Working paper:

Nature Based Solutions for Heat Stress Management in cities

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Contents

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Abstract

Integrated Research and Action for Development (IRADe) in association with Urban Local bodies of Bhubaneswar, Delhi and Rajkot is engaged in developing Climate Adaptive Heat Action Plans for three Indian cities. Nature-based solutions (NBS) for heat stress management can become an integral component of the Heat Action plans and is now being proposed for the three cities. NBS serve multiple purposes including climate adaptation and pollution mitigation. In the urban areas of tropical countries like India, NBS solutions like blue and green infrastructure offer cost-effective solution to reduce the impact of heat waves and urban heat island effect. Studies have proven[1] that green infrastructure reduces temperature compared to open and constructed areas, with green facades have mitigating effects of 5–10 percent on the physiologically equivalent temperature and trees up to 13 percent. Green roofs are known to reduce temperature by 1.70 degree Celsius[2] and a hybrid green-blue roof in the range of 5 to 9 degree Celsius on rooftops. Urban waterbodies can improve human comfort in littoral zones in high temperature periods of hot summer days. Artificial water facilities such as ponds, waterfall, and fountains can help reduce temperature on the leeward side[3]. Incorporating Heat-adaptive planning into city infrastructure plans will allow natural airflow around built infrastructures, thereby enabling heat stress mitigation at no extra cost. In tropical regions, a wind velocity of 1–1.5 m/s in a climate-sensitive built environment can create a cooling effect equivalent to a 2 degree Celsius drop in temperature[4]. Strategic design of urban greenery and blue infrastructure can effectively enhance the urban environment and outdoor thermal comfort in Indian cities that suffer from heat stress. A heat stress vulnerability hotspot mapping has already been prepared for the three cities by IRADe and NBS framework will be devised for these cities. It will be communicated to the local and national level policy makers. Implementation of NBS through the heat action framework will help achieve several Sustainable Development Goals of the United Nations such as health and wellbeing [3], sustainable cities and communities [11], climate action [13], and poverty reduction [1].

Keywords

Nature-based solutions (NBS), heat stress management, cost-effective solution, blue and green infrastructure, hotspot mapping

[1] "Evaluating the cooling effects of green infrastructure: A systematic review of methods, indicators and data sources", *Koc et.al, 2018*

[2] Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy, Herath et al, 2017

[3]. Novel water facilities for creation of comfortable urban micrometeorology, Nishimura et al

[4] Urban heat island and wind flow characteristics of a tropical city, Rajagopalan et al

1. Introduction

IPCC's Fifth Assessment Report[5] indicates that the last 50 years have witnessed a hike in the frequency of hot days, nights, and heat waves globally. Between 1979 and 2017, the frequency of instances of wet-bulb temperatures at or above 27°C (81°F) has more than doubled. Future projections of temperature indicate a steady increase across the three periods (the 2030s, 2050s, 2080s), with anomalies reaching 4-5°C for high emission scenarios by 2080. *Heat waves:* Heat wave is a "silent disaster" and adversely affects the health, livelihood and productivity of people. Heat waves result in mortality of people, agricultural losses, and increases many risks such as health-related risks, power shortage and accidents, among others. Health impacts of heat are more severe in urban areas, where residents are exposed to higher and nocturnally sustained temperatures due to the Urban Heat Island (UHI) effect (Climate Council of Australia, 2016). According to the *Global Climate Risk Index 2020*[6], countries in South Asia are among the most vulnerable globally to the impacts of climate change. Climate change induced heatwaves pose severe risk to the highly populated cities that are already facing increased Urban Heat Island induced heat stress. As noted in the *Fourth IPCC Assessment on Climate Change (IPCC, 2007)*[7], heat waves may become more frequent, intense and of longer duration because of anthropogenically forced climate change. Heat stress induced deaths in 2100 are estimated to be about 85 per 100,000 globally[8] and above 100 per 100,000 in lower-income groups.

Heat Waves in India: On World Environment Day, June, 2018, *State Environment Report, Government of India,* stated *-India is facing its hottest decade, water & air pollution are up and trash Generation has doubled* [9]. The year 2019 was the seventh warmest year on record since nation-wide meteorological records commenced in 1901. The years 2006 – 2016 has been recorded as the hottest Decade in India, leading to almost $4.3 million loss due to extreme weather events between 2005 to 2014. In 2020, Churu in Rajasthan bagged the record of being the hottest place in not just India, but the entire world, on 26th May. On the same day, 10 of the 15 world's hottest places were in India, including Delhi NCT which recorded its hottest day of May in 18 years at 47.6 ºC. Parts of North Western, Northern and Central plains experienced severe heat waves during the month of May. Data from weather stations between 1979 and 2017 reveal that the extreme combinations of heat and humidity doubled in much of India.

Need for Adaptation and Mitigation Efforts: India has lost as many as 22,223 lives to heat waves between 1992 and 2015. Health impacts of heat are more severe in urban areas, where residents are exposed to higher temperatures. The people in vulnerable communities like slums are particularly vulnerable to heat morbidity and mortality. Over 65 million people live in slums in India (MoHUA).

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[5]IPCC (fifth assessment report of working Group I, 2014[#])
[6]Global Climate Risk Index 2020, Germanwatch
[7] IPCC (2007) Climate Change 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, New York, Cambridge University Press
[8]Climate Change and Heat-Induced Mortality in India, Climate Impact Lab 2019
[9] Hindustan Time, New Delhi Metro 5th June, 2018

Vulnerable communities, like those in slums, are adversely affected by the summer heat waves, especially through induction of heat through the roof. Moreover, Electricity demand in cities increases by 2–4% for each 1°C increase in temperature. India is projected to see 10% increase in death rates due to climate change (Climate Impact Lab, 2019). In some parts, summer temperatures are projected to increase by 3°C–6°C at a scenario of 4°C global warming and by 2°C at a scenario of 2°C global warming by 2100[10]. Therefore, there is a need for intervention that addresses heat health in congested urban areas.

