mapping
	Total surface area of wetlands	LULC mapping
	Total surface area of restored wetlands	LULC mapping
	Water quality	Analysis of physicochemical and biological parameters
	Extreme climate events	Monitoring IMD data
	Reduction in flood events	Data management of yearly flood events
	Reduction in landslide events	Data management of yearly landslide events
	Thermal comfort score	Survey
Social	Reduced diseases due to flood	Data from the Sanitation department
	Increased use of green policies	Number of policies availed
	Responsible community behavior	Behavioural changes
Economical	Increase in green jobs	Data management and Survey
	Adoption of green policies for NbS	Policy assessment

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8. RECOMMENDATION AND WAY FORWARD

City profiling of Pune's biophysical state was undertaken through primary and secondary data collection. Pune city is seeing intensifying competition for urban space due to the ongoing urbanisation under a changing climate condition. Pune city is also prone to Urban

Heat Island effect. The changing climate has led to an increase in climate change events like flash floods, heat waves and flood-induced landslides. These events have increased in the city and have adversely impacted socio-economic conditions. Based on the assessments several interventions have been proposed for achieving climate resilience in the city through the implementation of NbS.

The city has already adopted several plans for mitigating climate change but is lacking adaptive measures. Hence, the implementation of Nature-based Solutions can help in promoting adaptive measures in the city. Suitable NbS are proposed by taking into account the current and future environmental and socio-economic challenges.

Pune city is already rich in natural resources and hence, the restoration and conservation of the existing green and blue resources within the city are considered the foremost solution for the development of climate resilience in the city. Urbanization has decreased green spaces in the city potentially creating challenges for recreating new green space development. Green infrastructures such as green roofs, green facades/ hedges, vertical gardens, corner parks, and pergolas can increase the green cover in the city and contribute to regulating temperature at the micro-level. In built-up areas waterlogging issues can be addressed by creating bio-swales, bio-retention, permeable pavements, etc.

For successful implementation of the NbS in the city to significantly contribute to climate resilience, it is necessary to adopt approaches that develop strong community ownership and participation. Along with the existing policies in the city, for example, increasing electricity through solar energy, use of e-vehicles, footpath development, rainwater harvesting, and green cover policy, it is recommended to integrate NbS along with these existing policies wherein blue-green infrastructure development is promoted and required financing is projected for providing direct and indirect benefits to the citizens.

The initiative can be promoted through developing behavioural changes in citizens by educating them on actions required for the conservation of ecosystems and highlighting their importance in climate resilience and other benefits. Establishing a database on climate-related hazards and vulnerabilities will help in deriving a better understanding of their influence on the city. Data on current resources, hazards, and the state of the ecosystem should be made available through studies and the involvement of stakeholders in a usable format. Additionally, capacity building of the stakeholders should be undertaken for developing their expertise in the phases of implementation, maintenance and monitoring.

WAY FORWARD:

Mapping and Inventorisation of terrestrial and aquatic habitat is important for the city's planning

Identification of stakeholders for implementation of NbS

Developing modules for capacity building

Identification of locations with extreme built-up areas and heavy pollution load

Mapping of infrastructure for developing green infrastructure

Biodiversity assessment of the region to map locations with exotic species coverage and developing a strategic plan

Economic valuation of ecosystem services to evaluate the benefits provided by biodiversity

Awareness among citizens regarding the importance of ecosystems, waste management, and climate change

ANNEXURE

ANNEXURE 1: METHODOLOGY FOR GIS MAPPING

Land Use Land Cover (LULC) Map:

LULC map was developed for the years 2013 and 2020 to assess the factors contributing to the reduction of the green spaces in the city. Landsat 8 satellite imagery was procured for November 2013 and November 2020 from the UGGS Earth Explorer website. Before processing the image removal of interference such as cloud, haze, and aerosols was done in QGIS software using a semi-automatic plugin. A false-colour composite band was created to obtain the LULC classification map using the same plugin (Fig. 45).

Resource Map:

Google Earth Engine was used to mark prominent natural resources like forests/ hills, gardens/parks, dense vegetation, rivers, and lakes. Further, the file was developed in QGIS software for which it was converted from kml (Keyhole Markup Language) to shape format. Different representative symbols for each type of resource were placed using 'Symbology tool' in the same software and exported using 'Print Composer tool' to get the final map.

Drainage Pattern Map:

Drainage map was developed using ALOS PALSAR DEM (Digital elevation model), which was downloaded from JAXA 3D website. A gap-filling procedure was done in ArcGIS software to remove any gaps present in DEM. To extract the drainage layer from DEM, a terrain processing tool was utilised. Pour points were marked using the drainage layer and with reference to these points, the catchment areas were delineated using the watershed tool in the software.

