NERSC Technical report no. 466

Sustainable City Development – Environmental Scenarios in the Global South -

Report on the URSA MAJOR Hackathon 2024

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TITLE	REPORT ID
Sustainable City Development – Environmental Scenarios in the Global South - Report on the URSA MAJOR Hackathon 2024	NERSC Technical report no. 466 **DOI: 10.5281/zenodo.16759079**
EDITORS & ORGANIZERS	**DATE**
Bindu G., Chandu PJ., Ajith Joseph K., Igor Esau, Sobah A. Petersen, Alexander Baklanov and Lasse H. Pettersson	4th March 2025
FUNDING AGENCY	**PROJECT CREDIT**
Research Council of Norway (RCN); INTPART - International Partnerships for Excellent Education, Research and Innovation	*URSA-MAJOR: URban Sustainability in Action: Multi-disciplinary Approach through Jointly Organized Research schools* RCN INTPART project no. 322317
VENUE	**LOCATION**
URSA MAJOR Hackathon 2024: Sustainable City Development – Environmental Scenarios in the Global South.	Renai Blue Waters Cherai, Kochi, India. Dates: 11th –16th November 2024 Co-organized by: Nansen Environmental Research Centre (India) and Nansen Environmental Remote Sensing Center, Norway
APPROVAL	
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The Editors Preface

The world today is witnessing an unprecedented pace of urbanization, with cities evolving as epicentres of economic activity, technological innovation, and demographic concentration. According to UN, 55% of the world's population lives today in urban areas, a proportion that is expected to increase to about 70% by 2050. While urbanization brings opportunities, it also poses formidable challenges—particularly in the Global South, where rapid population growth, inadequate infrastructure, environmental degradation, and climate vulnerability converge in complex ways. Global South faces some of the most pressing environmental and developmental challenges from deteriorating air quality to climate vulnerability and fragmented urban governance. Addressing these multifaceted challenges demands not only scientific and technological solutions but also inclusive, interdisciplinary, and participatory approaches.

The Research Council of Norway–funded project *URSA MAJOR: URban Sustainability in Action: A Multi-disciplinary Approach through Jointly Organized Research Schools* is coordinated by the Nansen Environmental and Remote Sensing Center in Norway with partner institutions from Norway, India, US and Germany. Within its broader vision the *URSA MAJOR Hackathon 2024: Sustainable City Development – Environmental Scenarios in the Global South* was conceptualized. The hackathon, hosted in the coastal city of Kochi, India, served as a vibrant, transdisciplinary platform where young researchers, early-career professionals, as well as academic and practitioner experts converged to ideate, collaborate, and co-create solutions for urban sustainability, tailored to the realities and aspirations of the Global South.

The hackathon brought together 22 young researchers, students, and 12 experts from diverse disciplines and geographies to explore sustainable urban transformation through immersive, hands-on engagement. Over six days of intensive interaction - preceded by preparatory sessions, lectures and followed by continued research and dialogues among the student and expert participants. The participants delved into the intricacies of **air quality monitoring and modelling, remote sensing of environmental status,** and **barriers for smart city development**, with a clear emphasis on actionable outcomes and policy relevance. Through continued engagement toward publishable research outputs, this initiative bridges the gap between theory and practice, data and decision-making, science and society – across their individual disciplines.

Participants were mentored by a distinguished panel of national and international experts who brought a wealth of knowledge and multi-disciplinary experience across domains such as atmospheric sciences, environmental engineering, climate studies, urban governance, numerical modelling and digital technologies. Tools such as AERMOD for air dispersion modelling, GIS for spatial analysis, and qualitative policy review methods were integrated into group research activities, thereby exposing participants to real-world challenges and identification of research-driven solutions.

This technical report *Sustainable City Development – Environmental Scenarios in the Global South - Report on the URSA MAJOR Hackathon 2024* is presented as part of the NERSC publication series, documents the process, content, and outcomes of the hackathon in depth. From keynote lectures and technical sessions to group projects and post-hackathon impacts, it reflects the spirit of co-learning and -creation, problem-solving, and transdisciplinary collaboration that defined the hackathon. It highlights the outcomes of three research group projects (in Section 8) focusing on:

- **Urban Heat Island and land use change in Kochi**,
- **Comparative air quality assessment in Delhi and Kochi**, and
- **Social and institutional challenges to smart city governance in India**.

Beyond these specific outputs, the hackathon underscored a more profound message: that sustainable urban transformation in the Global South (and elsewhere) must be knowledge-based, inclusive, context-sensitive, and forward-looking. It also reaffirmed the importance of investing in young minds, fostering cross-border academic collaboration, and creating learning environments that functions across disciplines.

We hope this report will serve as a valuable reference for scholars, city planners, policymakers, and stakeholders interested in urban sustainability, especially within the Global South context. Moreover, we aspire for the ideas and methodologies presented here to inspire similar initiatives worldwide that combine scientific rigor, local knowledge, and global solidarity.

Special thanks are due to our keynote speakers, guest lecturers, mentors, and administrative teams whose commitment made the event a success. Above all, we acknowledge the young researchers—the true protagonists of this hackathon—whose enthusiasm, curiosity, and perseverance give us hope for a more sustainable urban future. Their active and skilful contributions to the completion of this event and the follow up work with resulting report and scientific publications is very valuable. A particular thanks to the staff of NERCI for a smooth and professional organisation and implementation of the hackathon.

The support from the Research Council of Norway to the project *URban Sustainability in Action: Multi-disciplinary Approach through Jointly Organized Research schools* (INTPART Grant # 322317) has been essential for the implementation of the hackathon and its follow up research cooperation.

Kochi / Bergen, 4th March 2025.

The Editors

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Executive Summary: URSA MAJOR Hackathon - Highlights

URSA MAJOR Hackathon on *Sustainable City Development - Environmental Scenarios in the Global South* was conducted during 11-15 November 2024 in Kochi, India, focusing on the themes:

- Air Quality Monitoring & Modelling,
- Remote Sensing of Environmental Status,
- Barriers for Smart City Development (Social Science).

The vision of the hackathon was to promote sustainable city development with a special focus on environmental challenges in the Global South. The hackathon included four Technical Sessions, where scientific experts and practitioners provided lectures, initiated groupwork by the participants and final presentations by the participants. For each of the above themes research groups was established to work on small scale research projects (SSRPs) to be implemented as a part of the hackathon. The activities in each group were planned in three stages: Pre hackathon, Hackathon and Post hackathon activities.

Pre hackathon was conducted two weeks prior to the hackathon during which workflow was discussed online, and study materials were distributed. The participating young researchers were given training under expert guidance from national and international organizations, with Hands-on experience with urban environmental challenges, Exposure to multi-disciplinary research and an opportunity to contribute to urban sustainability and policy development. The small-scale research projects were prepared and given to participants to dive into focused research projects under expert guidance, simulating real-world challenges. It was planned in such a manner that they will gain practical research experience, contribute solutions to urban issues, collaborate with international experts and other participants, choose a topic that aligns with their interests, work alongside like-minded peers, engage in research and prototype solutions and finally showcase the findings and solutions to a panel of experts.

There was a total of 22 young researcher participants from research institutions, universities and companies in India and abroad. Each group was working under the guidance of a group of national and international experts. Team air quality worked on the SSRP '*Assessing Urban Growth and its impacts on Surface Urban Heat Island in the Kochi City, Kerala*', the Remote sensing group worked on '*Assessing Urban Air Quality: A Comparative Study of Pollutant Trends in Delhi and Kochi (2019-2023)*' and the social science group worked on '*Analyzing Kochi's SMART city initiatives its challenges and solutions*'.

Post hackathon all three student groups have been working on producing publishable output reports and results of their research findings and studies (Section 8). Built on this report also a final policy summary report of the hackathon will be submitted to the local state authorities for their planning further along these lines. Research results from the hackathon will be assessed for peer review publication among the participants.

The structure of the report

This report starts with an Introduction (Section 1), followed by a brief overview of the hackathon event. A summary of the Keynote address *Toward Environmental- & Climate-Smart, Resilient & Sustainable Cities: UN and WMO Integrated Strategy, Methodology, and Tools – Global South Focus* by Professor Alexander Baklanov, is given in Section 3. Section 4 summarizes *The urban hackathon: Ideas and expected outcomes* - an introductory talk given by Professor Igor Ezau. Sections 5 to 7 summarizes all the expert presentations given in three plenary thematical technical sessions focusing on:

- Technical session 1: Air quality monitoring and modeling (Day 1 and 2)
- Technical Session 2: Remote sensing of the environmental status (Day 3)
- Technical Session 3: Barriers for Smart City Development - Social science (Day 4)

Section 8 include the three reports from each of the research group projects, completed by the student and expert participants. Section 9 briefly summarize the conclusions and next steps following the hackathon. The contents of each section are the responsibility of their respective participants and authors, as listed.

The URSA-MAJOR Hackathon Program and the list of all Participants are included in the Annexures.

1 Introduction

1.1 Background

The URSA-MAJOR project is dedicated to advancing sustainable urban transformation through multi-disciplinary research, capacity building, and technological interventions. The URSA-MAJOR hackathon was organized to provide a platform for young researchers and students to apply and expand their skills in addressing research driven practical urban sustainability issues.

1.2 Objectives & Outcome

The objectives were to:

- Encourage innovative data-driven approaches to urban sustainability.
- Provide participants with access to cutting-edge tools like AERMOD for air quality modeling.
- Facilitate collaboration between researchers, managers and policymakers.
- Develop potential solutions for real-world implementation.

The outcome was to

- Equip students and researchers with hands-on experience in sustainable urban development.
- Foster interdisciplinary collaboration to tackle urban environmental challenges.
- Develop practical solutions for local governance implementation.
- Advance urban monitoring and decision-support systems.

1.3 Impact and Key Outcome

Urbanization in the Global South presents unique challenges, including rapid population growth, rising air pollution, and climate-induced risks. The hackathon focused on identifying scalable, technology and policy-based solutions tailored to these regions, applying interdisciplinary knowledge. Thematical the hackathon focused on:

- Air Quality Monitoring & Modelling
- Remote Sensing of Environmental Status
- Barriers to Smart City Development

With the expected Key Outcomes to give the participants:

- Hands-on experience with urban environmental challenges.
- Exposure to interdisciplinary research methodologies.
- Contribution to urban sustainability and policy recommendations.
- Small-scale research projects (SSRP) under expert guidance.

2 Event Overview

The URSA MAJOR Hackathon 2024 was successfully held from November 11th to 16th at Renai Blue Waters Cherai, Kochi, India. This international event brought together young researchers, scientists, and students to collaborate on innovative solutions for sustainable urban transformation, with a focus on the Global South. The hackathon was organized as part of the URban Sustainability in Action Multi-Disciplinary Approach through Jointly Organized Research schools (URSA MAJOR) initiative, fostering cross-disciplinary collaboration.

The primary aim of the hackathon was to develop practical and data-driven solutions to urban sustainability challenges, particularly addressing issues such as air pollution, urban heat islands, and climate resilience. The URSA MAJOR Hackathon on Sustainable City Development was structured to cover multiple themes through expert talks, technical sessions, hands-on activities, and group work. The event spanned five days, focusing on air quality monitoring, remote sensing applications, and social science aspects of smart city development. The hackathon emphasized the use of tools like the AERMOD simulation model for urban pollution simulations, GIS applications, and remote sensing technologies. The hackathon attracted 22 participants, who were divided into three groups based on their areas of interest and expertise. Each group worked under the guidance of mentors.

Inaugural address was given by Ms. Sreekala, Chairperson KSPCB followed by introduction about the project by Lasse H Pettersson and the hackathon by Dr. Bindu. G., Dr. Ajith Joseph, Executive Director welcomed the guests. Dr. Alexander Baklanov, Professor Niels Bohr Institute, University of Copenhagen, Denmark gave the keynote address on '*Towards Environmentally and climate-smart, resilient & sustainable cities'*. The invited lectures in the technical sessions were attended by all participants. Each thematic student groups followed up specifically "their" technical lectures in their SSPR activities.

3 *Keynote address*: Toward Environmental- & Climate-Smart, Resilient & Sustainable Cities: UN and WMO Integrated Strategy, Methodology, and Tools – Global South Focus

By Prof. Alexander Baklanov
Climate & Geophysics, Niels Bohr Institute, University of Copenhagen, Denmark

3.1 Introduction

Urbanization is one of the most defining trends of the 21st century, with more than half of the global population living in cities. While cities occupy only 2% of the Earth's landmass, they contribute approximately 70% of the global GDP, consume over 60% of the world's energy, and are responsible for 70% of greenhouse gas (GHG) emissions and global waste. This concentration of human activity makes urban areas both a key contributor to climate change and highly vulnerable to its impacts. This report outlines the United Nations (UN) and World Meteorological Organization (WMO) integrated strategies, methodologies, and tools for developing climate-smart, resilient, and sustainable cities, with a specific focus on the Global South.

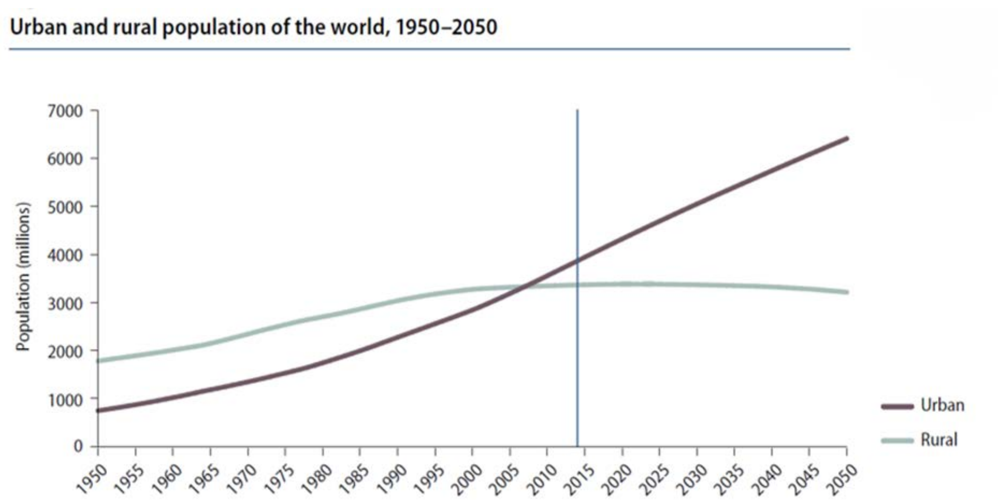

***Figure 1**: World Urbanization Prospects. United Nations, Department of Economic and Social Affairs, Population Division (UN, 2014).*

3.2 The Urban Challenge: Climate Change and Vulnerability

Cities face heightened risks due to climate change. Approximately 90% of disasters affecting urban areas are hydro-meteorological in nature, including storms, floods, and heatwaves. Urban regions are particularly vulnerable due to increased human density and complex infrastructure. Climate models indicate that urban areas will continue to experience significant temperature and precipitation changes, increasing the frequency and intensity of extreme weather events.