Year	Death Record
2010	1274
2011	798
2012	1247
2013	1216
2014	1677
2015	2422
2016	1111
2017	220
2018	25
2019	94 (till 16.6.19)
	210 (30.6.19)-MHFW

Table: Heatwave deaths in India. NDMA, Ministry of Home Affairs, GoI, 2019

2. Nature based solutions

Nature-based Solutions (NBS) are defined by IUCN[11] 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". NBS deliver multiple benefits, including the reduction of climate risks—like the mitigation of urban heat islands (UHI) effect. Besides their direct impact on reducing heat stress, NBS can also help address other key challenges faced by city authorities. Studies have shown that NBS, in the medium to long-term, can cause an urban compaction effect due to attraction of residents from peripheral areas to areas surrounding attractive NBS, thus reducing the effects of urban heating and urban sprawl[12].

[10] https://www.fortuneindia.com/polemicist/not-war-but-climate-change-might-devastate-south-asia/103297
[11] IUCN, https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions
[12] Short and medium- to long-term impacts of nature-based solutions on urban heat, *Sustainable Cities and Society*. https://doi.org/10.1016/j.scs.2020.102122.

Nature based solutions within urban areas helps in

- Increasing the well-being of urban populations
- Providing multifunctional services, including micro-climate regulation
- Improving energy efficiency of buildings
- Mitigating carbon emissions

Growing importance of NBS: NBS such as green infrastructure are being increasingly acknowledged by academicians, scientists, and urban planners as they are cost-effective and aid in climate adaptation and mitigation13. NBS allows city authorities to help ecosystems to adapt to and mitigate the impacts of climate change14. NBS is gaining momentum in European cities over the past years as viable solutions to urban climate challenges15. The Paris Climate Agreement, for example, clearly identifies the role of nature to address the adverse impacts of climate change within the cities. In total, more than 65% of the parties of the Paris Agreement have included NBS as a mechanism to meet their NDC commitments. A total of about 103 countries have highlighted at least one or more type of NBS actions for achieving adaptation under their respective NDC[16].

Types of NBS: The most commonly used Nature Based Solutions for heat adaptation in urban areas can be classified into

- Green Infrastructure (Use of greenery)
- Blue Infrastructure (Use of water bodies)
- Grey Infrastructure (Use of Built architecture)

2.1 Green infrastructure:

Among the various NBS available, Urban green infrastructure (UGI) has been increasingly promoted as a key measure to mitigate heat stress in cities caused by the urban heat island effect and climate

City of Milan, Italy: The city's strategic environmental plan, recognizes 'green infrastructure' as the best way to achieve environmental targets, promote social development and improve social welfare. The plan provides guidelines to the different municipalities for the management and creation of ecosystems and outlines the funding mechanisms. Vertical garden and Green Urban Areas are two key NBS strategies that the city has adopted. Studies showed that the Urban parks had a definitive cooling effect in areas surrounding the Urban Green Areas. It also showed that the vertical garden in two towers was capable of reducing particulate concentration.

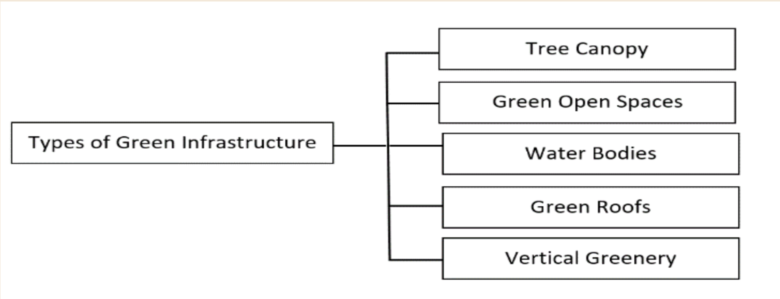
Glasgow, Scotland: Glasgow has increased its green areas by 20%. Consequently, the city is poised to cut its urban heat island effect in half by 2050.

[13] Nature-based Solutions for Resilient Ecosystems and Societies, DOI: 10.1007/978-981-15-4712-6
[14] A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas, https://doi.org/10.1016/j.envsci.2017.07.008
[15] Seven lessons for planning nature-based solutions in cities, https://doi.org/10.1016/j.envsci.2018.12.033

[16] Seddon et al 2020, Global Recognition of the Importance of Nature-Based Solutions to Climate Change Impacts.

change impacts, including climate variability and extremes[17]. Green infrastructure is one of most cost effective solution to reduce the impact of heat waves and reducing urban heat island effect in the cities. Green infrastructure solutions include creating and managing green spaces. Such solutions can be adopted at urban and peri-urban spaces where in policy guidelines for maintaining minimum vegetation cover in the cities as well as maintaining them are required to be created and implemented. It has been scientifically proven[18] that such solutions reduce temperature compared to the ambient air temperature compared to open and constructed areas. Green infrastructure especially the trees act as temperature sinks and create cooling effects. Studies also confirm the extension of greenspace cooling into surrounding built-up areas, thereby reducing the UHI of areas that are adjacent to greenspaces. [19] Strategic design of urban greenery can thus effectively enhance the urban environment and outdoor thermal comfort in tropical countries such as India.[20]

Types of Green Infrastructure[21]



Vertical Greenery: Vertical greenery, especially green facades, act as an efficient UHI mitigation pathway for dense urban areas which offer little to no room for additional sprawling green cover on the ground. Vertical greenery not only prevents heat related morbidity and mortality in the day time, but also reduce urban heat island effect during nocturnal hours. Green facades have mitigating effects of 5%–10% on the physiologically equivalent temperature (PET), a universal index for the biometeorological assessment of the thermal environment.[22] In peak tropical temperatures, greenfacades were recorded to reduce temperature by 1.70 ◦C approximately[23]. Vertical greenery

[17] Using green infrastructure for urban climate-proofing: An evaluation of heat mitigation measures at the micro-scale, Zolch et al, 2016.