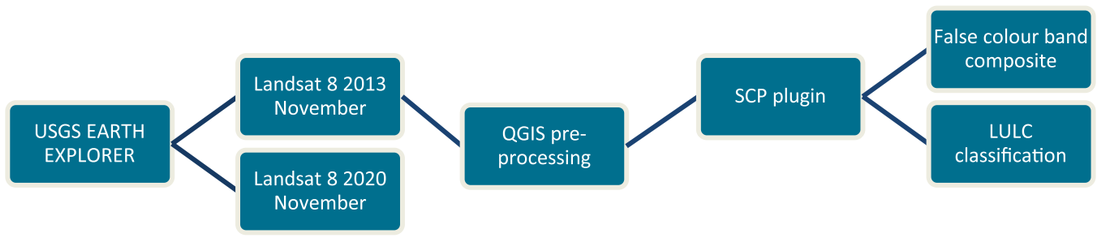

Fig 44. Process for developing LULC Map

ANNEXURE 2: LIST OF STAKEHOLDERS

S. no.	Department/ Organisation
1	Environment Officer, PMC
2	Garden Department, PMC
3	Water Supply Department, PMC
4	Disaster Management Department, PMC
5	Solid Waste Department, PMC
6	Building and Construction Department, PMC
7	Groundwater Directorate of Surveys & Development Agency
8	Deputy Conservator of Forest Department
9	Regional Forest Officer, Bhamburda
10	Regional Forest Officer, Wanaworie
11	Green Hills NGO
12	Samuchit Enviro Tech.
13	Cycle for Pune
14	PhD. student

ANNEXURE 3: LIST OF SPECIES FOR PLANTATION

List of Native Tree Species for Plantations:

SN	Botanical name	Common English Name	Common Marathi Name	Nature
1	*Aegle marmelos*	Indian Bael	Bael	Semi-Deciduous
2	*Alstonia scholaris*	Devils tree	Satvin	Evergreen
3	*Artocarpus heterophyllus*	Jackfruit	Phanas	Evergreen
4	*Azadirachta indica*	Margosa tree	Kadulimb	Evergreen
5	*Bauhinia variegata*	Variegated bauhinia	Kanchan	Deciduous
6	*Bauhinia racemosa*	Camel-foot tree	Kachnar	Deciduous
7	*Butea monosperma*	Flame of the forest	Palasha	Deciduous
8	*Caryota urens*	Fishtail palm	Beherli mad	Evergreen
9	*Cassia fistula*	Indian Laburnum	Bahava	Deciduous
10	*Cordia dichotoma*	Indian Cherry	Bhokar	Semi-Deciduous
11	*Dalbergia latifolia*	Indian rose wood	Sisvi	Evergreen
12	*Dalbergia sissoo*	North Indian rose wood	Shisham	Evergreen
13	*Diospyros melanoxylon*	Indian Ebony	Tendu patta	Deciduous
14	*Ficus benghalensis*	Banyan tree	Vad	Evergreen
16	*Ficus racemosa*	Cluster fig	Goolar	Evergreen
17	*Ficus religiosa*	Bodhi tree	Bodhi tree	Semi-Deciduous
18	*Grewia tiliifolia*	NA	Dhaman	Semi-Deciduous
19	*Haldina cordifolia*	Haldu	Haldu	Deciduous
20	*Holoptelea integrefolia*	Indian Elm	Vavla	Evergreen
21	*Lagerstroemia speciosa*	Queen flower	Jarul	Deciduous
22	*Madhuca indica*	Indian butter tree	Mahua	Semi-Deciduous
23	*Mangifera indica*	Mango	Amba	Evergreen
24	*Mimusops elengii*	Spanish cherry	Bakul	Evergreen
25	*Mitragyna parvifolia*	True Kadamb	Kalamb	Deciduous
26	*Neolamarckia cadamba*	NA	Kadamba	Semi-Deciduous
27	*Nyctanthes arbor-tristis*	Night-flowering Jasmine	Parijaat	Evergreen
28	*Phyllanthus emblica*	Indian goose berry	Avala	Evergreen
29	*Pongamia pinnata*	Indian Beach Tree	Karanj	Evergreen
30	*Saraca asoca*	Sorrowless tree	Sita ashok	Evergreen
31	*Sesbania grandiflora*	Weat Indian pea	Agasthi	Deciduous
32	*Syzygium cumini*	Java plum	Jambhun	Evergreen
33	*Terminalia arjuna*	Arjun tree	Arjuna	Deciduous
34	*Terminalia bellirica*	Bastard myrobalan	Beheda	Deciduous
35	*Terminalia catappa*	Indian Almond	Deshi Badam	Deciduous
36	*Thespesia populnea*	Indian Tulip tree	Bhend	Evergreen

Source: (Rahangdale & Rahangdale, 2017; Mirza, Seasonal Plant Diversity of Gautala Reserve Forest, District Aurangabad, 2021; Bhalerao, Verma, Didwana, & Teli, 2014; Bhosale, Ghule, Aundhe, & Jagtap, 2009; Rahangdale, Bhise, Rahangdale, & Kambhar, 2013; Mokat & Kharat, 2018).