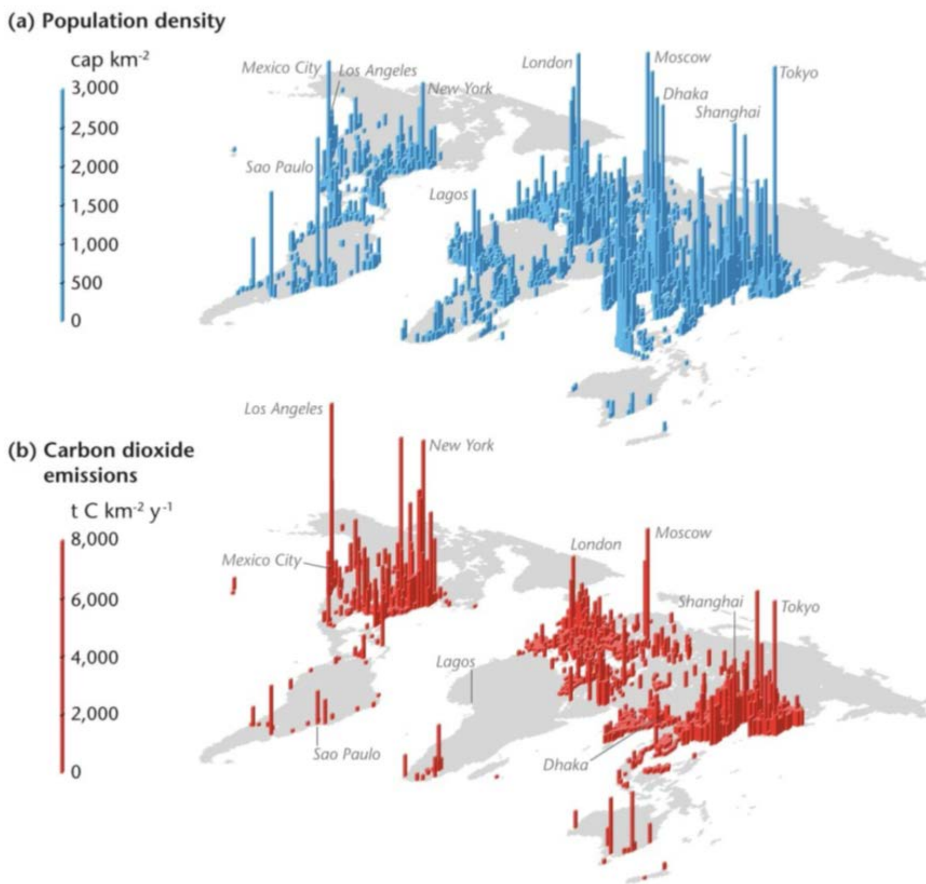

***Figure 2**: Cities are main sources of air pollution and responsible for > 70% of CO_2 emissions. Source: Oke et al. (2017).*

One major issue is the strong feedback loop between urbanization and climate change. Cities drive climate change through massive emissions of greenhouse gases while simultaneously being the most affected by its impacts. This dual role means that cities must address both mitigation (reducing emissions) and adaptation (building resilience to climate impacts) in an integrated manner. The urgency for cities to act is amplified by the fact that they are at risk of multiple natural hazards, which will likely intensify by 2025.

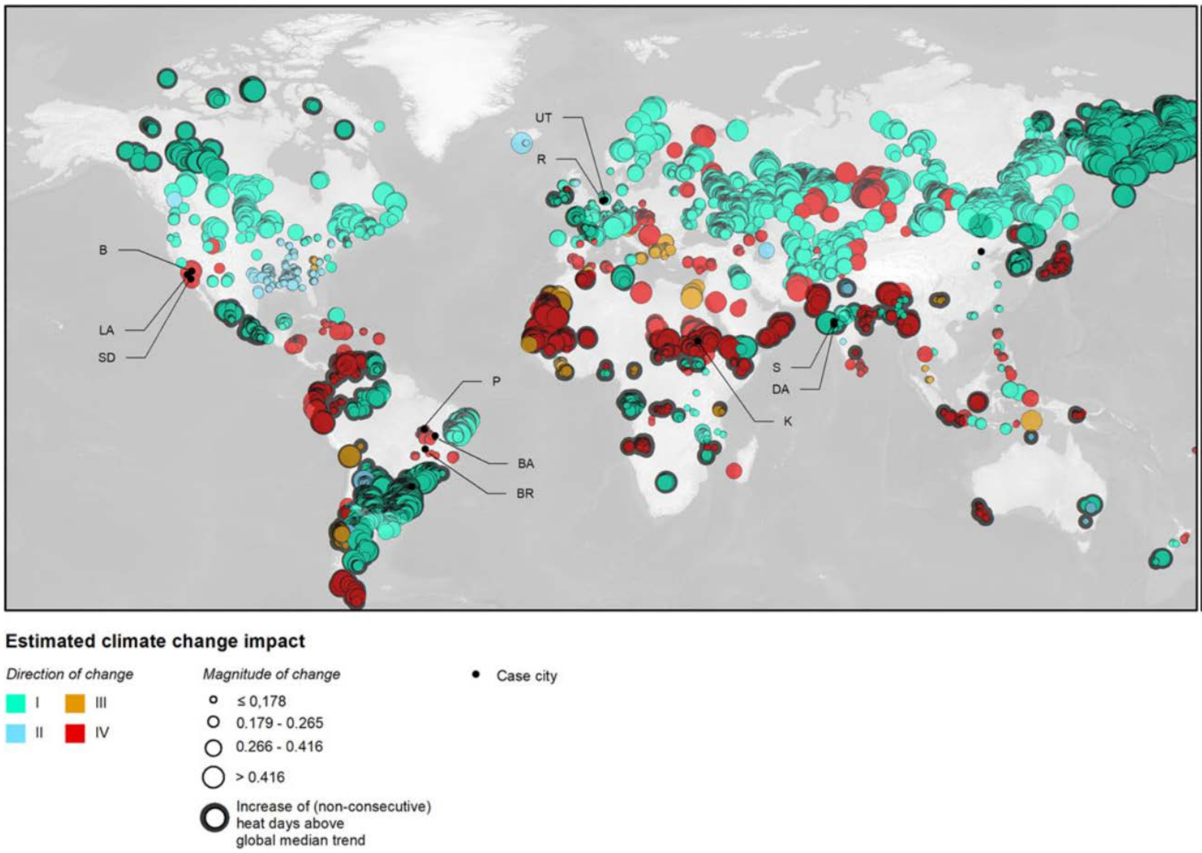

***Figure 3**: Mapping direction of change in temperature from 1901 until 2014 and precipitation from 1901 until 2013 in cities. The direction of change is indicated by colour, where I - equals warmer and wetter; II - colder and wetter; III - colder and drier; and IV - warmer and drier conditions. Classification of the magnitude of change corresponds to quartiles, Source: Scheuer et al. (2017); Creutzig et al. (2019)*

3.3 Integrated Urban Systems (IUS): A Holistic Approach

To address these challenges, the WMO has developed the Integrated Urban Weather, Environment, and Climate Services (IUS) framework (WMO, 2019, 2021; Baklanov et al, 2018, 2020; Grimmond et al. 2020). This framework emphasizes a comprehensive, science-based approach to urban management by integrating multiple disciplines—meteorology, climate science, hydrology, and environmental monitoring. The IUS framework is designed to improve urban resilience through advanced multi-hazard early warning systems and sustainable urban planning.

The main objectives of IUS are:

1. **Resilience:** Enhance urban capacity to cope with and recover from multi-hazard risks through early warning systems.

2. **Sustainability:** Support long-term urban planning and sustainable development goals (SDGs).
3. **Efficiency:** Optimize resource use through cross-cutting urban services.
4. **Consistency:** Ensure cohesive policies by integrating diverse urban services.
5. **Effectiveness:** Facilitate risk communication and foster public-private partnerships.

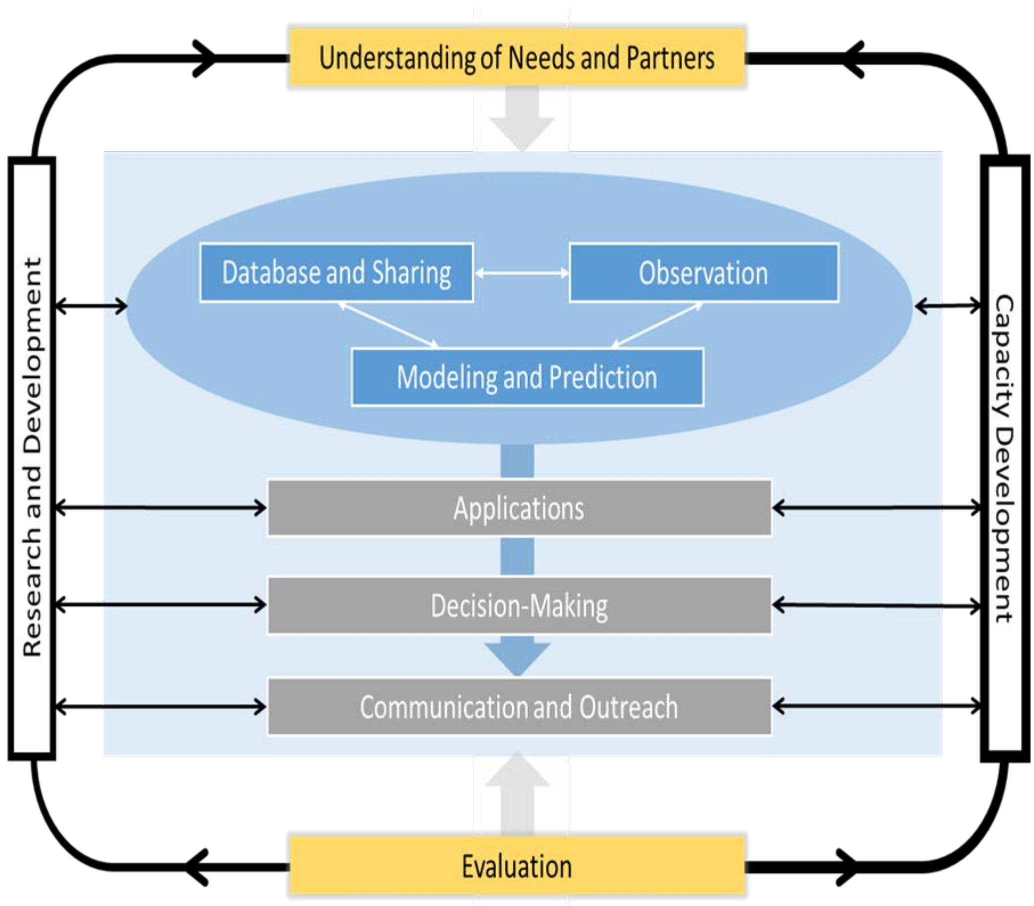

Figure 4: *Components of the development an Integrated Urban Weather, Environment and Climate Service (IUS) (WMO, 2019).*

3.4 Urban Atmospheric Processes and Climate Dynamics

Urban climates differ significantly from rural areas due to various atmospheric and anthropogenic processes. Key contributors to the urban climate include:

- **Urban Heat Island (UHI) Effect:** Increased temperatures in cities due to heat retention by concrete, asphalt, and other urban materials (WMO, 2023).

- **Air Pollution:** Emissions from vehicles, industries, and human activities contribute to poor air quality and climate change.
- **Land-Use Changes:** Urban expansion modifies local climates by altering natural landscapes and water systems.
- **Wind Patterns:** Buildings and city infrastructure disrupt natural airflow, reducing wind velocity and increasing local warming.

These processes not only worsen local air quality and public health but also have cascading effects on broader climatic systems. Addressing these challenges requires advanced multi-scale modeling and integrated climate monitoring.

3.5 Mitigation and Adaptation Strategies

Effective mitigation and adaptation strategies require both physical and behavioral changes. The IUS approach emphasizes three key components (WMO, 2019; Grimmond et al., 2020):

1. **Physical Modifications:** Implementing surface materials with high reflectivity, increasing green and blue infrastructure (parks, lakes), and optimizing urban design to improve airflow and reduce heat retention.
2. **Behavioral Changes:** Promoting energy efficiency, reducing consumption, and encouraging sustainable transportation to lower emissions.
3. **Policy Integration:** Designing holistic urban policies that consider the long-term effects of today's decisions, including trade-offs between mitigation and adaptation measures.

Successful examples include Hong Kong's Air Ventilation Assessment (AVA) framework, which integrates climate data into urban planning, and the Paris Urban Heat Island mitigation program, which employs reflective surfaces and increased vegetation (Baklanov et al., 2020).

3.6 Multi-Hazard Early Warning Systems

Cities must adopt comprehensive early warning systems to address the increasing risks posed by extreme weather events. The WMO promotes integrated multi-hazard warning systems that provide (Grimmond et al., 2014; Tang et al., 2021):

- **Impact-based Forecasting:** Predicting not only the weather but also its potential impact on urban areas.
- **Seamless Data Integration:** Combining data from weather, climate, and environmental monitoring systems.
- **Urban-specific Models:** Developing models tailored to the unique characteristics of urban environments, including population density and infrastructure complexity.

Notable pilot projects include:

- **Shanghai's Multi-Hazard Early Warning System (MHEWS):** A model for integrated climate and weather monitoring that informs urban management decisions (Tang et al, 2021).
- **Tokyo's TOMACS Program:** Focused on urban climate monitoring and disaster risk reduction (Misumi et al., 2019).
- **SAFAR Initiative in Indian Cities:** Monitoring and forecasting urban air quality to protect public health (Beig et al, 2015).

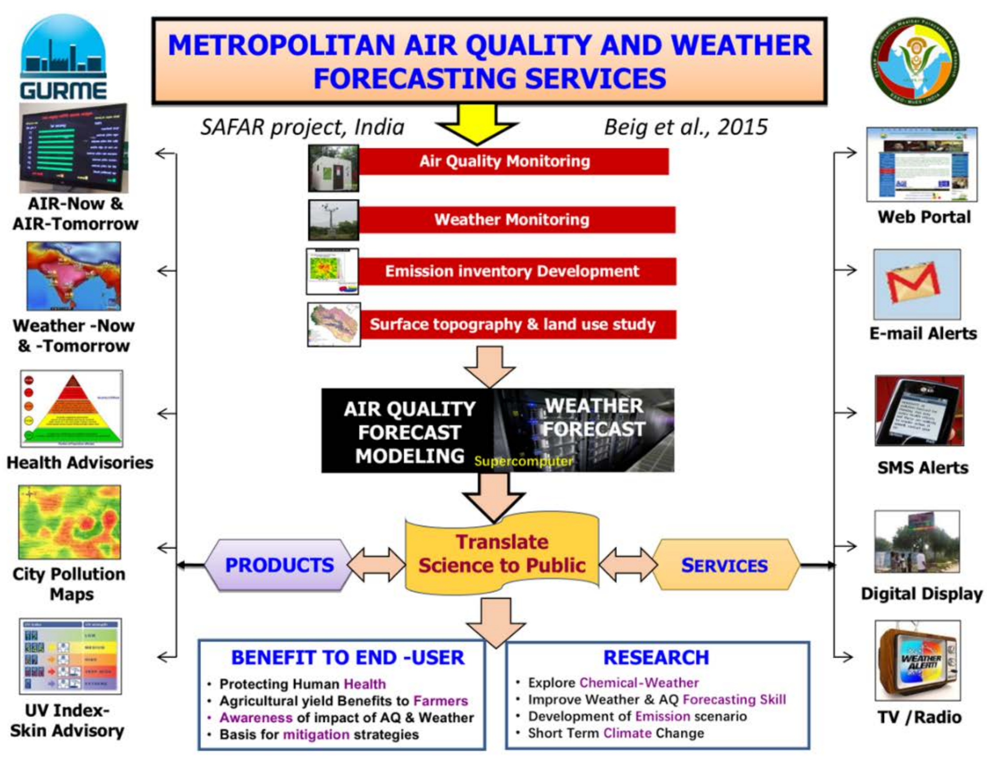

Figure 5: SAFAR Initiative in Indian Cities (Beig et al, 2015).