[18] "Evaluating the cooling effects of green infrastructure: A systematic review of methods, indicators and data sources", *Koc et.al, 2018*

[19] The cooling effect of green infrastructure on surrounding built environments in a sub-tropical climate: a case study in Taipei metropolis, Shih

[20] Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy, Herath et al, 2017

[21] Same as 1

[22] Using green infrastructure for urban climate-proofing: An evaluation of heat mitigation measures at the micro-scale, Zolch et al

[23] Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy, Herath et al, 2017

systems were highly effective on external wall surface temperature reductions in the range of 1.61 °C–1.72 °C[24].

Singapore government has introduced the Landscaping for Urban Spaces and High-Rises (LUSH) Programme. The program aims to make Singapore a green city and has been widely acknowledged as one of the most innovative Urban Greenery Project. Here are some salient features of the program

- To create vertical greenery and extensive green roofs in the city buildings
- To support rooftop urban farming through the Landscape Replacement scheme
- To encourage rooftops to be used for sustainability-related features; and
- To set Green Plot Ratio standards for private developments to safeguard sufficient density of greenery.

Tree Canopy/Increase in the afforestation cover: It is often seen that the current forest cover in many cities is less than 5% of the city area. Elaborating, cities certainly lack in terms of city level policies. The forest cover is governed through national forest policy and state/district forest policies, but city being the functioning unit is missed out. Therefore, the adaptation is vital and necessary. Due to their distinctive features like low cost and high durability small interventions like the geometry and scale of street canyons, the amount of heat absorbing materials in urban facades, minimization of the additional anthropogenic heat, and a higher vegetation ratio can help in reducing the urban heat island effect aggravated by the Global climate change. Cities can increase green cover through creation of Urban parks, shrubs, and bio retention cells in streets.

Urban trees can modify air temperature, increase air humidity, reduce wind speed, and modify air pollutants[25]. Specific features of species, like structure and density of the treetop, size, shape and color of leaves, tree age and growth, can influence the performance of solar radiation attenuated by canopy, air temperature and air humidity[26]. Human thermal comfort is based on the physiologically equivalent

A study conducted on 10 urban parks in Tel Aviv analyzed the cooling effects of parks with different sizes (0.2–0.36 ha) and different vegetation quality and diversity. It was found that parks with dense vegetation cover have the greatest effectiveness in terms of cooling and thermal comfort. The greatest cooling effect was observed in summer, when the parks managed to reduce the temperature by up to 3.8 °C, resulting in a PET of 18 °C (PET = Physiological Equivalent Temperature, which is an indicator of human comfort under temperature variations). In comparison, a smaller effect was observed in winter, when temperature reduction was 2 °C and the resulting PET was 10 °C. (Aram et al 2019, Urban green space cooling effect in cities).In Seoul, it was found that small green areas of 300 m2 resulted in 1 °C temperature reduction and an area of 650 m2 up to 2 °C. (Aram et al 2019, Park et al 2017, The influence of small green space type and structure at the street level on urban heat island mitigation.)

[24] The impact of urban green infrastructure as a sustainable approach towards tropical micro-climatic changes and human thermal comfort, Galagoda, 2018
[25] Influence of singular trees and small clusters of trees on the bioclimate of a city – a case study, Streiling, S., A. Matzarakis, (2003).
[26] Effect of tree planting design and tree species on human thermal comfort in the tropics, Abreu-Harbich et.al

temperature (PET). It is scientifically proven that PET can be reduced between 12 and 16 ◦C by individual trees and cluster of trees can reduce between 12.5 and 14.5 ◦C. Trees have the strongest impact with an average PET reduction of 13% compared with existing vegetation. Trees shades provide evapotranspirative cooling.[27] There is always a linear reduction in the air temperature for increasing shares of tree crown cover in hot and arid climates.[28] The most efficient species for UHI mitigation are species such as Mango Tree (M. indica), Tulip tree (S. campanulata), Mirindiba/Amarelão (L. glyptocarpa), Malabar Plum/Common Plum (S. cumini) , Partridgewood (C. pluviosa)[29].

Green roofs (cover the roof by plants): The effectivity of façade greening with regards to mitigating urban heat has been examined by a range of case studies: It can decrease the (cooling) energy demand of a building as it weakens wind speed; and the shading effect from leaves contributes to cooling façades. Façade greening is observed as one of many ways to establish vegetation in cities and ascribe a cooling effect to urban fabric in general. In peak tropical temperatures, green roofs were recorded to reduce temperature by 1.70 ◦C approximately[30]. Cool roofs can reduce neighborhood air temperatures by 0.3 ◦C when implemented on residential homes.[31] A hybrid green-blue roof can reduce temperatures in the range of 5°C to 9°C on rooftops[32].

The green roof pictured here below is atop the Vice Media Headquarters in Brooklyn, New York. The green roof acts as a biodiverse habitat and provides providing multiple benefits.

Fig. Green roof in Brooklyn, New York

The city of Amsterdam provided a budget of 20 million euro for the Green Agenda 2015-2018, and mandated installation of 50,000 m2 of green roofs. The program garnered tremendous support and funding for the green initiatives were streamlined to aid in the implementation.