List of Climbers/ Twiners for Facades:

CLIMBERS/ TWINERS FOR GREEN FACADES			
SN	**Botanical Name**	**Local Name**	**Type**
1	*Clitoria ternatea*	Gokarna	Flowering ornamental
2	*Calycopteris floribunda*	Ukshi	Flowering ornamental
3	*Cissus quadrangularis*	Hadjodi	Foliage ornamental
4	*Cocculus hirsutus*	Vasan vel	Foliage ornamental
5	*Combretum albidum*	Pahad vel	Foliage ornamental
6	*Combretum indicum*	Madhumalti	Flowering ornamental
7	*Dregea volubilis*	NA	Foliage ornamental
8	*Ficus repens*	Creeping ficus	Foliage ornamental
9	*Gymnema sylvestre*	Madhunashini/ Gudmar	Foliage ornamental
10	*Jasminum grandiflorum*	Chameli	Flowering ornamental
11	*Jasminum officinale*	Jai	Flowering ornamental
12	*Piper betle*	Pan vel	Foliage ornamental
13	*Piper nigrum*	Kalimiri	Foliage ornamental
14	*Tinospora cordifolia*	Gulvel	Foliage ornamental
15	*Tylophora asthmatica*	Dam-ki-bel	Foliage ornamental

Source: (Rahangdale, Bhise, Rahangdale, & Kambhar, 2013; Mirza & Patil, 2020; Bhosale, Ghule, Aundhe, & Jagtap, 2009; Rahangdale, Bhise, Rahangdale, & Kambhar, 2013; Rathi & Rathi, 2020; Goli, Goli, Vaddi, Pal, & Narayanam, 2018; Pradhan, Suri, Pradhan, & Biswasroy, 2013; Government of Karnataka, 2010; Plant of the World Online, n.d.)

List of Herbs for Roof top Gardening:

SN	Habit	Scientific name	Nursery name	Origin
1	Shrub	*Ocimum sanctum*	Tulsi	Native
2	Shrub	*Centilla asiatica*	Brahmi	Native
3	Shrub	*Bacoppa monerii*	Neer Brahmi	Native
4	Shrub	*Ocimum basilicum*	Sabja	Native
5	Shrub	*Withania somnifera*	Ashwaagandha	Native
6	Shrub	*Cymbopogan sps.*	Citronella grass	Native
7	Shrub	*Cymbopogan citratus*	Lemon grass	Native
8	Shrub	*Chrysopogon zizanioides*	Vetiver grass	Native
9	Shrub	*Ocimum aromaticum*	Ajwain	Native
10	Shrub	*Elettaria cardamomum*	Velchi	Native
11	Shrub	*Plumbago zeylanica*	White Plumbago	Native
12	Shrub	*Plumbago capensis*	Blue Plumbago	Native

Source: (Government of Karnataka, 2010; Rahangdale & Rahangdale, 2017; Patil, Mali, & Bhadane, 2008; Mirza & Patil, 2020).

List of Shrubs for Roof-top Gardening:

SN	Habit	Botanical name	Nursery Name	Origin
1	Herb	*Ocimum sanctum*	Tulsi	Native
2	Herb	*Centella asiatica*	Brahmi	Native
3	Herb	*Bacopa monnieri*	Neer Brahmi	Native
4	Herb	*Ocimum basilicum*	Sabja	Native
5	Herb	*Withania somnifera*	Ashwagandha	Native
6	Herb	*Cymbopogan sps.*	Citronella grass	Native
7	Herb	*Cymbopogan citratus*	Lemon grass	Native
8	Herb	*Chrysopogon zizanioides*	Vetiver grass	Native
9	Herb	*Trachyspermum ammi*	Ajwain	Native

Source: (Government of Karnataka, 2010; Rahangdale & Rahangdale, 2017; Patil, Mali, & Bhadane, 2008; Kumar & Jnanesha, 2017; Bhosale, Ghule, Aundhe, & Jagtap, 2009; Desale, Bhamare, Sawant, Patil, & Kamble, 2013)

Plants for Butterfly Garden:

Sr. No.	Scientific name	Habit	Common name	English common name	Category	Origin	Season	Fragrance - high	Fragrance - Mild	Nectar plant
1	*Artabotrys hexapetalus*	Strangling shrub	Hari - champa	Ylang-ylang vine	Flowering	Native	April - July	✓	✓	✓
2	*Clitorea ternatea*	Climber/ twinner	Gokarna	Blue pea	Flowering	Native	Year round	–		
3	*Combretum indicum*	Climber/ twinner	Madhumalti	Rangoon creeper	Flowering	Native	Throughout the year	✓	–	✓
5	*Jasminum multiflorum*	Strangling shrub	Kund	Shrubby jasmine	Flowering	Native	December - February	✓	–	✓
6	*Magnolia champaca*	Tree	swarna		Flowering	Native	June - September	✓	–	✓
7	*Murraya paniculata*	Shrub	Chinese Box	Kamini	Flowering	Native	Throughout the years	✓	–	✓
8	*Nerium oleander*	Shrub	Kanher	Oleander	Flowering	Native	Throughout the year	✓	–	✓
9	*Nyctanthes arbo-tristis*	Tree	Parijat	Tree of sorrow, Queen of night	Flowering	Native	July - October	✓	–	✓
10	*Passiflora edulis*	Climber/ twinner	Krushna kamal	Passion flower	Flowering	Native	July - August	✓	–	✓
11	*Thunbergia grandiflora*	Climber/ twinner	-	Clockvine	Flowering	Native	February -	–	✓	–
12	*Vallaris solanacea*	Climber/ twinner	Dudh-ki-bel	Bread flower	Flowering	Native	–	✓	–	✓
13	*Vitex negundo*	Shrub	Nirgudi	Indian chaste tree	Flowering	Native	April - August	–	✓	✓

Source: (Rahangdale, Bhise, Rahangdale, & Kambhar, 2013; Mirza & Patil, 2020; Suthari, Sreeramulu, Omkar, & Raju, 2014; Desale, Bhamare, Sawant, Patil, & Kamble, 2013; Rajashekharan, 2007; Gaikwad, Gore, & Garad, 2014)

ANNEXURE 4: POTENTIAL SOURCES OF FUNDS

International

Green Climate Fund

European Commission Funds

Asian Development Bank

Climate Policy Initiative (CPI)

International Fund for Agricultural Development

Subnational Climate Finance initiative (SCF)

Adaptation Fund

National

National Clean Energy and Environment Fund

Compensatory Afforestation Fund

Green India Mission

The Mahatma Gandhi National

Rural Employment Guarantee Act (MGNREGS)

National Bank for Agriculture and Rural Development

Regional

PMRDA

PMC

Private Sector (CSR Funds)

- **Green Climate Fund:** GCF was created to support the efforts of developing countries in responding to the challenge of climate change. GCF can structure its financial support through a flexible combination of grant, concessional debt, guarantees or equity instruments to leverage blended finance and crowd-in private investment for climate action in developing countries.
- **European Commission Funds:** Under Horizon 2020 and Horizon Europe, the European Commission funds research and innovation projects that propose NbS to fight climate change and biodiversity loss.
- **The Asian Development Bank (ADB):** The Asian Development Bank (ADB) assists its members and partners by providing loans, technical assistance, grants, and equity investments to promote social and economic development.
- **International Fund for Agricultural Development:** IFAD is both a specialised agency of the United Nations and an international financial institution (IFI), established to mobilise resources for agriculture and rural development in developing countries.
- **CSR Funds:** Most of the investments by the private sector are through CSR funds. Non-CSR funds have been used for investing in reducing dependency on fossil fuels by shifting to solar and wind power for their operations. Many firms have initiated measures like groundwater recharge and water monitoring systems to reduce their water footprint throughout their operational systems chain. Targets in resource efficiency, and net-zero footprints have brought about such investments observed in private companies.
- **Other:** Instruments such as equity financing used for funding solar power projects under the National Solar Mission and Indian rupee-dominated Green Bonds like the one used by NTPC are also fast becoming mainstream instruments. Private companies like Tata Cleantech, etc. have also raised money through issuing green bonds or obtaining concessional loans from banks to endow their environmental projects.
  - » Many NbS case studies in India are funded through grants from state and national governments, grants and loans from public sector institutions like NABARD and IREDA and grants and low-cost loans from international development finance institutions (DFIs) like USAID, World Bank, KFW, JICA, GEF etc. In the case of private sector financing, a bulk of the forestry and water-related NbS were funded through CSR grants. Non-CSR funds from corporations have mostly contributed to energy security through renewable power generation.

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