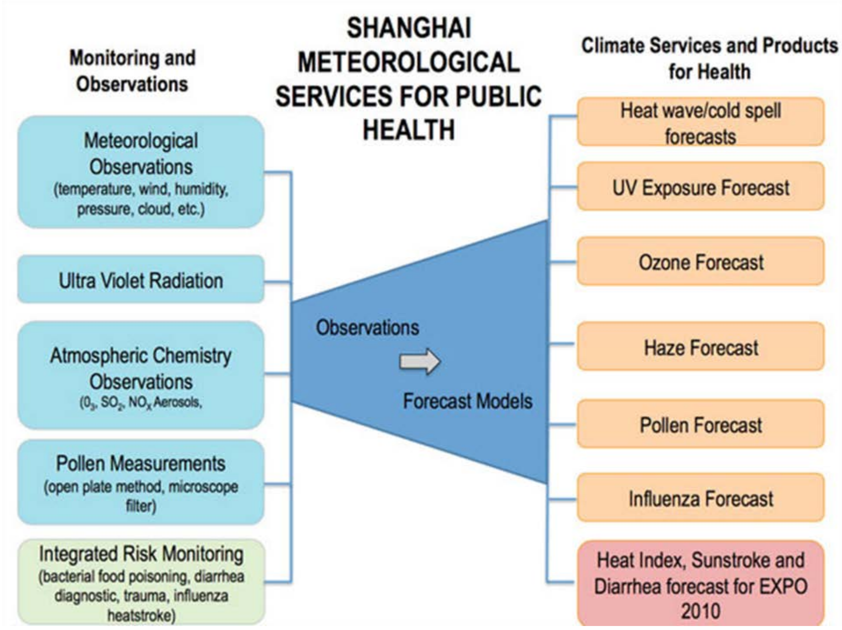

Figure 6: *GURME Pilot Project part of Shanghai Multi-Hazard Early Warning System (MHEWS) (Tang et al., 2021).*

3.7 Case Studies and Global Demonstration Projects

Several cities worldwide have adopted the IUS approach, offering valuable insights for future urban planning (e.g. WMO, 2023):

- **Oslo, Norway:** Focused on urban air quality forecasting and integrating climate data into city planning.
- **Copenhagen, Denmark:** Developed urban hydrology models to manage rising sea levels and storm surges.
- **Phoenix, USA:** Implemented integrated field laboratories for urban weather prediction.
- **Beijing, China:** Established the SURF program for comprehensive air quality and urban heat monitoring.

These case studies demonstrate the effectiveness of integrated systems in improving urban resilience and sustainability.

3.8 The Role of the Global South

The Global South faces unique challenges due to rapid urbanization, limited resources, and heightened climate vulnerability. Collaborative international projects are crucial for enhancing climate resilience in these regions. The WMO's IUC4CRC project in Thailand exemplifies how integrated urban climate systems can support climate-smart city initiatives in developing economies (WMO-GIZ, 2023).

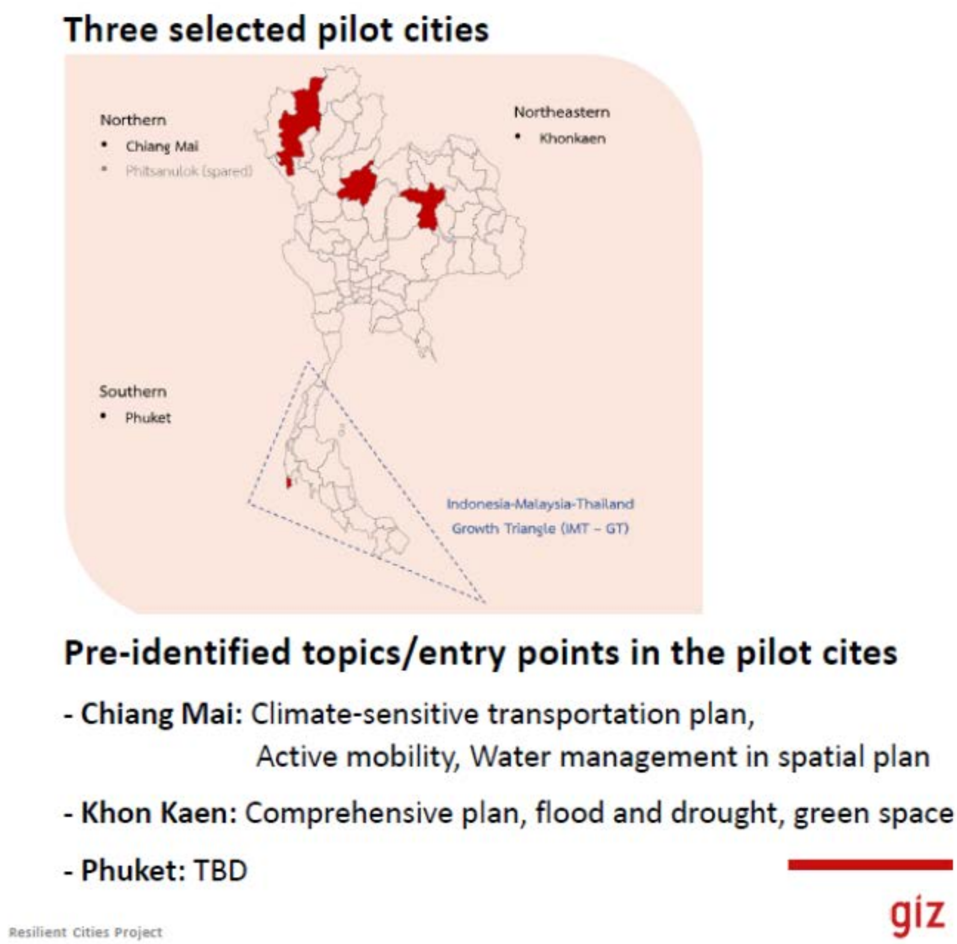

***Figure 7**: New GIZ-WMO-TMD project: "Integrated Urban Climate, Weather and Environment Systems for Climate-smart and Resilient Cities: Thailand study (IUC4CRC)".*

Additionally, youth engagement through initiatives like **Youth Climate Diplomacy** is essential for fostering long-term climate action and empowering future leaders.

3.9 Conclusion and Way Forward

Building climate-smart and sustainable cities requires a multi-faceted approach that integrates science, technology, policy, and community engagement. The WMO's IUS framework offers a robust methodology for addressing the dual challenges of climate mitigation and adaptation.

To successfully transition toward sustainable urban futures, cities must:

1. Implement integrated weather, climate, and environmental monitoring systems.
2. Adopt evidence-based policies that balance mitigation and adaptation goals.
3. Foster multi-sectoral collaboration through the IUS framework.
4. Promote citizen participation and education for long-term climate resilience.

By embracing these strategies, cities—particularly in the Global South—can mitigate climate risks, enhance public health, and secure a more sustainable future for all.

3.10 References

Baklanov, A., C.S.B. Grimmond, D. Carlson, D. Terblanche, X. Tang, V. Bouchet, B. Lee, G. Langendijk, R.K. Kolli, A. Hovsepyan, 2017: From urban meteorology, climate and environment research to integrated city services. Urban Climate, 23, 330–341, https://doi.org/10.1016/j.uclim.2017.05.004

Baklanov, A., B Cárdenas, T-C Lee, S Leroyer, V Masson, L T Molina, T Müller, C Ren, F R Vogel, J A Voogt (2020) Integrated urban services: experience from four cities on different continents, Urban Climate, 32, https://doi.org/10.1016/j.uclim.2020.100610

Baklanov, A., Korsholm, U. S., Nuterman, R., Mahura, A., et al. (2017) The Enviro-HIRLAM online integrated meteorology–chemistry modelling system: strategy, methodology, developments, and applications (v. 7.2), Geosci. Model Dev., 10, 2971-2999, https://doi.org/10.5194/gmd-10-2971-2017

Baklanov, A., L.T. Molina, M. Gauss (2016) Megacities, air quality and climate. Atmospheric Environment, 126, 235–249. doi:10.1016/j.atmosenv.2015.11.059

Baklanov, A., S. Grimmond, A. Mahura, M. Athanassiadou, (2009) Meteorological and Air Quality Models for Urban Areas. Springer Book, 2009, 184 p.

Baklanov, A. A. and Nuterman, R. B. (2009) Multi-scale atmospheric environment modelling for urban areas, Adv. Sci. Res., 3, 53–57, https://doi.org/10.5194/asr-3-53-2009

Baklanov, A., Mestayer, P. G., Clappier, A., Zilitinkevich, S., Joffre, S., Mahura, A., and Nielsen, N. W. (2008) Towards improving the simulation of meteorological fields in urban areas through updated/advanced surface fluxes description, Atmos. Chem. Phys., 8, 523–543, https://doi.org/10.5194/acp-8-523-2008

Baklanov, A., Hänninen, O., Slørdal, L. H., Kukkonen, J., Bjergene, N., Fay, B., Finardi, S., Hoe, S. C., Jantunen, M., Karppinen, A., Rasmussen, A., Skouloudis, A., Sokhi, R. S., Sørensen, J. H., and Ødegaard, V. (2007) Integrated systems for forecasting urban meteorology, air pollution and population exposure, Atmos. Chem. Phys., 7, 855–874, https://doi.org/10.5194/acp-7-855-2007

Beig, G. et al. (2015) System of Air Quality Forecasting and Research (SAFAR - India). World Meteorological Organization (WMO), Global Atmosphere Watch Programme (GAW). GAW Report No. 217, 62p., https://library.wmo.int/idurl/4/55147

Creutzig, F, S Lohrey, X Bai, A Baklanov, R Dawson, S Dhakal, WF Lamb (2019) Upscaling urban data science for global climate solutions. Global Sustainability 2, e2, https://doi.org/10.1017/sus.2018.16

Grimmond S., Tang Xu, Baklanov A., 2014: Towards integrated urban weather, environment and climate services. *WMO Bulletin* 63 (1) 10-14.

Grimmond, S., V. Bouchet, L.T. Molina, A. Baklanov, et al., (2020) Integrated urban hydrometeorological, climate & environmental services: Concept, methodology and key messages, Urban Climate, https://doi.org/10.1016/j.uclim.2020.100623

Misumi R. et al (2019) Results of the Tokyo Metropolitan Area Convection Study for Extreme Weather Resilient Cities (TOMACS). BAMS, 2027–2041, DOI: https://doi.org/10.1175/BAMS-D-18-0316.1

Nuterman, R., Mahura, A., Baklanov, A., Amstrup, B., Zakey, A. (2021) Downscaling system for modelling of atmospheric composition on regional, urban and street scales, Atmos. Chem. Phys., 21, 11099–11112, 2021 https://doi.org/10.5194/acp-21-11099-2021

Oke, T. R., G. Mills, A. Christen, J. A. Voogt, 2017 : *Urban Climates*. Cambridge University Press, ISBN 0521849500, 525p.

Scheuer S, Haase D, Volk M (2017) Integrative assessment of climate change for fast-growing urban areas: Measurement and recommendations for future research. PLoS ONE 12(12): e0189451. https://doi.org/10.1371/journal.pone.0189451

Sokhi, RS, A Baklanov, KH Schlünzen (Eds.), 2019: Mesoscale Modelling for Meteorological and Air Pollution Applications.. Anthem Press, https://anthempress.com/mesoscale-modelling-for-meteorological-and-air-pollution-applications

Tang X, Sassa K, Brasseur GP, Cullmann J, and Fang Z. (2021). Collaboration in MHEWS through an integrated way. In: Understanding and reducing landslide disaster risk, Eds. K. Sassa, M. et al., 479–497. Cham, Switzerland: Springer.

UN, 2014: 2014 revision of the World Urbanization Prospects. United Nations, Department of Economic and Social Affairs, Population Division, 10 July 2014, New York.

WMO, 2019: Guidance on Integrated Urban Hydro-Meteorological, Climate and Environmental Services, Volume I: Concept and Methodology. Grimmond, S., V Bouchet, L Molina, A Baklanov, P Joe, etc. World Meteorological Organization, Publication #1234, 52p. https://library.wmo.int/idurl/4/56760

WMO, 2021: Guidance on Integrated Urban Hydro-Meteorological, Climate and Environmental Services, Volume II: Demonstration Cities. World Meteorological Organization, Publication #1234, 166p. https://library.wmo.int/idurl/4/57316

WMO, 2023: Guidance on measuring, modelling and monitoring the canopy layer urban heat island (CL-UHI). Schlünzen K.H., Grimmond S., Baklanov A. (eds.), WMO-No. 1292, 88p,https://library.wmo.int/index.php?lvl=notice_display&id=22236

WMO-GIZ, 2023: Integrated Urban Climate, Weather and Environment Systems for Climate-smart and Resilient Cities: Thailand study (IUC4CRC). Grant Agreement with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). PI A.Baklanov, World Meteorological Organization (WMO), Geneva, Switzerland. 28.03.2023.

WWOSC Book: Seamless Prediction of the Earth System: from Minutes to Months, (G Brunet, S Jones, PM Ruti Eds.), (WMO-No. 1156), Geneva, 2015 (Chapters 12 and 18), http://library.wmo.int/pmb_ged/wmo_1156_en.pdf

Yang, J., Yu, W., Baklanov, A. et al. Mainstreaming the local climate zone framework for climate-resilient cities. Nature Communication 16, 5705 (2025). https://doi.org/10.1038/s41467-025-61394-w

Zhang, Y. and A. Baklanov (Eds), 2020: Training Materials and Best Practices for Chemical Weather /Air Quality Forecasting (CW-AQF), WMO ETR-6, 587 pages, https://library.wmo.int/doc_num.php?explnum_id=10439

Zilitinkevich S.S., Kulmala M., Esau I., Baklanov A., 2015: Megacities – Refining Models to Client Environment. WMO Bulletin, Vol. 64(1), 20-22.