[27] Using green infrastructure for urban climate-proofing: An evaluation of heat mitigation measures at the micro-scale, Zolch et al
[28] Same as previous
[29] Same as 9
[30] Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy, Herath et al, 2017
[31] Urban forestry and cool roofs: Assessment of heat mitigation strategies in Phoenix residential neighborhoods, Middel et al
[32] Application of green blue roof to mitigate heat island phenomena and resilient to climate change in urban areas: A case study from Seoul, Korea, Shafique

2.2 Blue Infrastructure

Due to the temperature reduction and humidity increase effects from the evaporation of surface water, urban waterbodies can improve human comfort in littoral zones in high temperature periods of hot summer days.[33] The mitigation effects of Urban Blue Infrastructure (UBI) on surface urban heat island can be as high as 8.0 °C in summer in urban lakes. [34] Small lakes and ponds which have long been ignored in global processes and cycles, however, have unexpectedly high importance in UHI mitigation.[35] In general, during the high temperature hours of a hot summer day, a waterbody can effectively improve human comfort in the littoral zone[36], with the greatest effect in the area 10–20 m from the water's edge. Blue infrastructure next to lawns, on a sunny day in sub-tropical climate, are known to make the temperatures 0.7 °C cooler[37]. Rooftop ponds can reduce heat flux into indoor space on the top floor, with the most effective cooling offered by a shaded pond with floating wet towels[38]. Artificial water facilities, including a shallow pond, a small waterfall, and a spray fountain create an air temperature decline area on the leeward side[39]. During the establishment of heat-mitigating blue infrastructure, it is critical to incorporate the air circulation profile of the city into the design and planning aspect.

2.3 Grey Infrastructure

Air acts as an important factor in controlling the thermal profile of a city. The cooling effect of wind helps to mitigate the adverse effects of heat island on the micro climate and human thermal comfort. City planning bodies should incorporate heat-adaptive planning which allows for the natural airflow around built infrastructures, thereby enabling UHI mitigation at no extra cost. A study on Wind flow in tropical cities revealed that a "Step up configuration" of building layout can distribute the wind evenly and allow the wind to reach the leeward side of each building, which in turn improves the overall natural ventilation and thermal comfort at pedestrian level[40]. In tropical regions such as Singapore, a wind

Stuttgart, Germany has planned air ventilation corridors with an aim to improve the UHI in the city. Development on the valley slopes has prevented air from moving through the city, which worsens the air quality and contributes to the urban heat island effect. A Climate Atlas was developed for the Stuttgart region and a number of planning and zoning regulations were recommended to preserve and increase open space in densely built-up areas. It resulted in preservation and enhancement of air exchange and cool air flows in the city. (Climate ADAPT, https://climate-adapt.eea.europa.eu/metadata/case-studies/stuttgart-combating-the-heat-island-effect-and-poor-air-quality-with-green-ventilation-corridors)

[33] Evaluation of human thermal comfort near urban waterbody during summer, Xu et al
[34] Understanding the relationship between urban blue infrastructure and land surface temperature, Wu et al
[35] Emerging global role of small lakes and ponds: little things mean a lot, John A. Downing
[36] Evaluation of human thermal comfort near urban waterbody during summer, Xu et al
[37] Influence of blue infrastructure on lawn thermal microclimate in a subtropical green space, Fung & Jim
[38] Experimental studies on a novel roof pond configuration for the cooling of buildings, Runsheng et al
[39] . Novel water facilities for creation of comfortable urban micrometeorology, Nishimura et al
[40] Urban heat island and wind flow characteristics of a tropical city, Rajagopalan et al

velocity of 1–1.5 m/s creates cooling effect which is equivalent to a 2 C drop in temperature[41]. Apart from relief from heat stress, wind also contributes to the reduction of carbon dioxide emissions and reliability on mechanical air conditioners [42]. Furthermore, the air pollution in cities can be dissipated by appropriate wind induced airflows. Thereby it is critical that natural wind flow direction and wind speed factors of the city is incorporated into UHI mitigation strategies.

Rooftops of buildings can also provide opportunities to reduce the impact of heat wave in cities. During heat waves, it is necessary to have adaptive solutions that reduce heat impact and the increase in energy demand. In vulnerable communities, it is not feasible to provide cooling solutions through conventional technologies such as air-conditioners or coolers. Cool roofs have the potential to combat heat waves because of their efficiency in reducing the induction of heat onto the roofs. Cool roofs can reduce indoor temperatures lower by 2 to 5°C. Cool roofs could also reduce outdoor air temperature by 0.5 °C on average, and up to a maximum of ~3 °C, thereby reducing average Urban Heat Island intensity by ~23%, and can reduce heat related mortality associated with the UHI by ~25%.

Climate Smart Homes: In Indian cities, the most vulnerable heat hotspots tend to be around slums and regions where advanced Green infrastructures like Vertical greenery might not be possible. In such zones, alternative building materials for houses can act as a natural inhibitor of heat stress. Bamboo based houses, especially, offer protection from both heat and floods. Experts note that there are innovative bamboo houses that can be manufactured in a week, which includes design elements such as a tilted roof that captures rainwater and reduces heat gain, and elevated stilts that prevent floodwaters from entering the home[43]. Bamboo housing pilot programs have already been tried out in the cities of Ahmedabad and Surat, India[44] and they are known to be provide a very significant improvement in the heat exposure of those in highly vulnerable zones like the slums.

Assessment of the cooling effect of Different NBS: In order for the NBS choice to be successful and cost effective, there needs to be a framework to assess the effectiveness of the proposed NBS. In case of green urban infrastructure (GUI), it is essential to use proven methods to assess the cooling effect provided by GUI, the results of which can be employed by planners to support the design and management of these infrastructures. A method based on the Cascade Model45, which describes the

> New York City's CoolRoofs program has coated over 6.7 million sq. ft. of rooftop space since 2009 and is targeted to at-risk buildings. They city's Cool Neighborhoods program was initiated to help create biophysical and social resilience to heat-health impacts within the communities in order to help New Yorkers can best adapt to a warmer climate. The programs now serve as a prototype for heat health actions in other aspiring cities.