4 *The urban hackathon*: Ideas and expected outcomes

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4.1 Introduction

"Smart cities need smart solutions". This ***maxima*** has become a commonplace of the perpetual search for sustainable environmental, managerial, architectural, and socioeconomic solutions of the modern urban development challenges. The idea of smart cities has undergone an impressive evolution. In their early days, smart city developers were seeking for a total separation of anthropic and natural environments in a city under "glass dome" as presented, e.g., by a famous architect Ralph Erskin for the cities at the North (Erskine, 1968; Jull, 2016). Later, a concept of so-called "winter city" became more popular. A winter city embraces integration of urban development with natural and climatic environments in which the city is embedded (Pressman, 1996). Urban sustainability were considered as the result of nature-based solutions, an architecture of co-adaptations of socioeconomic and physical environments (Kabisch et al., 2016; Raymond et al., 2017). This development of a humanistic concept of a smart city went in parallel with the development of another kind – the technocratic development that makes its accent on technological and above all on information and communication sort of solutions (Jiang et al., 2022). Only very recently these "humanistic" and "technocratic" concepts of a smart city began to converge. Today, the International Standard Organization (ISO) defines a smart city in its ISO-37122:2019 document as the city that: "*increases the pace at which is provides social, economic and environmental sustainability outcomes and responds to challenges such as climate change, rapid population growth, and political and economic instability by fundamentally improving how it engages society, applies collaborative leadership methods, works across disciplines and city systems, and uses data information and modern technologies to deliver better services and quality of life … without unfair disadvantage of others or degradation of natural environment.*" [1]

The concept of smart cities has been criticized for its techno-centricity and somewhat peripheral attention to the citizens and urban environmental sustainability (Raspotnik et al., 2020). A visionary study of future smart cities by Batty et al. (2012) has predominantly discussed the effects of digitalization as well as the impact of information and communication technologies. The European Parliament has stated: "*The idea of smart cities is rooted in the creation and connection of human capital, social capital and information and communication technology (ICT) infrastructure to generate greater and more sustainable economic development and a better quality of life.*"[2] Although ecological and air quality problems were acknowledged as roots of the broader life quality challenges in city (Batty et al., 2012), their solution has been

[1] https://www.iso.org/standard/69050.html, accessed March 30, 2025.
[2] European Parliament. (January 2014). Mapping Smart Cities in the EU. http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/507480/IPOL-ITRE_ET(2014)507480_EN.pdf, accessed March 31, 2019.

subordinated to the technology of digital twins, i.e. digital models and interacting urban components, that are expected to resolve the complexity of the city as a system (Caldarelli et al., 2023), (Deren et al., 2021). In India's "Smart City Mission" context, "smart solutions" fall within the realms of e-governance, management of waste, water and energy, and urban mobility but fail to relate to urban green space and forest management (Dwevedi et al., 2018). The examples of techno-centric projects could be easily multiplied (Gracias et al., 2023), (Silva et al., 2018).

By contrast, Jiang et al. (2020) study, that compared urban governance in the Global North (Helsinki, Finland) and the Global South (Singapore), calls for a ''smart urban governance'' that moves away from the techno-centered to a human-centered way of governing smart cities. The authors conceptualized this move to smart governance with the following diagram (Figure 1). The diagram highlights that a socio-spatial context of a smart city would be invalid without access to information about the state of the urban physical environment and its embedding spatial component.

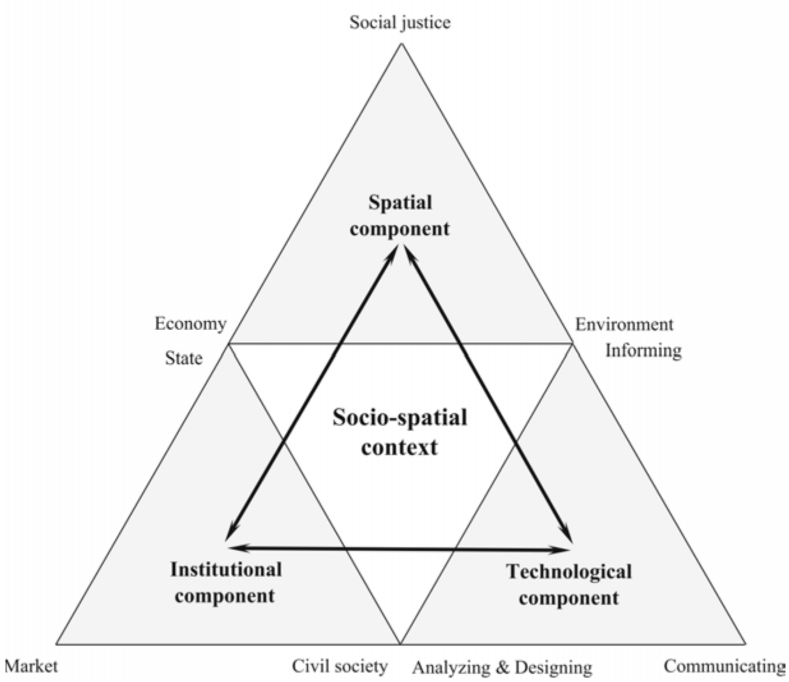

Figure 1. The conceptual components of the smart urban governance according to Jiang et al. (2020).

Increasing number of case studies in both northern and southern cities make notes on the high relevance of the urban spatial component and environmental processes therein. High-resolution meteorological data and climate models were found essential for smart city governance (Chapman et al., 2015). Spatially-resolving models have proved to be necessary to minimize the population exposure to air pollution and other detrimental environmental factors (Wolf et al., 2021; Zhang et al., 2021). Smart urban forest projects (Nitoslawski et al., 2019) reveal a knowledge gap related to socio-environmental interactions, defined here as interactions between society and its physical environments in the city. The potential of digital infrastructure and new data technologies is not fully utilized to enhance and facilitate citizen stewardship and empowerment in governing urban space.

This contribution looks at ideas and perspectives of productive utilization of digital technologies to "smartening" of the urban physical environment. We deliberately embrace here the human-centric concept of a smart city. In this concept, technologies are subordinated to the holistic decision-making process that serves interests of urban society. Smartening in this concept must deliver a better quality of life, eliminate without unfair burden or degradation of natural environment. Due to the remaining knowledge gaps and previous overfocus on technology, smart solutions for such smart cities are still sparce, fragmented, and contested. In such circumstances, a participatory co-production approach might bring significant benefits and accelerate the process of "smartening". Here, we consider the approach through urban hackathons as described below.

4.2 What is an urban hackathon?

A ***hackathon*** is a special kind of workshop in which people come together to state, discuss, and solve problems by means of collaborative brainstorming. The term "hackathon" has been coined by professionals in digital information and communication technology and reflects their goal to hack or to solve a concrete technical problem or to open access to some sort of data or computing systems. The learning theory embraced and reframed this term in recognition of a specific learning environment, which is characterized by the "presence of a high density of high-skilled people in a given area" (Jaskiewicz et al., 2019). The participants of a hackathon are expected to transform ideas into models, designs, and programs that can later improve and extend the status quo. The learning theory does not specify what kind of skills should be present at the hackathon.

A civic ***(urban) hackathon*** is focused on improving city services, city governance, and promoting the use of open data. Urban hackathons could be further narrowed to a search for nature-based environmental solutions, e.g., solutions to monitor and improve urban air quality, that are based on smart city technologies. An urban hackathon as a collaborative learning event aims to share expertise and knowledge. It ultimate while not always achievable goal is to develop cross- and trans-disciplinary solutions to complex, often wicked, problem related to smartening of cities. Participants of the urban hackathon come from various disciplines (technology, urban planning, environmental science, and community activism, etc.), but all of them united to develop innovative solutions that integrate urban governance components, as illustrated in Figure 1. The goal is to enhance urban sustainability, resilience, and livability by leveraging nature-based approaches within the framework of smart city technologies.

It is important to emphasize that while traditional conferences focus more on transferring knowledge, traditional hackathons focus more on solution (software) development, urban hackathons are more about collaboratively generating solutions, societal engagement, and science promotion. Three main factors contribute to successful urban hackathons as social learning events (Jaskiewicz et al., 2019). These factors are: (a) supporting individuals in obtaining specific expert knowledge and skills, (b) nurturing data literacy in communities of practice, and (c) enabling participants to prototype open-data services.

Urban hackathons are relatively uncharted territory within the field of learning as well as for academia in general. Scarce literature, e.g., (Yuan and Gasco-Hernandez, 2021), on learning and open innovation in hackathons put the emphasis combining and improving a wide array of skills by working together across disciplines in contexts that may vary greatly across cultures, and between communities involved in the hackathons.

4.3 Format of an urban hackathon

The hackathon format presumes that the participants' focus on the "making" of concrete services or products through a learning-by-doing approach. Joint making activities shall accelerate developing across disciplines and promote rigorous multidisciplinary methods, strategies and metrics. In this way, the hackathon format is designed to facilitate starts of ambitious projects and enable effective knowledge/expertise transfer and learning. It is expected that communities of practice will emerge where participants share skills and perform routines of collaboration (Vuorikari et al., 2022).
A typical urban hackathon is usually a small (less than 100 participants) and diverse (because of its intrinsic cross-disciplinarity) event. This human-centric orientation of urban hackathons dramatically distinct them from their techno-centric counterparts. The latter are often (but not necessarily) large and narrow-steered events – the type of gatherings that are efficient in solving a concrete problem to which a concrete and final working solution could be thought. Since urban hackathons deal with ill-posed and wicked socially loaded problems, such concrete solutions could not be thought of, and hence, they are rather activities to discuss feasible approaches, to learn from available expertise, and to build up skills and capacity of the participants. Thus, in essence, a hackathon is a 2-3 day "pressure-cooker" event where both experts and non-expert stakeholders are involved. Urban hackathon format is open for inclusion of citizens with no prior knowledge of coding or other data skills in joint making of a preliminary prototype of a technological product or service, using one or more forms of open data (Jaskiewicz et al., 2019).

Figure 2. A scheme illustrating a typical hackathon timeline and steps (Gama et al., 2018).

Nevertheless, the urban hackathon has a well-defined structure, steps, and timeline, i.e., the organizational elements that ensure effective production of knowledge and mutual learning. Those elements are shown in Figure 2 after Gama et al. (2018).

The hackathon timeline consists of:

1. **Pre-Hackathon Preparation:**
    a. *Theme Selection*: Organizers define the specific focus on nature-based solutions, such as green infrastructure, urban biodiversity, or ecosystem services.
    b. *Participant Recruitment*: Diverse participants are invited, including technologists, ecologists, urban planners, designers, and community representatives.
    c. *Resource Gathering*: Relevant data sets, tools, and technologies are assembled to support participants in developing solutions.
2. **Kick-off and Orientation:**
    a. *Introduction Session*: Participants are briefed on the hackathon's objectives, rules, and available resources.
    b. *Expert Talks*: Subject matter experts provide insights into nature-based solutions and smart city technologies to inspire participants.
3. **Team Formation and Ideation:**
    a. *Networking Activities*: Participants engage in activities to form interdisciplinary teams.
    b. *Brainstorming Sessions*: Teams identify specific challenges related to urban nature-based solutions and begin ideating potential projects.

4. **Development Phase:**
    a. *Prototyping*: Teams work on developing prototypes or models of their proposed solutions, using available data and technology.
    b. *Mentorship*: Mentors from relevant fields provide guidance and feedback to help refine ideas and ensure feasibility.
5. **Presentation and Evaluation:**
    a. *Pitch Sessions*: Teams present their solutions to a panel of judges, highlighting the innovation, impact, and scalability of their projects.
    b. *Judging Criteria*: Solutions are evaluated based on criteria such as creativity, practicality, environmental impact, and potential for implementation.
    c. *Prizes*: Winning teams receive awards, which may include funding, incubation opportunities, or partnerships with city governments or environmental organizations.
    d. *Showcase*: Successful projects are showcased to stakeholders, including city officials, investors, and the public.
6. **Post-Hackathon Follow-up:**
    a. *Implementation Support*: Organizers facilitate connections between teams and relevant stakeholders to support the implementation of viable solutions.
    b. *Feedback and Reflection*: Participants provide feedback on the hackathon experience, and organizers reflect on outcomes to improve future events.

A common result of a hackathon includes novel approaches dealing with challenges but rarely a concrete software solution. In such a sense, an urban hackathon is a difficult and often inconclusive exercise. The learning processes were proven to be more complex and challenging to leverage the initially expected outcome, perhaps due to considerable diversity of participants and cases. Jaskiewicz et al. (2019) attribute this difficulty to a generally shared lack of explicitly articulated motivations to participate in the hackathon. Despite all the enthusiasm of participants of our hackathon in Kochi (November 2024), we experienced similar difficulties.

4.4 Expected Outcomes of an Urban Hackathon: Innovating Smart Cities

The format and contents of the urban hackathon are optimal for their main goal – innovating smart cities. We have already mentioned the specifics of such events: open exchange of ideas; trans-, cross-, and multi-disciplinary research; open data and modeling; and finally, co-production with non-expert stakeholders. Thus, the urban hackathon cannot be considered as a techno-centered exercise but is seen as an exercise in urban system dynamics. Figure 3 (Bai et al., 2016) illustrates this idea of smart cities as an open multilayered system of systems. Correspondingly, we may expect the outcomes of the urban hackathon to transform disconnected diversity of targeted solutions (micro-solutions) into interlinked systems of solutions addressing the urban nexus.

The difference between the targeted and nexus solutions is perhaps the most important characteristics that specify the difference in the outcomes between traditional techno-centered and civic hackathons. By focusing on nature-based solutions for smart cities, the urban hackathons may have outcomes that harmonize the ecological and economic nexus in the cities. For example, a hackathon could search for an innovative approach to improve urban air quality without excessive economic burden on economic activity and life standards of citizens.

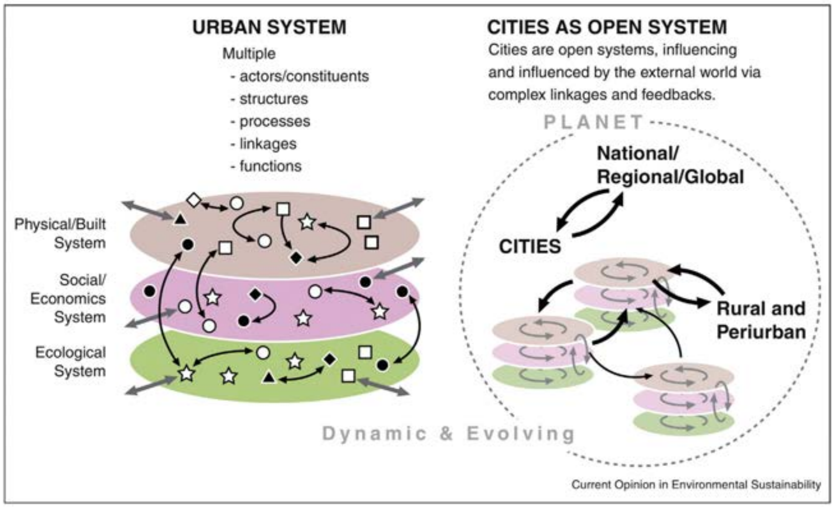

Figure 3. Schematic illustration of an open urban systems' dynamics (Bai et al., 2016).