[41] Urban heat island and wind flow characteristics of a tropical city, Rajagopalan et al
[42] The effect of the London urban heat island on building summer cooling demand and night ventilation strategies, Kolokotroni
[43]https://www.weforum.org/agenda/2018/11/bamboo-house-for-manila-slums-wins-top-prize-in-future-cities-contest
[44] https://www.mahilahousingtrust.org/wp-content/uploads/Bamboo-Pilot-Brochure.pdf
[45] Ibid 40

links between structure, functions and services provided by an ecosystem, can be used to understand the cooling impact of proposed NBS at a particular urban center. The functions mainly involved in the cooling capacity of GUI are shading and evapotranspiration46.

Choice of NBS for different functionality: There is a need to consider NBS evaluation during the planning stage of new developments in the urban areas. Impact assessment processes such as the Strategic Environmental Assessment (SEA), can help to promote the proposal and implementation of nature-based solutions in cities, as well to compare the expected effectiveness of these solutions[47]. An evaluation of different types of NBS in Europe (using f205 NBS case studies) revealed the preferred type of NBS for different purposes. Green infrastructure was the most preferred for heatwaves[48].

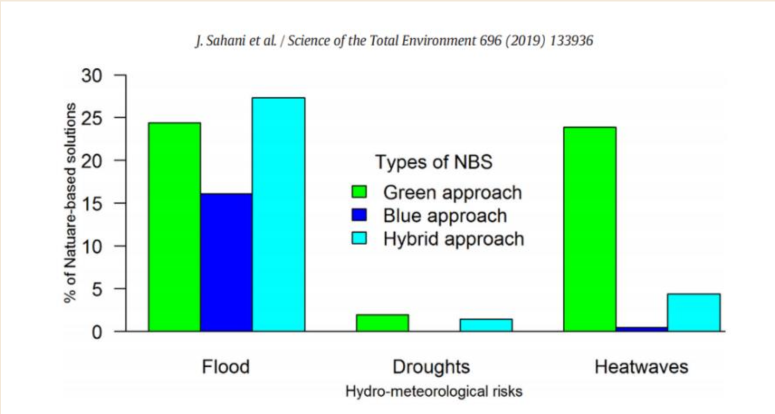


Fig: Nature-based solutions used in various parts of Europe

Framework for Implementing NBS: NBS applicative framework based on the DPSIR (Driving force–Pressure–State–Impact–Response) model is widely used to study their effects on the dynamics of urban areas. The DPSIR model can be used to evaluate the adaptive and mitigative services offered by the different NBS options available[49]. The Model proposes a seven-stage process for situating co-benefit assessment within policy and project implementation. The seven stages include: 1) identify problem or opportunity; 2) select and assess NBS and related actions; 3) design NBS implementation processes; 4) implement NBS; 5) frequently engage stakeholders and communicate co-benefits; 6) transfer and upscale NBS; and 7) monitor and evaluate co-benefits across all stages. The DPSIR model is a valuable tool for guiding thinking and identifying the multiple values of NBS implementation, thereby adding in the choice of NBS type and the best approach to implement it.

[46] Ibid 40
[47] Promoting Nature-Based Solutions for Climate Adaptation in Cities Through Impact Assessment. DOI: 10.4337/9781783478996.00025

[48] J. Sahani et al. / Science of the Total Environment 696 (2019) 133936
[49] A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas, Raymond et al 2017

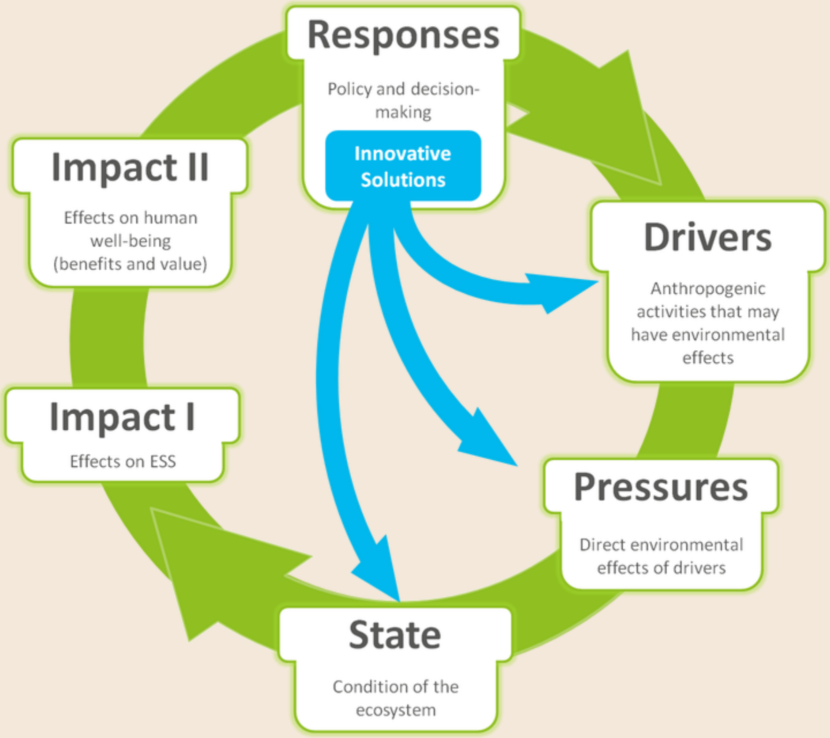


Fig: DPSIR Model[50] - A framework for assessing and implementing the co-benefits of nature-based solutions, Raymond et al 2017

Ecosystem based Approach for NBS Implementation: A study done in Nagpur city[51] evaluated the applicability of Ecosystem based approach of NBS implementation in the city, thus serving as a potential model for NBS use in other Indian cities. The study classified the application of the NBS umbrella for five categories of ecosystem-based approaches in Indian cities (AbC area based conservation, EbM ecosystem-based management, ER ecological restoration, EE ecological engineering, EbA ecosystem-based adaptation, CAS climate adaptation services, Eco-DRR ecosystem-based disaster risk reduction, GI green infrastructure). A similar approach will be adopted for NBS choice and implementation in Delhi, Rajkot and Bhubaneswar.

[50] *https://freshwaterblog.net/2018/12/14/the-dessin-software-tool-for-ecosystem-service-assessment-in-urban-freshwaters/*

[51] Applicability of Nature-Based Solution Through Green Infrastructure Approach to Enhance Green Cover in Urban Transition Scenario. Shruti Lahoti, 10.1007/978-981-15-4712-6

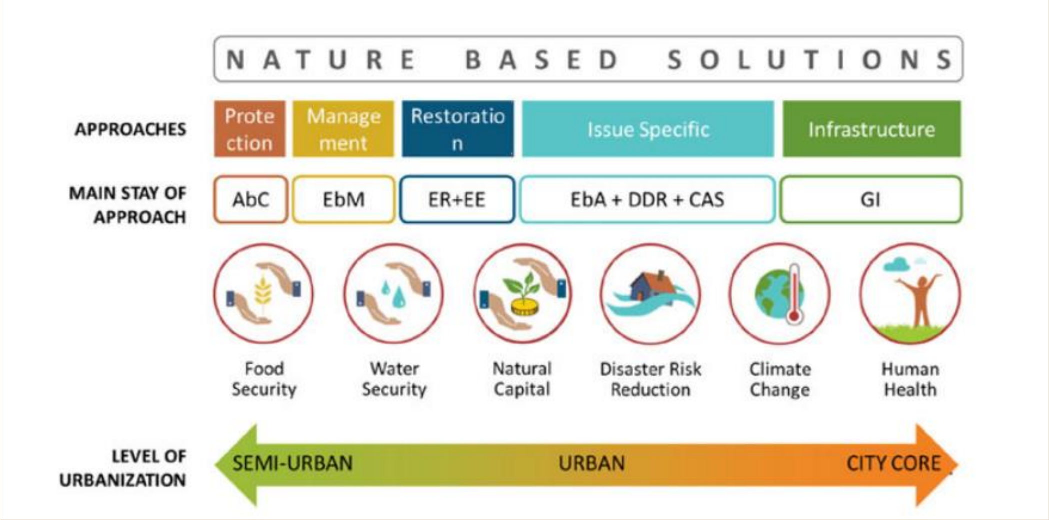


Fig: Conceptual representation of application of the NBS umbrella for five categories of ecosystem-based approaches.

Source: Applicability of Nature-Based Solution Through Green Infrastructure Approach to Enhance Green Cover in Urban Transition Scenario

3. NBS for Mitigation and Adaptation to Heat waves

Heat Stress Action Plans: In order for cities to adopt and mitigate heat stress, comprehensive heat adaptation plans are necessary. A number of countries in Asia, including India have already implemented heat wave action plans. Though some these plans propose green infrastructure as a heat mitigation strategy, the plans in general lack a comprehensive appraisal of Nature Based Solutions (NBS). To manage the mounting heat stress risk in Delhi, Rajkot, and Bhubaneswar, Integrated Research for Action and Development (IRADe), a leading South Asian research institute and think tank, spearheaded an inter-disciplinary research study on Climate Adaptive Heat Stress Action Plans, being funded by International Development Research Centre (IDRC) Canada. The Action plans focused on Identification of the thermal hotspot; spatial vulnerability of populations during extreme heat events in selected areas; heatwave impacts of extreme heat events on the health, work productivity and livelihoods of vulnerable population in selected areas; Selection of appropriate, innovative and affordable climate adaptation measures for improving health and livelihood resilience of the urban population, with consideration of the associated cost effectiveness; Strengthening the capacity of key stakeholders to facilitate the implementation of the Heat Stress Action Plans and their long-term sustainability in the selected areas through training opportunities.

Our paper proposes to draw up a methodology to identify priority areas and implement NBS in the three cities. The main objectives are: (i) to identify areas/zones where NBS is most needed; (ii) To identify most suitable NBS; and (iii) to provide policy guidelines for administrative bodies and local bodies to implement these NBS in their cities.

NBS solution for Delhi, Bhubaneshwar & Rajkot: Adopting NBS can help the cities reduce heat stress, provide sustainable pathways for achieving resilience, and result in multiple benefits for cities that are projected to grow significantly in the near future. As a part of adaptation and mitigation measure, the researchers now propose Nature Based Solutions. The implementation of NBS requires a strategic evaluation of the existing thermal hotspots in these cities and the most effective green or blue infrastructure for the concerned thermal hotspots and vulnerability zones.

3.1 Implementing NBS

The types of NBS must be evaluated based on their relevance to the city geography, climatology, financial mechanism available and the feasibility proposed solution. Developing targeted, climate- and landscape-specific NBS interventions for different land uses can help to inform the choice of NBS[52]. We will use DPSIR model for evaluating the effectiveness of different NBS choices which are selected for their ecosystem-function and cooling effectiveness.