4.5 The urban hackathon on air quality in smart cities

Now, we will describe a concrete example of urban hackathons, namely, the hackathon organized by the URSA-MAJOR research schools' project in the city of Kochi, India, in November 2024. Following the experience in (Jaskiewicz et al., 2019), this hackathon focused on open data and models that could be applied to solve the air quality and urban public space challenges that cities in both the Global South and the Global North experience. As expected, many participants initially showed insufficient motivation and weak inclination towards the proposed multi-disciplinary project work. To some, the learning curve was steep as it required to look at the problem from out the box. Inspiration was found in performing ad-hoc data visualizations, storytelling, and simply browsing through available datasets and discovering intriguing facts. Nevertheless, the choice of air quality in smart cities as the focus of the hackathon held the activity up and intensive. The air quality challenge is an essential part of the urban environmental nexus (which also includes water quality, waste disposal, and urban space management), and hence, it was intuitively understood by participants as an important challenge worth the invested efforts.

Air quality in smart cities requires cross- and multi-disciplinary approach as it integrates data and modeling across scales (Myeong and Shahzad, 2021). Experience with Integrated Urban Services (Baklanov et al., 2020) encourages approaches that seamlessly combine different physical and data-driven models. This seamless combination is to be explored and developed to concrete technological solutions. This is the focal point where our urban hackathon could become a value.

Conceptually, the Kochi hackathon combines the projects that explore the decision-making processes (the social group), the data acquisition and analysis, the results attribution and transformation, and the core air-quality and climate modeling. The whole interaction process was overlooked by recognized experts in the fields, whereas the integrative research lines were supervised by Prof. Alexander Baklanov (Baklanov et al., 2018).

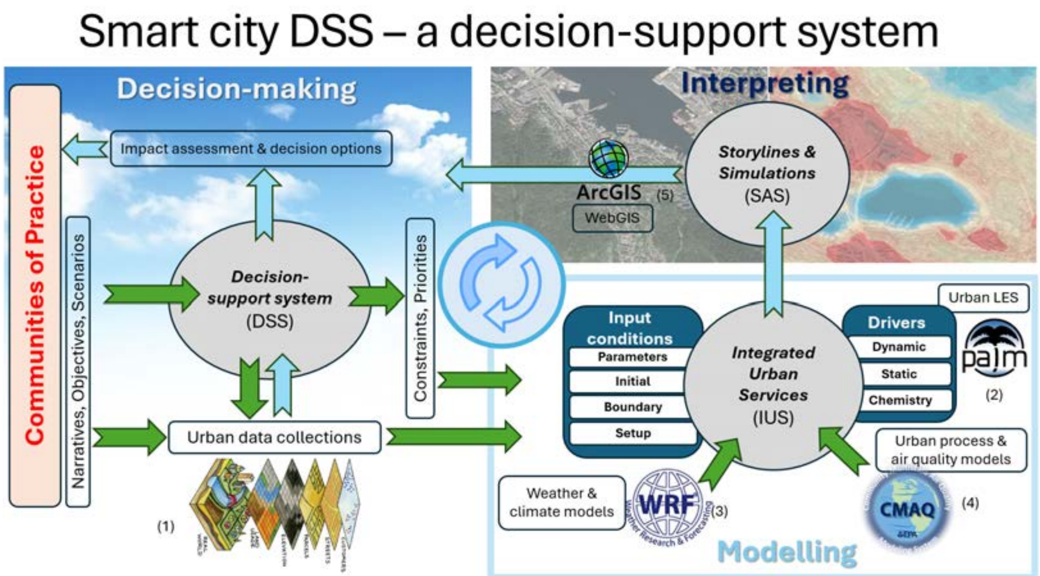

Figure 4. The concept of a model-enhanced decision-support system for a smart city (Esau et al., 2024).

Our urban hackathon was designed to pivot cross-disciplinary interactions, but unfortunately missed trans-disciplinarity because participants did not have access to any existing decision-support system. Nevertheless, all three parts of the concept in Figure 4 were included in the group's discourse and operationalize through training exercises. Specifically, Storylines and Simulations (SAS) that integrates *qualitative (expert narratives) and quantitative (model simulations)* scenarios, was extended from the studies (Alcamo, 2008; Houet et al., 2016) to Web-GIS storytelling as presented in (Miles et al., 2023).
By integrating air quality modeling into hackathon projects, participants created solutions that are not only technologically advanced but also socially impactful. These initiatives can help bridge the gap between urban socioeconomic and physical environments, leading to healthier and more sustainable cities.

4.6 Conclusions

The urban hackathons offer a unique opportunity to address complex urban environmental issues by combining technological innovation with a deep understanding of urban dynamics. Through collaborative efforts, these events can contribute to the development of smarter, cleaner, and more equitable urban environments on local, regional, and global scales. The theory and

concepts of the urban hackathons have been successfully tested during the URSA MAJOR hackathon in Kochi, India, in November 2024. The main ideas – related to development of an integrated urban decision-support system enhanced by seamlessly coupled models – have proved their robustness and efficiency when discussed in diverse auditorium of techno-experts, non-experts (students and stakeholders), and human-oriented visioners.
Our experience was drastically different from what is typically delivered at traditional scientific conferences where participants learn from others' results. In this sense, our hackathon was an "unconference" – i.e., a gathering that promote spontaneous discussions and collaborative projects rather than predetermined presentations. Following 10 hackathon rules as defined in (Garcia et al., 2020), the hackathon was able to leverage urban sustainability ideas and deliver a set of concrete outcomes.

4.7 References

Alcamo, Joseph, 2008. Chapter Six The SAS Approach: Combining Qualitative and Quantitative Knowledge in Environmental Scenarios, in: Alcamo, J. (Ed.), Environmental Futures: The Practice of Environmental Scenario Analysis. Elsivier, Amsterdam, pp. 123–150. https://doi.org/10.1016/S1574-101X(08)00406-7

Bai, X., Surveyer, A., Elmqvist, T., Gatzweiler, F.W., Güneralp, B., Parnell, S., Prieur-Richard, A.H., Shrivastava, P., Siri, J.G., Stafford-Smith, M., Toussaint, J.P., Webb, R., 2016. Defining and advancing a systems approach for sustainable cities. Curr. Opin. Environ. Sustain. 23, 69–78. https://doi.org/10.1016/j.cosust.2016.11.010

Baklanov, A., Cárdenas, B., Lee, T. cheung, Leroyer, S., Masson, V., Molina, L.T., Müller, T., Ren, C., Vogel, F.R., Voogt, J.A., 2020. Integrated urban services: Experience from four cities on different continents. Urban Clim. 32. https://doi.org/10.1016/j.uclim.2020.100610

Baklanov, A., Grimmond, C.S.B., Carlson, D., Terblanche, D., Tang, X., Bouchet, V., Lee, B., Langendijk, G., Kolli, R.K., Hovsepyan, A., 2018. From urban meteorology, climate and environment research to integrated city services. Urban Clim. 23, 330–341. https://doi.org/10.1016/j.uclim.2017.05.004

Batty, M., Axhausen, K.W., Giannotti, F., Pozdnoukhov, A., Bazzani, A., Wachowicz, M., Ouzounis, G., Portugali, Y., 2012. Smart cities of the future. Eur. Phys. J. Spec. Top. 214, 481–518. https://doi.org/10.1140/epjst/e2012-01703-3

Caldarelli, G., Arcaute, E., Barthelemy, M., Batty, M., Gershenson, C., Helbing, D., Mancuso, S., Moreno, Y., Ramasco, J.J., Rozenblat, C., Sánchez, A., Fernández-Villacañas, J.L., 2023. The role of complexity for digital twins of cities. Nat. Comput. Sci. 3, 374–381. https://doi.org/10.1038/s43588-023-00431-4

Chapman, L., Muller, C.L., Young, D.T., Warren, E.L., Grimmond, C.S.B., Cai, X.-M., Ferranti, E.J.S., 2015. The Birmingham Urban Climate Laboratory: An Open Meteorological Test Bed and Challenges of the Smart City. Bull. Am. Meteorol. Soc. 96, 1545–1560. https://doi.org/10.1175/BAMS-D-13-00193.1

Deren, L., Wenbo, Y., Zhenfeng, S., 2021. Smart city based on digital twins. Comput. Urban Sci. 1, 4. https://doi.org/10.1007/s43762-021-00005-y

Dwevedi, R., Krishna, V., Kumar, A., 2018. Environment and Big Data: Role in Smart Cities of India. Resources 7, 64. https://doi.org/10.3390/resources7040064

Erskine, R., 1968. Architecture and town planning in the north. Polar Rec. (Gr. Brit). 14, 165–171. https://doi.org/10.1017/S003224740005659X

Esau, I., Belda, M., Miles, V., Geletič, J., Resler, J., Krč, P., Bauerová, P., Bureš, M., Eben, K., Fuka, V., Jareš, R., Karel, J., Keder, J., Patiño, W., Pettersson, L.H., Radović, J., Řezníček, H., Šindelářová, A., Vlček, O., 2024. A city-scale turbulence-resolving model as an essential element of integrated urban services. Urban Clim. 56, 102059. https://doi.org/10.1016/j.uclim.2024.102059

Gama, K., Alencar, B., Calegario, F., Neves, A., Alessio, P., 2018. A Hackathon Methodology for Undergraduate Course Projects, in: 2018 IEEE Frontiers in Education Conference (FIE). IEEE, pp. 1–9. https://doi.org/10.1109/FIE.2018.8659264

Garcia, L., Antezana, E., Garcia, A., Bolton, E., Jimenez, R., Prins, P., Banda, J.M., Katayama, T., 2020. Ten simple rules to run a successful BioHackathon. PLOS Comput. Biol. 16, e1007808. https://doi.org/10.1371/journal.pcbi.1007808

Gracias, J.S., Parnell, G.S., Specking, E., Pohl, E.A., Buchanan, R., 2023. Smart Cities—A Structured Literature Review. Smart Cities 6, 1719–1743. https://doi.org/10.3390/smartcities6040080

Houet, T., Marchadier, C., Bretagne, G., Moine, M.P., Aguejdad, R., Viguié, V., Bonhomme, M., Lemonsu, A., Avner, P., Hidalgo, J., Masson, V., 2016. Combining narratives and modelling approaches to simulate fine scale and long-

term urban growth scenarios for climate adaptation. Environ. Model. Softw. 86, 1–13. https://doi.org/10.1016/j.envsoft.2016.09.010
Jaskiewicz, T., Mulder, I., Morelli, N., Pedersen, J., 2019. Hacking the hackathon format to empower citizens in outsmarting "smart" cities. Interact. Des. Archit. 8–29. https://doi.org/10.55612/s-5002-043-001
Jiang, H., Geertman, S., Witte, P., 2022. Smart urban governance: an alternative to technocratic "smartness." GeoJournal 87, 1639–1655. https://doi.org/10.1007/s10708-020-10326-w
Jull, M., 2016. Toward a Northern Architecture: The Microrayon as Arctic Urban Prototype. J. Archit. Educ. 70, 214–222. https://doi.org/10.1080/10464883.2016.1197672
Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Haase, D., Knapp, S., Korn, H., Stadler, J., Zaunberger, K., Bonn, A., 2016. Nature-based solutions to climate change mitigation and adaptation in urban areas: Perspectives on indicators, knowledge gaps, barriers, and opportunities for action. Ecol. Soc. 21. https://doi.org/10.5751/ES-08373-210239
Miles, V., Esau, I., Pettersson, L., 2023. Using web GIS to promote stakeholder understanding of scientific results in sustainable urban development: A case study in Bergen, Norway. Sustain. Dev. 1–13. https://doi.org/10.1002/sd.2787
Myeong, S., Shahzad, K., 2021. Integrating Data-Based Strategies and Advanced Technologies with Efficient Air Pollution Management in Smart Cities. Sustainability 13, 7168. https://doi.org/10.3390/su13137168
Nitoslawski, S.A., Galle, N.J., Van Den Bosch, C.K., Steenberg, J.W.N., 2019. Smarter ecosystems for smarter cities? A review of trends, technologies, and turning points for smart urban forestry. Sustain. Cities Soc. 51, 101770. https://doi.org/10.1016/j.scs.2019.101770
Pressman, N.E.P., 1996. Sustainable winter cities: Future directions for planning, policy and design. Atmos. Environ. 30, 521–529. https://doi.org/10.1016/1352-2310(95)00012-7
Raspotnik, A., Grønning, R., Herrmann, V., 2020. A tale of three cities: the concept of smart sustainable cities for the Arctic. Polar Geogr. 43, 64–87. https://doi.org/10.1080/1088937X.2020.1713546
Raymond, C.M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M.R., Geneletti, D., Calfapietra, C., 2017. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. Environ. Sci. Policy 77, 15–24. https://doi.org/10.1016/j.envsci.2017.07.008
Silva, B.N., Khan, M., Han, K., 2018. Towards sustainable smart cities: A review of trends, architectures, components, and open challenges in smart cities. Sustain. Cities Soc. 38, 697–713. https://doi.org/10.1016/j.scs.2018.01.053
Vuorikari, R., Kluzer, S., Punie, Y., 2022. DigComp 2.2: The Digital Competence Framework for Citizens - With new examples of knowledge, skills and attitudes. Publications Office of the European Union, Luxembourg. https://doi.org/10.2760/490274
Wolf, T., Pettersson, L.H., Esau, I., 2021. Dispersion of particulate matter (PM2.5) from wood combustion for residential heating: optimization of mitigation actions based on large-eddy simulations. Atmos. Chem. Phys. 21, 12463–12477. https://doi.org/10.5194/acp-21-12463-2021
Yuan, Q., Gasco-Hernandez, M., 2021. Open innovation in the public sector: creating public value through civic hackathons. Public Manag. Rev. 23, 523–544. https://doi.org/10.1080/14719037.2019.1695884
Zhang, Y., Ye, X., Wang, S., He, X., Dong, L., Zhang, N., Wang, H., Wang, Z., Ma, Y., Wang, L., Chi, X., Ding, A., Yao, M., Li, Y., Li, Q., Zhang, L., Xiao, Y., 2021. Large-eddy simulation of traffic-related air pollution at a very high resolution in a mega-city: evaluation against mobile sensors and insights for influencing factors. Atmos. Chem. Phys. 21, 2917–2929. https://doi.org/10.5194/acp-21-2917-2021

5 *Technical session 1*: Air quality monitoring and modeling (Day 1 and 2)

5.1 Air Pollution

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Introduction

Air pollution is the introduction of harmful substances, including gases, particles, and biological molecules, into the atmosphere. These pollutants adversely affect human health, ecosystems, and the environment. The World Health Organization (WHO) states that the combined effects of ambient and household air pollution lead to approximately 7 million premature deaths annually.