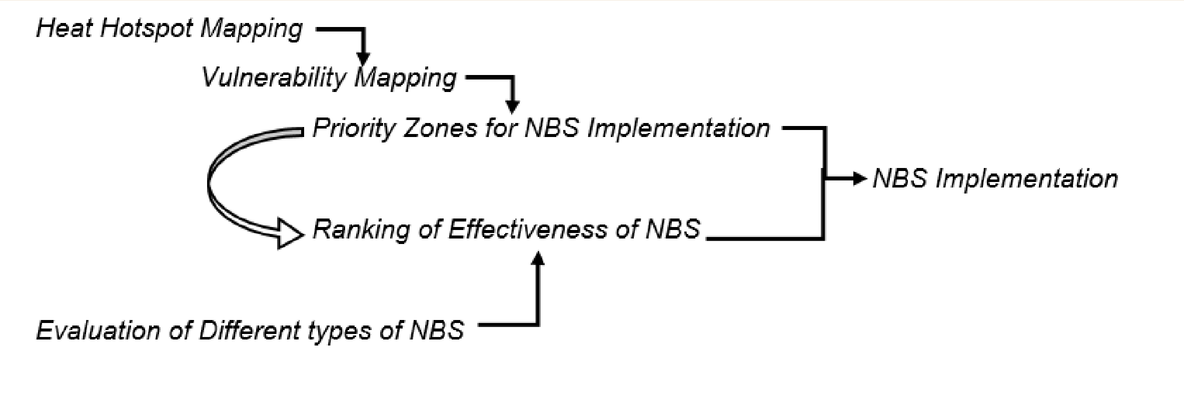


Figure - Methodology for NBS Implementation

Identifying Priority Zones for NBS Implementation: Identifying hot spots within a city can help focus interventions where they are most needed during heat waves. Such thermal maps provide information about the areas which have the accumulation of hotspots, and therefore population living there is under high physiological and socio-economic risks due to thermal stress. Thus, specific measures to curb the problem of heat stress for the resident population can be taken using these maps. The hotspot maps so generated are useful for policymakers and city administrators in analysing the local factors contributing to heat-stress in different wards and devising NBS to reduce heat stress in these areas.

Heat Hot-spot Mapping: The thermal hot-spot maps give insight into the differences in hot spot distribution within cities. *Historical Climatology*: To understand the climatological variations in summer months in the three study cities, an analysis was conducted over a particular period of time. The climatological parameters analysed were: Maximum Temperature (Tmax), Minimum Temperature

[52] Makido, Y. Nature-Based Designs to Mitigate Urban Heat: The Efficacy of Green Infrastructure Treatments in Portland, Oregon. Atmosphere 2019, 10, 282.

(Tmin), Relative Humidity measured in the morning at 8:30 AM [RH (830)], and Relative Humidity measured in the evening at 5:30 PM [RH (1730)]. The mean monthly values of these parameters for the summer months of March, April, May and June were plotted against the long-term climatological mean for these parameters for the respective months, to see the deviation in these parameters for the mentioned months over a particular study period in each city. An analysis of the intra-city temperature variance as per the land use at several locations in the cities was conducted with an objective to identify the correlation between changes in land use and temperature.

Heat Hotspots: The surface temperature maps of the cities were developed using LANDSAT 8 satellite data and superimposed on the ward-boundaries map of the city to develop the city hot spot area. Wards with temperature above 40 degrees Celsius were delineated across the city. Thermal heat spots were mapped through remote sensing using LST images. Thermal hotspots maps were developed using Landsat 8 data. The LST derived from satellite data (NDVI – Normalized Difference Vegetation Index and LSE –Land Surface Emissivity) was validated with ambient air temperature recorded by IMD station within the city as well as the data received from Automatic Weather stations installed within the city by municipality. Landsat 8 provided a range of open-source data at a spatial resolution of 30 m.

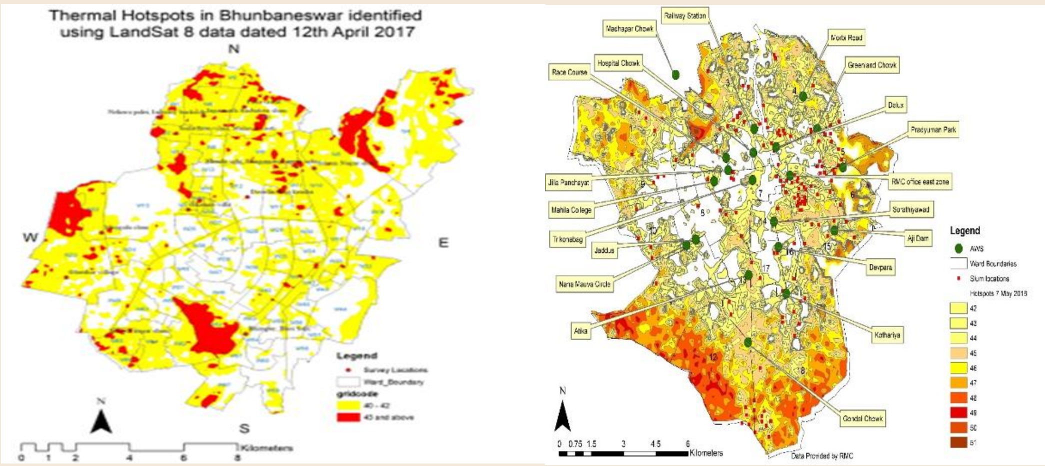


Fig: Thermal Hotspot maps of Bhubaneswar and Rajkot

Vulnerability Mapping: In addition to the heat hotspot mapping, a vulnerability mapping was also done for the cities to identify zones or areas where exposure to heatwave is more lethal. The objective of this process is to rank the neighborhoods or wards according to the thermal benefits that they are expected to receive from the proposed NBS. The existing thermal hotspots and vulnerability hotspot maps, along with a geographical survey of the built environment in those areas, will be used to analyze and determine the priority zones for NBS implementation[53]. This thermal benefit classification enables us to prioritize interventions in order to take the maximum advantage of the microclimate regulation provided by the

[53] Ibid 40

NBS[54]. Vulnerability to heat is defined as a function of: the degree of exposure to the heat hazard, sensitivity to changes in weather/climate (the degree to which a person or system will respond to a given change in climate, including beneficial and harmful effects), and adaptive capacity (the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate) (IPCC, 2001). Heat stress vulnerability across the heat hotspot wards were analyzed using a comprehensive index, comprising of nine sectors - Sanitation, Water, Electricity, Health, Transportation, Housing, Cooking, Awareness and Heat symptoms and their respective sub sectors. The cumulative ward wise heat stress vulnerability analysis revealed wards in each city that were highly vulnerable to heat stress.

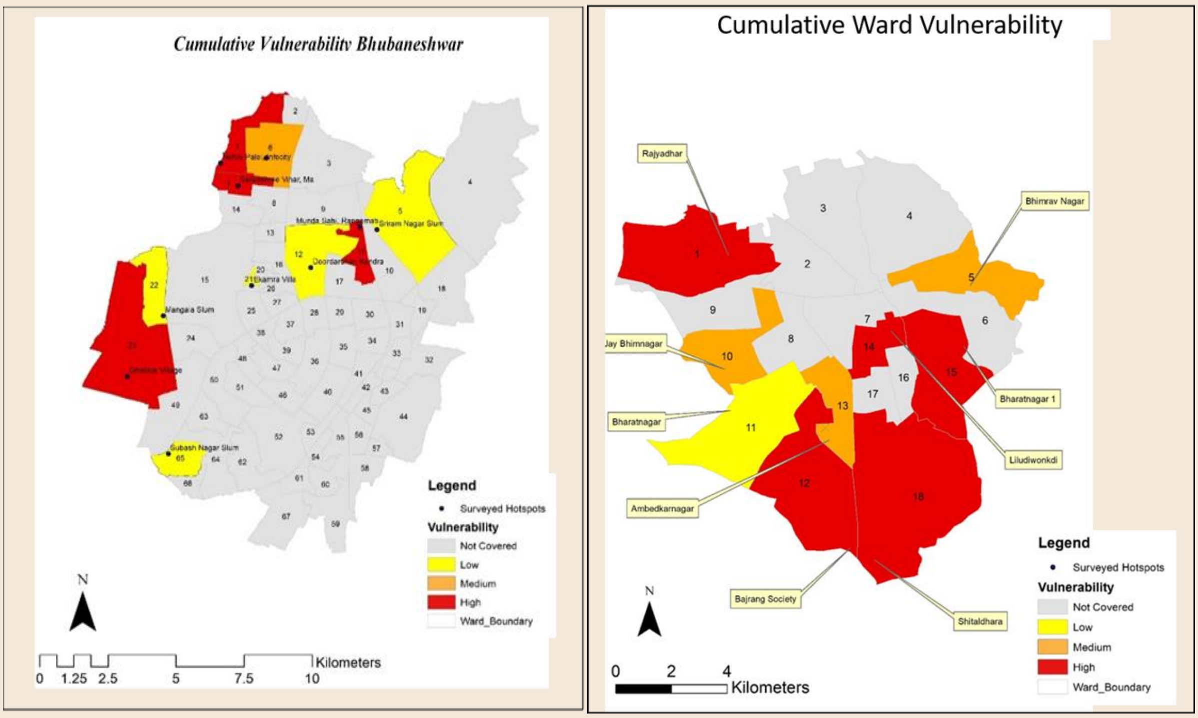


Fig: Most Vulnerable Wards in Rajkot and Bhubaneswar

Choice of NBS: Available list of NBS will be short-listed on basis of their cooling-effectiveness and sorted on basis of Ecosystem approach for different regions within the city. The sorted NBS will be then re-evaluated using the DPSIR model to understand the complexities involving NBS interaction with the ecosystem, its services towards mitigation and adaptation, and the potential avenues for further improvements. Below are a list of probable NBS that can be implemented alone or in an integrated manner with other solutions in Delhi, Rajkot, and Bhubaneswar[55], grouped in terms of their intervention method.

[54] Ibid 40
[55] Ibid 49

Solution	Intervention guideline	Probable intervention areas
Type 1	Improving existing natural or protected ecosystems	Mainly sprawl semi urban areas where a large part of the existing natural ecosystem is still intact like: lake catchment areas the hill areas some agricultural areas
Type 2	Developing sustainable management protocols and procedures for managed or restored ecosystems	Mainly peripheral urban areas within the administrative limits where some part of the existing natural ecosystem can still be partly restored and managed; Lake edges Parts of river the greens of hill the large-scale city level greens large roadside greens
Type 3	Creating new ecosystems	Mainly congested city core where the over urbanized areas need to create a new ecosystem mainly based on a large-scale engineering intervention Parks and Green cover Community level open spaces Green roof and Green walls for new community buildings Bamboo housing projects in highly vulnerable slum regions Small sized Parks and Green cover in unutilized landscapes within the city Air Ventilation Friendly Urban Planning for the newly developing areas on the boundaries of the cities

Finalization of NBS solution will be carried out after estimating the effectives of various NBS options in the identified vulnerability ward areas. It is highly probable that the most efficient NBS for Heat Stress adaptation and mitigation in the city core of Delhi, Rajkot, and Bhubaneswar are likely to be 1. Planting street tree species with high cooling potential in densely built areas, 2. Increasing green walls and roofs, and 3. Installation of cool-roof solutions. The confirmation of the same will be arrived upon a comprehensive assessment of NBS effectiveness in the vulnerability wards zones of the three cities.

4. Conclusion

The priority zones or wards for implementing Heat Stress adaptation and mitigation actions are readily available through the comprehensive heat stress vulnerability hotspot maps generated through an analysis of thermal hotspots, socio-economic vulnerability status, and the exposure to UHI. This paper proposes the use of different Nature Based Solutions (NBS) that are available for combating heat stress in three Indian cities (Delhi, Rajkot, Bhubaneswar) using a methodology, which uses existing DPSIR model and ecosystem based approach, to prioritize the most effective NBS. The researchers will carry out NBS assessment in the next steps to determine the most effective NBS for the identified vulnerability hotspots in the three cities. Upon finalizing the ideal NBS, implementation strategy will be adopted into the Heat Action Plans and will be communicated to stakeholders and local authorities who are actively engaged in climate adaptation and mitigation missions. Stakeholders must be involved in making the decision regarding the choice of NBS for the city and wards. For NBS to be successful, it also needs to be aesthetically appealing to citizens[56]. A streamlined funding mechanism must be available for initiation and integration of the NBS into existing and new climate adaptation strategies, including the Heat Action Plans.

[56] https://drift.eur.nl/publications/planning-nature-based-solutions-in-cities/