Definition of Air Pollutants

An air pollutant is any solid, liquid, or gaseous substance (including noise) present in the atmosphere in concentrations that can harm human health, living organisms, or the environment. Air pollution results from these pollutants, which include particulate matter, dust, soot, carbon monoxide, sulfur dioxide, oxides of nitrogen, hydrocarbons, chlorofluorocarbons (CFCs), lead compounds, asbestos dust, pollen, and even radioactive rays.

Sources of Air Pollution

Air pollution originates from multiple sources, categorized into four primary types:

- **Point Sources:** These include emissions from industrial chimneys, factories, and agricultural activities.
- **Area Sources:** Residential areas, gas stations, automotive services, petroleum refineries, mining operations, and construction activities contribute significantly to pollution.
- **Mobile Sources:** On-road vehicles (both light and heavy-duty), trains, ships, and airplanes are mobile contributors to air pollution.
- **Natural Sources:** Volcanic eruptions, forest fires, sea spray, thunderstorms, heavy winds, and pollen dispersion naturally contribute to air pollution.

Primary and Secondary Pollutants

Pollutants are classified into two categories:

- **Primary Pollutants:** Directly released into the atmosphere from sources. Examples include particulate matter (soot, dust), hydrocarbons (HCs), sulfur dioxide (SO_2), nitrogen oxides (NOx), and carbon monoxide (CO).
- **Secondary Pollutants:** Formed by the interaction of primary pollutants with other atmospheric components through physical or chemical reactions. Examples include acid rain, photochemical smog, and peroxyacetyl nitrate (PAN).

Particulate Matter (PM)

Particulate matter is composed of extremely small solid particles and liquid droplets suspended in the air. These particles include nitrates, sulfates, organic chemicals, metals, and allergens like pollen or mold spores.

- **PM10 (Particles ≤10 micrometers in diameter):** Can penetrate the respiratory system and cause lung-related diseases.
- **PM2.5 (Particles ≤2.5 micrometers in diameter):** These fine particles can reach deep into the lungs and enter the bloodstream, leading to serious health risks over long-term exposure.

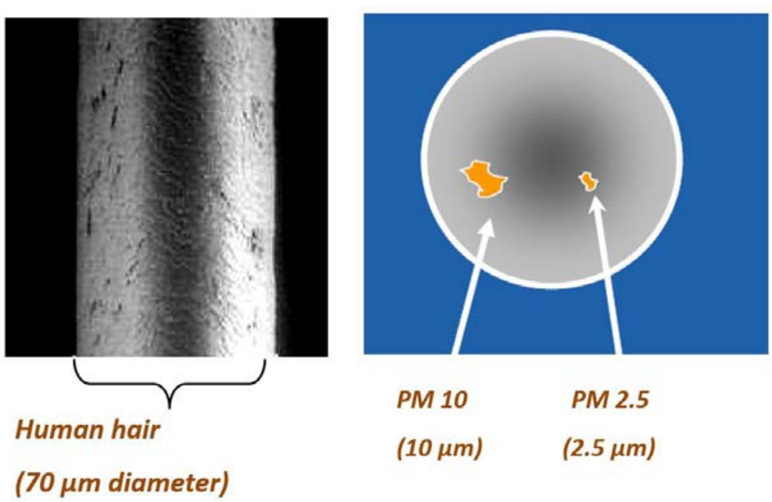


***Figure 1:** A comparison of particulate matter sizes relative to human hair thickness highlights their minute dimensions.*

National Ambient Air Quality Standards (NAAQS)

The Government of India has established air quality standards to regulate pollutant concentrations. These standards determine permissible levels of pollutants like sulfur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter (PM10, PM2.5), ozone (O_3), carbon monoxide (CO), ammonia (NH_3), and benzene.

Pollutant	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural, and Other Areas	Ecologically Sensitive Area (notified by Central Government)
Sulphur dioxide (SO_2), $\mu g/m^3$	Annual 24 hours	50 80	20 80
Nitrogen dioxide (NO_2), $\mu g/m^3$	Annual 24 hours	40 80	30 80
Particulate matter (< 10 µm) or PM_{10}, $\mu g/m^3$	Annual 24 hours	60 100	60 100
Particulate matter (< 2.5 µm) or $PM_{2.5}$, $\mu g/m^3$	Annual 24 hours	40 60	40 60
Ozone (O_3), $\mu g/m^3$	8 hours 1 hour	100 180	100 180
Lead (Pb), $\mu g/m^3$	Annual 24 hours	0.50 1.0	0.50 1.0
Carbon monoxide (CO), mg/m^3	8 hours 1 hour	02 04	02 04
Ammonia (NH_3), $\mu g/m^3$	Annual 24 hours	100 400	100 400
Benzene (C_6H_6), $\mu g/m^3$	Annual	05	05
Benzo(α)Pyrene (BaP) – particulate phase only, ng/m^3	Annual	01	01
Arsenic (As), ng/m^3	Annual	06	06
Nickel (Ni), ng/m^3	Annual	20	20

***Figure 2**: National ambient air quality standards*

Effects of Air Pollution

Effects on Public Health

Exposure to air pollution increases the risk of respiratory infections, cardiovascular diseases, and lung cancer. Children, elderly individuals, and those with pre-existing conditions are more vulnerable. The most harmful pollutant for human health is fine particulate matter (PM2.5), which deeply penetrates lung tissues.

Effects on Buildings and Infrastructure

Air pollution accelerates material degradation through:

- **Abrasion:** Solid particles traveling at high velocities cause surface wear.
- **Deposition and Erosion:** Accumulated pollutants on surfaces can alter their physical integrity.
- **Chemical Attacks:** Pollutants such as sulphur dioxide react with materials like leather and marble, leading to irreversible damage (e.g., acid rain corroding the Taj Mahal).
- **Corrosion:** Metals, including iron, rust faster due to pollutants in the atmosphere.

Figure 3: *Taj Mahal: A dying wonder (Pictorial representation)*

Effects on Plants

Air pollution reduces photosynthesis efficiency, stunts plant growth, and leads to physical damage such as leaf necrosis, premature leaf drop, and stem brittleness. Specific pollutants have distinct impacts:

- **Sulfur dioxide (SO_2):** Reduces chlorophyll content.
- **Nitrogen dioxide (NO_2):** Causes permanent leaf fall.
- **Ozone (O_3):** Induces necrosis, damaging leaves.

Effects on Animals

- **Respiratory and Neurological Issues:** Pollutants such as arsenic and lead cause respiratory distress, loss of appetite, and neurological problems.
- **Endocrine Disruptions:** Some pollutants interfere with hormone functions, affecting reproduction and development in animals.

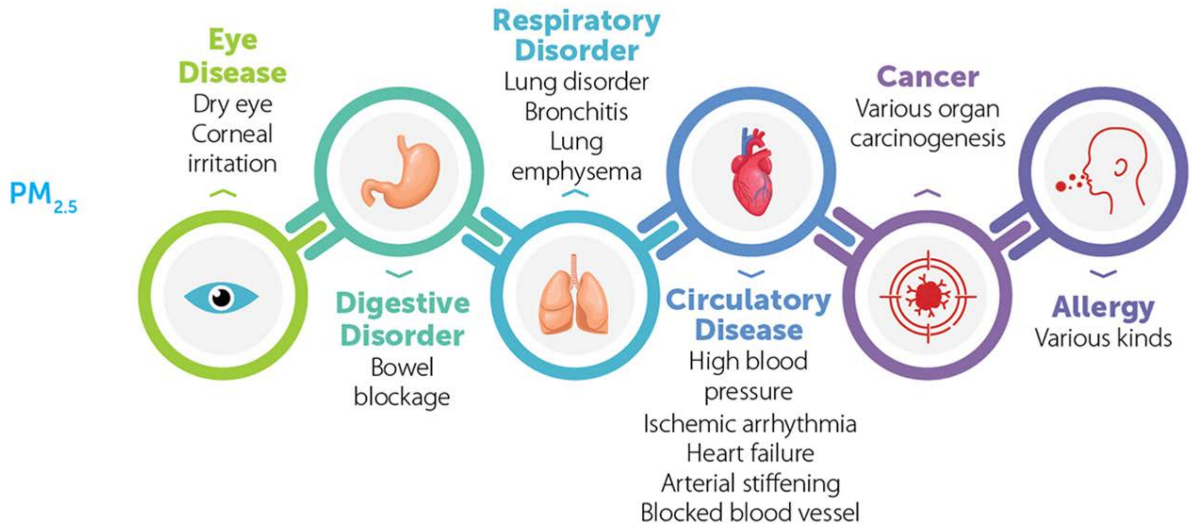


Figure 4: *Health effects of* $PM_{2.5}$

Global Warming and Air Pollution

Air pollution significantly contributes to global warming due to the accumulation of greenhouse gases such as carbon dioxide, CFCs, nitrogen oxides, and ozone.

- **Causes:** Deforestation, fossil fuel combustion, industrial emissions, and vehicle exhaust.
- **Effects:** Increased global temperatures, polar ice melting, rising sea levels, extreme weather conditions, and biodiversity loss.
- **Mitigation Strategies:** Afforestation, use of cleaner fuels, adoption of renewable energy sources, and preventing open burning.

Ozone Layer Depletion

The ozone layer in the stratosphere protects Earth from harmful ultraviolet (UV) radiation. However, chemicals like chlorofluorocarbons (CFCs), halons, and carbon tetrachloride degrade ozone, converting it into oxygen molecules.

- **Key Agreements:**
  - **Montreal Protocol (1987):** Regulated ozone-depleting substances (ODS).
  - **Kigali Agreement (2016):** Discussed control over hydrofluorocarbons (HFCs), which replaced CFCs.

Acid Rain

Acid rain results from high concentrations of sulphur and nitrogen compounds in the atmosphere.

Effects:

- Alters soil composition, affecting agriculture.
- Causes respiratory diseases in humans and animals.
- Corrodes buildings and monuments (e.g., the Taj Mahal).

Air Pollution Control Measures

Preventive Strategies

- Promoting green cover.
- Encouraging vehicle pooling.
- Preventing fuel spillage.

Air Pollution Control Devices (APCDs) in Industries

Industries can minimize emissions using:

- Dust catchers
- Cyclone separators

- Fabric filters (baghouses)
- Electrostatic precipitators
- Scrubbers

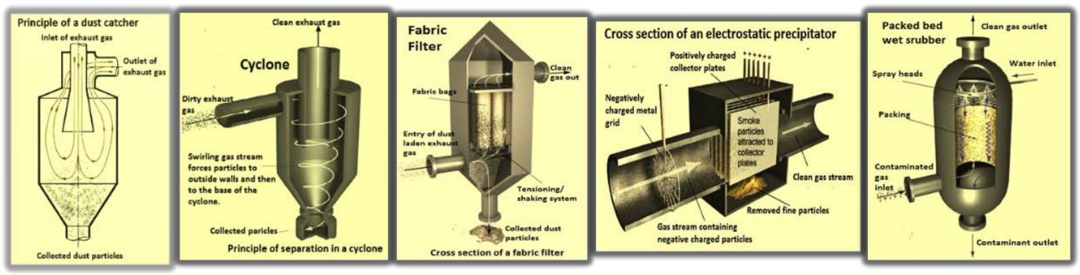


Figure 5: *Illustration of Dust catchers, Cyclones or multi cyclones, Fabric filters (bag houses), Electrostatic precipitators, Scrubbers*

Air Quality Monitoring in Kerala

The Kerala State Pollution Control Board monitors air quality through:

- **National Ambient Air Quality Monitoring Programme (NAMP):** 34 stations.
- **State Ambient Air Quality Monitoring Programme (SAMP):** 6 stations.
- **Continuous Ambient Air Quality Monitoring Stations (CAAQMS):** 9 stations in Kozhikode, Ernakulam, Thiruvananthapuram, Kollam, Kannur, and Thrissur. Parameters monitored: SO_2, CO, PM $_{2.5}$, O_3, PM_{10}, NH_3, NO_X, NO, NO_2, Wind Speed, Wind direction, Temperature, Relative Humidity, Rain, solar Radiation, Pressure

Figure 6: *Continuous Ambient Air Quality Monitoring Stations*

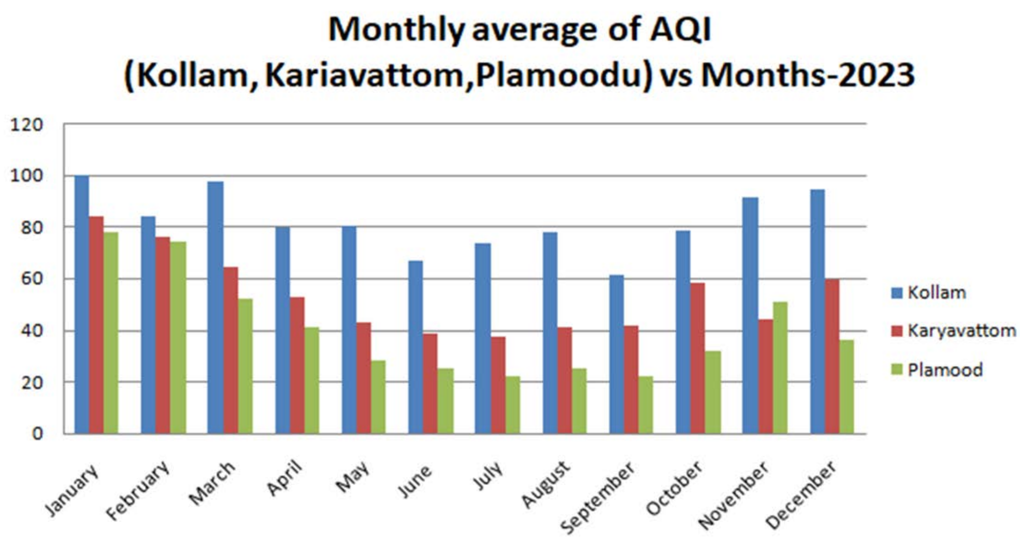


Figure 7: *trend in air quality index (AQI) of CAAQM stations in- 2023*

Air Quality Index (AQI)

AQI is a tool that relates pollutant concentration to public health impact. Higher AQI values indicate greater health risks. The air quality in Kerala generally ranges from "Good" to "Satisfactory," with the highest annual AQI reported in Thrissur (87) and the lowest in Pathanamthitta (30). Comparisons with Delhi highlight Kerala's significantly lower pollution levels.

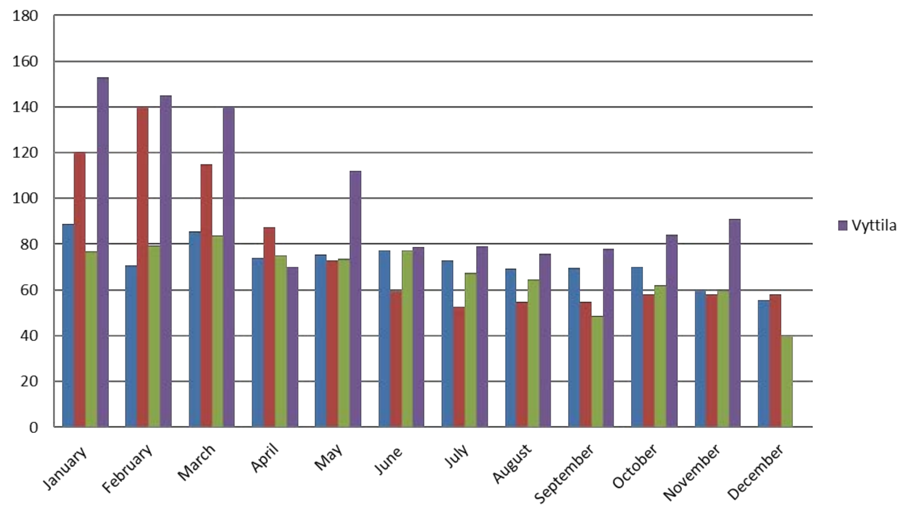


Figure 7: *Monthly average of AQI (Kannur, Thrissur, Eloor, Vyttila) vs Months-2023*

Based on the 2023 Air Quality Index (AQI) data, Kerala's annual average air quality ranges from "Good" to "Satisfactory." The highest annual average AQI was recorded at Ayyanthole in Thrissur district, with a value of 87. Conversely, Makkamkunnu in Pathanamthitta district reported the lowest annual average AQI, registering a value of 30.

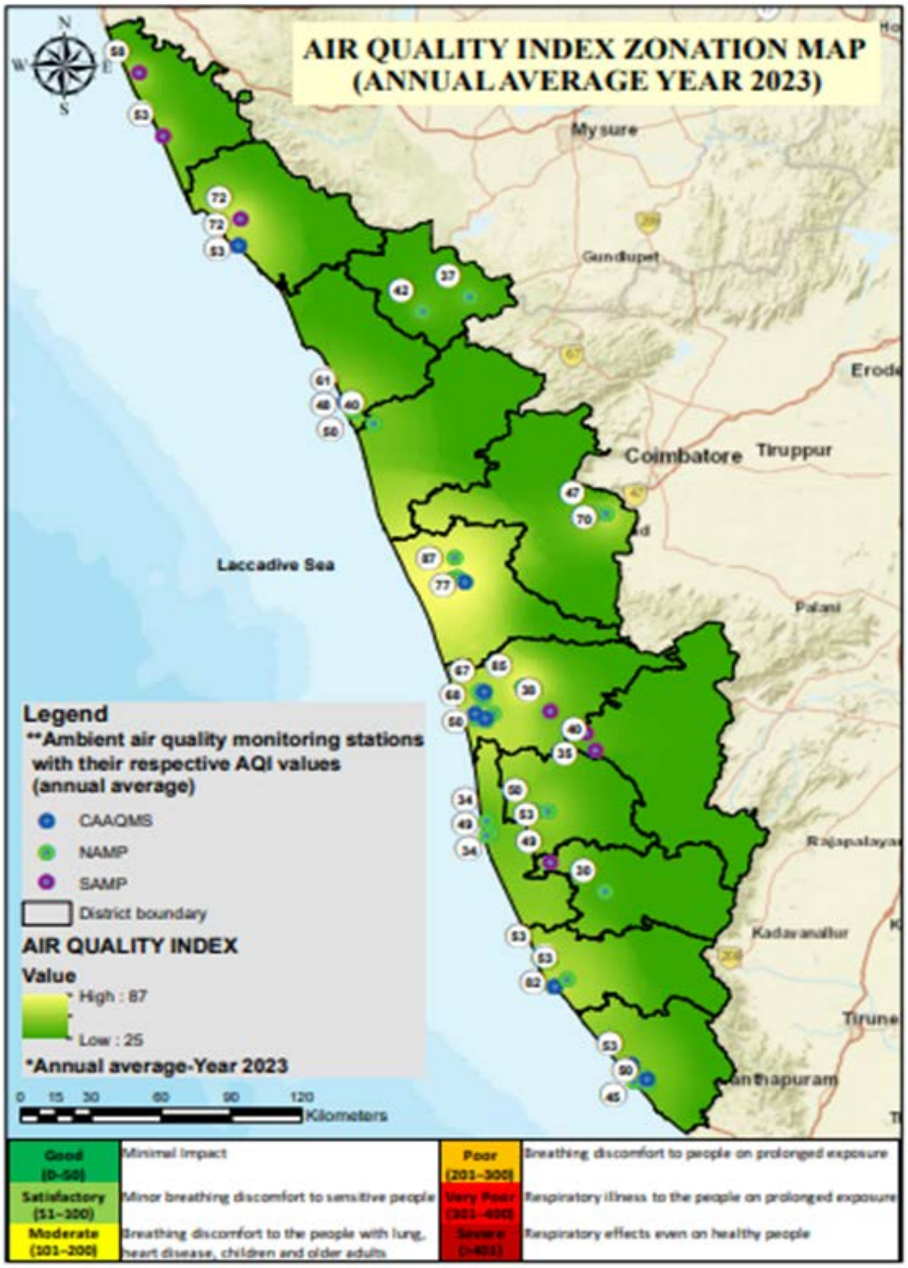


Figure 8: *Air quality index based zonation map of Kerala.*

Recommendations for Air Quality Improvement

Short-Term Actions:

- Enforcing stricter vehicle pollution controls.
- Implementing road dust suppression measures.

- Regulating construction dust.

Long-Term Actions:

- Retrofitting diesel vehicles with particulate filters.
- Installing vapor recovery systems in fuel stations.
- Phasing out old diesel vehicles.
- Expanding green buffer zones along roads.
- Strict enforcement of industrial emission standards.

Conclusion

While Kerala's air quality remains within safer limits, particulate matter is an emerging concern. Continuous monitoring, stringent regulations, and community awareness are crucial to mitigating air pollution and ensuring environmental sustainability.

5.2 An Introduction to Photoacoustic Gas Monitor – A Portable GHG Instrument

Vishnu N G, Research Scholar, School of Environmental Sciences, M G University, Kottayam

Introduction

Greenhouse gas (GHG) monitoring has become an essential aspect of environmental research and climate studies. Traditional methods of gas measurement often face challenges related to accuracy, sensitivity, and real-time data acquisition. The **LumaSense INNOVA 1512 Photoacoustic Gas Monitor** addresses these concerns by employing **photoacoustic infrared spectroscopy**, a highly precise method for detecting gases that absorb infrared light. This portable instrument is particularly useful for monitoring gases such as **carbon dioxide (CO_2), methane (CH_4), and dinitrogen oxide (N_2O)**, which are critical contributors to climate change.

***Figure1**: LumaSense INNOVA 1512 Photoacoustic Gas Monitor*

Working Principle

The INNOVA 1512 utilizes **photoacoustic infrared spectroscopy**, a technique based on the principle that gas molecules absorb infrared light at specific wavelengths, leading to molecular vibrations that generate acoustic waves. These acoustic signals are detected using highly sensitive microphones, and their intensity corresponds to the concentration of the target gas. This non-dispersive infrared (NDIR) method ensures precise measurement while minimizing interference from other atmospheric components.

Unlike conventional gas analyzers, which rely on chemical reactions or thermal conductivity, the photoacoustic method provides direct concentration values in **parts per million (ppm)** with high sensitivity. This makes the instrument highly suitable for field applications where real-time monitoring is required.

Components of the INNOVA 1512 Gas Monitoring System

The photoacoustic gas monitor consists of several key components that work together to ensure accurate measurements. The main unit, **INNOVA 1512**, is connected to a **laptop with specialized software**, enabling data acquisition and analysis. Essential accessories include **Teflon tubes** for gas sampling, **filters** to eliminate particulate interference, a **gas chamber**, and a **power supply**. The instrument requires careful calibration and handling to ensure optimal performance.

Advantages of Photoacoustic Gas Monitoring

One of the most significant advantages of using the INNOVA 1512 is its ability to provide **real-time data** with high accuracy. Unlike conventional gas analysis techniques, which may involve lengthy sample processing, the photoacoustic method delivers instantaneous results. The technology also reduces **measurement errors**, ensuring greater reliability in gas concentration assessments.

Another notable feature is its capability to **monitor multiple gases simultaneously**. This is particularly beneficial in environmental studies, where different GHGs contribute to atmospheric dynamics. The instrument's direct ppm readings further simplify data interpretation, making it an efficient tool for researchers and scientists.

Limitations and Challenges

Despite its numerous advantages, the INNOVA 1512 comes with certain limitations. One of the primary concerns is its **high cost**, which can be a barrier for widespread adoption, especially in developing regions. Additionally, the instrument requires a **continuous power source**, as it does not have an in-built battery. This can limit its usability in remote locations where power availability is a challenge.

Another factor to consider is the need for **proper maintenance and calibration**. The sensitivity of the photoacoustic method necessitates routine checks to ensure accurate performance. Dust or contaminants in the gas chamber can lead to erroneous readings, making it crucial to handle the instrument with care.

5.3 Health Effects of Air Pollution: Exposure Monitoring and Modelling Methods

Dr. Harish C. Phuleria, Associate Professor, Environmental Science & Engineering Department, IIT Bombay

Introduction

Air pollution is a significant public health challenge worldwide, impacting human health through both short-term and long-term exposure. Clean air policies have proven effective in improving public health, as demonstrated by the transformation of cities like Los Angeles, which saw a dramatic improvement in air quality through regulatory measures. Similar improvements have been observed in New Delhi, where air quality significantly improved during lockdowns. These examples highlight that clean air and blue skies are achievable through sustained policy intervention and technological advancements.

Effective air quality management requires a comprehensive understanding of the entire exposure pathway, from pollutant emission to health outcomes. This involves identifying the sources of airborne particulate matter (PM) and gaseous precursors, monitoring ambient air indicators, assessing personal exposure, and evaluating the dose delivered to target tissues. Understanding human health responses involves analyzing the mechanisms of damage and the body's ability to repair itself.

***Figure 1**: Air Quality Transformation – Los Angeles and New Delhi (Before and After)*

Air Pollution and Its Health Effects Across the Lifespan

Air pollution affects human health throughout the lifespan, from prenatal stages to old age. Early exposure to polluted air can result in developmental delays and respiratory conditions in children, while long-term exposure increases the risk of chronic diseases such as cardiovascular illness, respiratory disease, and cancer. The health impact of air pollution extends beyond physical effects, contributing to neurological and cognitive impairments over time.

In India, major causes of mortality are linked to air pollution, including ischemic heart disease, chronic obstructive pulmonary disease (COPD), lower respiratory infections, and stroke. According to the Global Burden of Disease study, air pollution is one of the leading risk factors for premature death and disability in India.

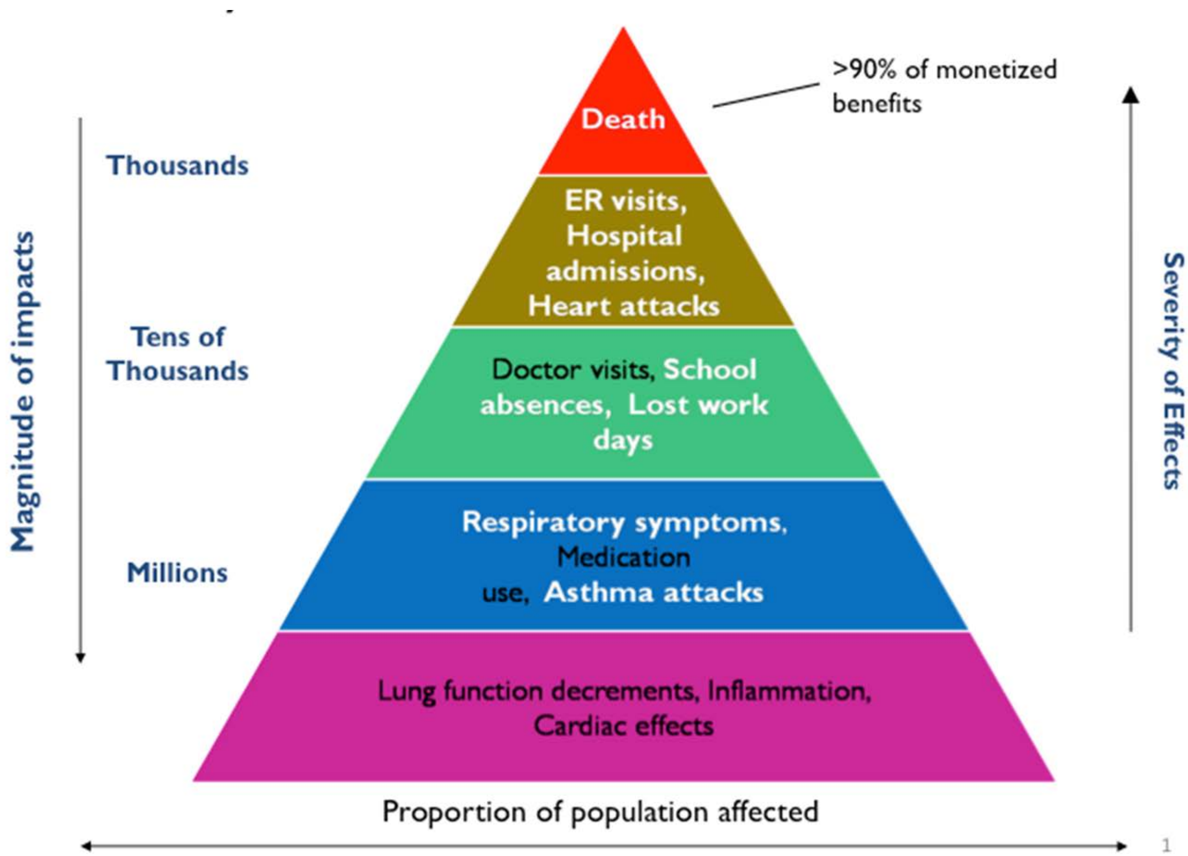


Figure 2: *Pyramid of Effects from Air Pollution – Health Impacts at Different Exposure Levels*

Types of Air Pollution Health Studies

Understanding the relationship between air pollution and health requires multiple research approaches. Epidemiological studies, which provide the bulk of current knowledge, collect observational data on human populations. These studies track both exposure levels and health outcomes to identify correlations between pollution and disease.

Other critical methods include toxicological studies, which analyze the biological effects of pollutants in controlled environments, and controlled exposure studies involving animals and humans to identify the mechanisms by which pollutants cause harm. Together, these methodologies provide a holistic understanding of air pollution's health impacts.

Epidemiological Approaches to Air Pollution Studies

Epidemiological studies focus on understanding the connection between air pollution and human health outcomes through data collection and statistical modeling. These studies typically rely on exposure assessment through a combination of objective measurements, questionnaires, and medical record analysis. Confounding factors such as age, gender, socioeconomic status, and pre-existing health conditions must be accounted for to ensure accurate results.

One significant example is the **Six Cities Study** conducted in the United States from 1974 to 1991. This prospective cohort study linked long-term air pollution exposure to increased mortality, particularly due to fine particulate matter (PM2.5) and sulfate particles.

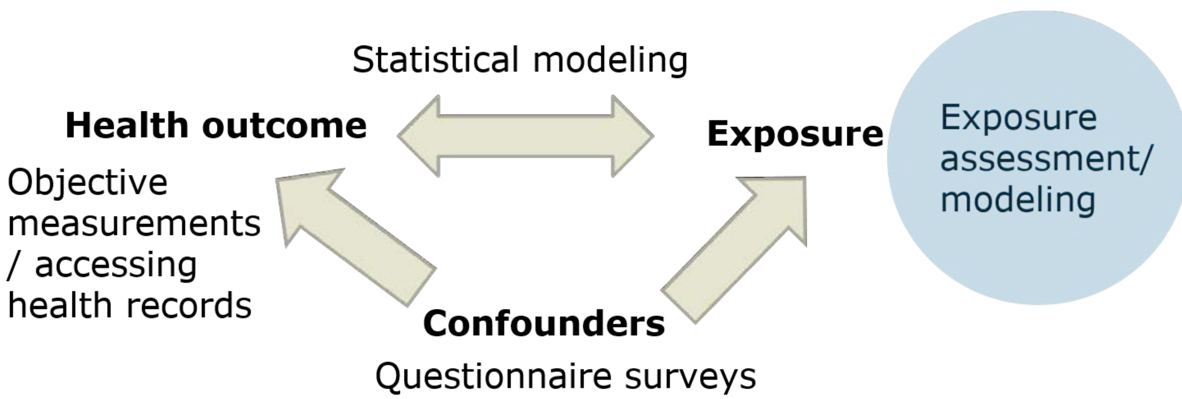


***Figure 3**: Process of Air Pollution Exposure Assessment in Epidemiological Studies*

Particulate Matter (PM) and Its Significance

The size of particulate matter (PM) plays a crucial role in determining its health effects. PM is categorized based on particle diameter:

- **PM10** (particles with a diameter ≤10 µm) can penetrate the upper respiratory tract.
- **PM2.5** (particles with a diameter ≤2.5 µm) is more harmful as it can enter the bloodstream and affect vital organs.
- **Ultrafine particles (UFPs)** are even smaller and may cause cellular damage through oxidative stress.

Studies indicate that PM2.5 has the most substantial evidence linking it to adverse health effects, including respiratory and cardiovascular diseases, cancer, and cognitive decline.

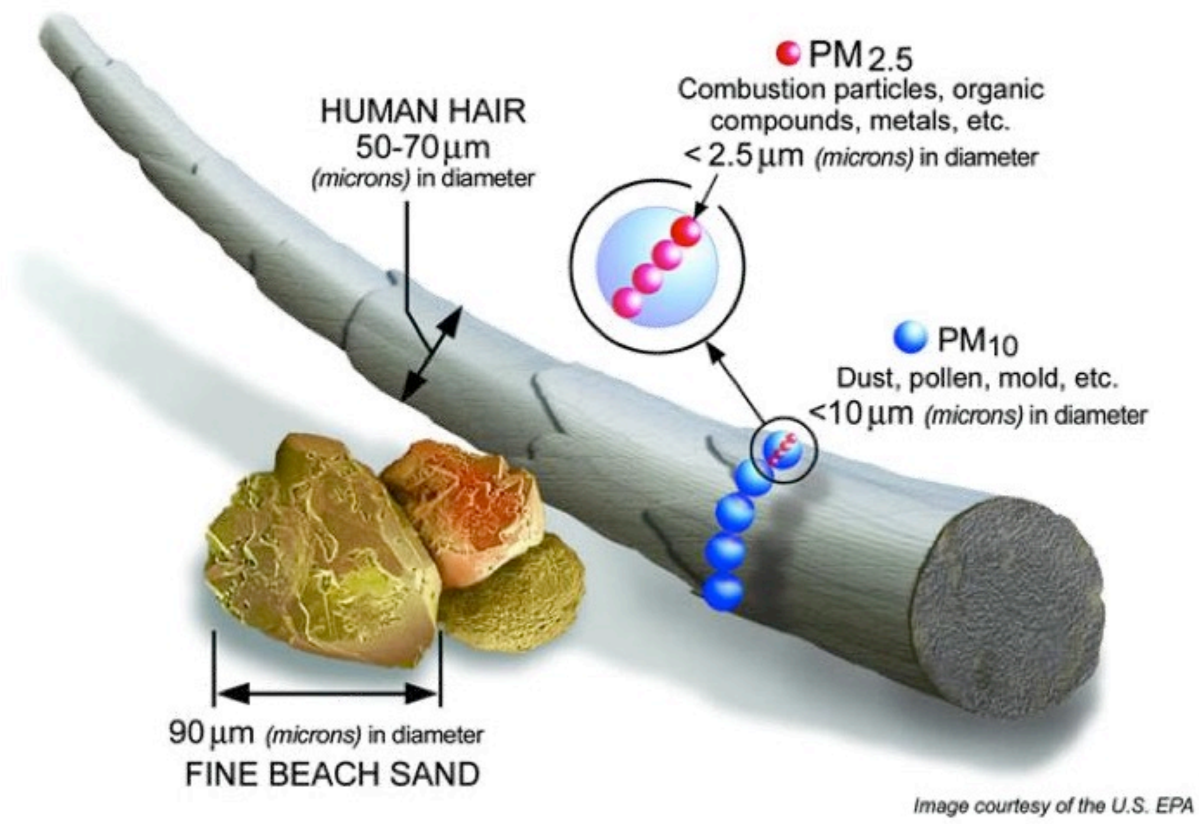


***Figure 4**: Comparison of PM Sizes and Their Penetration in the Human Body*

Monitoring Networks and Data Sources

Effective air quality assessment relies on data from multiple monitoring networks globally. In India, the **Central Pollution Control Board (CPCB)** and **Maharashtra Pollution Control Board (MPCB)** provide real-time air quality data. Internationally, agencies like the **US Environmental Protection Agency (USEPA)** and the **European Environmental Agency (EEA)** maintain extensive databases on air quality.

Monitoring data is crucial for regulatory compliance, epidemiological research, and informing public health policies. Advances in satellite-derived models, such as Aerosol Optical Depth (AOD) estimates, provide supplementary data for regions lacking ground-based monitors.

Air Pollution Exposure Modeling Methods

Since it is impractical to measure pollution everywhere, models play a crucial role in estimating air pollution exposure. Models are used for various purposes, including regulatory compliance, policy evaluation, and epidemiological studies.

Key exposure modeling approaches include:

1. **Land-Use Regression (LUR) Models** – These use geographic and environmental variables to predict pollution levels.
2. **Dispersion Models** – Simulate pollutant movement and concentration based on physical and chemical processes.
3. **Hybrid Models** – Combine data from multiple sources, including satellite observations and ground monitors.

A well-known application of LUR models is the **SAPALDIA** (Swiss Cohort Study on Air Pollution and Lung and Heart Diseases in Adults), which analyzes long-term health effects of air pollution exposure in Switzerland.

Case Study: APEAL Study (India)

The **APEAL (Air Pollution Exposure on Adolescent's Lung Development)** study is a longitudinal research project running from **December 2020 to December 2026**, focusing on adolescent lung development in relation to air pollution exposure.

This study measures PM2.5 and NO2 levels using advanced air pollution monitoring tools in **Delhi, Bangalore, and Mysore**. Data from **240 households** are collected during both winter and summer seasons. The study aims to understand how long-term exposure to particulate pollution affects respiratory health in developing adolescents.

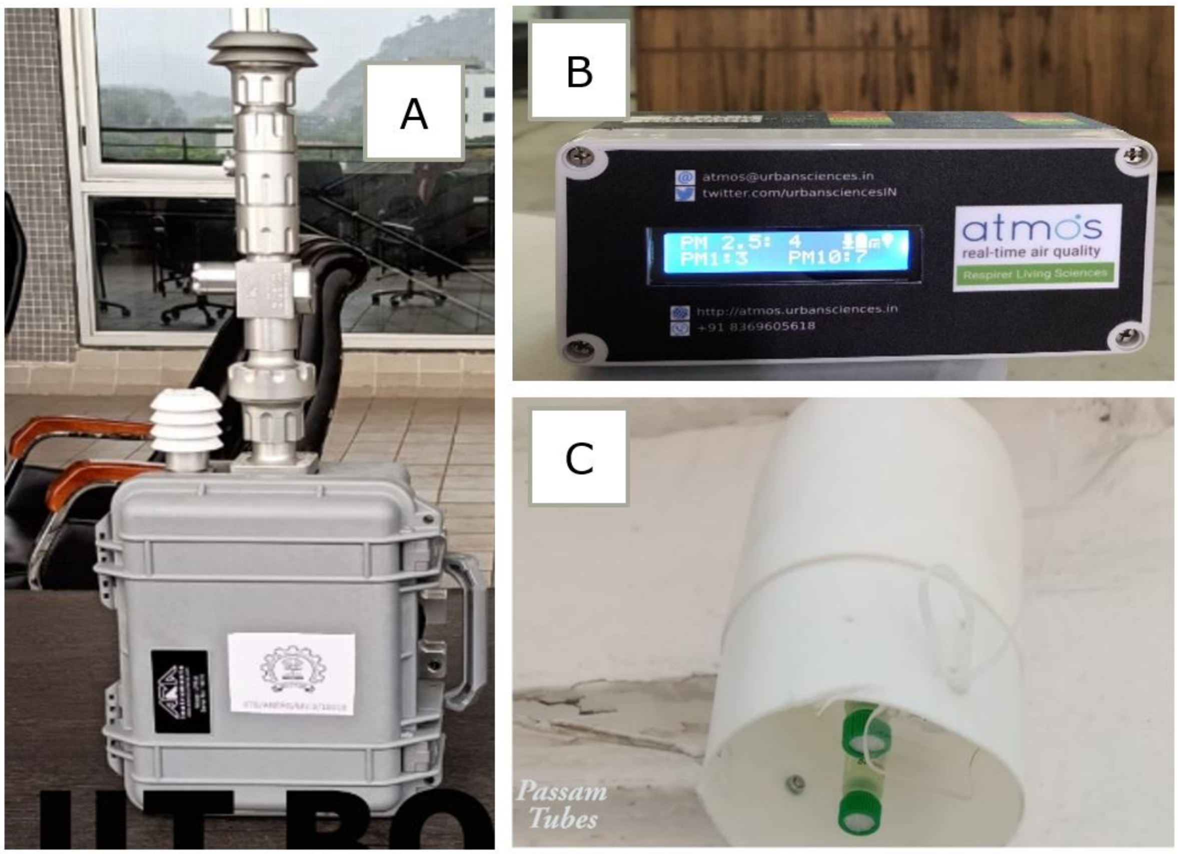


Figure 5: Air Pollution Sampling Setup; A-Minivol $PM_{2.5}$, B- Atmos PMx, C- Passam NO_2

Inter-City Variability in PM Toxicity

Emerging evidence suggests that the toxicity of particulate matter depends on its chemical composition rather than just its mass. PM from industrial areas, for instance, may be more harmful than PM from natural sources due to the presence of heavy metals and other toxic substances.

Recent research highlights that PM2.5 mass concentrations do not always correlate with health impacts, making it critical to consider chemical composition in future regulatory standards.

Key Open Questions and Future Directions

Despite advances in air pollution research, several questions remain unanswered. These include understanding the comparative toxicity of different PM components, identifying the best metrics for regulation, and improving exposure classification accuracy. Future research should focus on long-term exposure studies, developing advanced hybrid models, and investigating the mechanisms through which air pollution affects health.

Exposure assessment remains critical to understanding air pollution's health effects. High-resolution models, combined with ground-based measurements and emerging technologies like low-cost sensors, will provide a more comprehensive picture. Over the next decade, better personal exposure data and improved source toxicity analysis will inform future air quality regulations and public health interventions.

Conclusion

Air pollution is a major public health concern with far-reaching effects on human health throughout life. Comprehensive exposure assessment using advanced modeling techniques is essential for understanding and mitigating these impacts. Research indicates that particulate matter's chemical composition may be as critical as its mass concentration in determining toxicity.

Moving forward, integrated monitoring methods, improved exposure models, and cross-city studies will play a crucial role in shaping air quality regulations and safeguarding public health.

5.4 WRF Cloud Microphysics & Atmospheric Icing

Pravin Punde, Researcher, The Artic University of Norway, Tromsø, Norway

Introduction

Atmospheric icing is a significant challenge in cold climates, affecting infrastructure like **wind turbines, power lines**, and **aircraft**. It occurs when **supercooled water droplets** freeze upon contact with surfaces. This phenomenon can lead to **mechanical failures**, **energy production losses**, and **increased maintenance costs**. The **Weather Research and Forecasting (WRF) model**, a mesoscale numerical weather prediction model developed by the **National Center for Atmospheric Research (NCAR)**, is widely used to simulate and predict atmospheric conditions, including **icing events**.

***Figure 1**: Atmospheric icing on electrical infrastructure in Ålvikfjellet, Norway (2013).*

Types of Atmospheric Icing

Atmospheric icing can be classified into three main categories based on the meteorological conditions:

1. **In-cloud Icing**: Occurs when supercooled liquid droplets within clouds freeze upon contact with objects. This is the most common form of icing at **higher altitudes** where cloud cover persists.
2. **Wet Snow Icing**: Happens when partially melted snow adheres to structures. This typically occurs at temperatures between **0°C and 2°C**.
3. **Freezing Rain**: Forms when **supercooled raindrops** freeze immediately on contact with surfaces, creating a layer of ice. This is especially hazardous for **wind turbines** and **power lines** due to the rapid accumulation of ice mass.

***Figure 2**: Wet snow accumulation on power lines (BKK Nett, Norway).*

Numerical Weather Prediction (NWP) and the WRF Model

Numerical Weather Prediction (NWP) uses **mathematical models** to simulate atmospheric processes and forecast future weather conditions. The modeling process involves:

1. **Initialization**: Collecting observational data (e.g., temperature, wind speed) from ground stations, satellites, and weather balloons.
2. **Model Integration**: Applying physical equations that describe atmospheric behavior over time.
3. **Output Generation**: Producing forecasts in the form of maps, graphs, and numerical datasets.

The **WRF model** is a versatile, community-supported NWP tool suitable for both **research** and **operational forecasting**. It supports multiple physical parameterization schemes, allowing detailed modeling of complex atmospheric processes like **cloud microphysics** and **boundary layer dynamics**.

WRF Model Setup for Davvi Wind Farm

For this study, the WRF model configuration was designed to capture atmospheric conditions at the **Davvi Wind Farm**. Key parameters include:

- **Microphysics Scheme**: Thompson scheme, which handles cloud processes like condensation and ice formation.
- **Planetary Boundary Layer**: Mellor-Yamada-Nakanishi-Niino (MYNN) 2.5 level scheme, for modeling turbulence and vertical mixing.
- **Radiation**: Rapid Radiative Transfer Model for Global models (RRTMG) for shortwave and longwave radiation.
- **Land Surface**: Noah-MP scheme, which represents surface energy and moisture fluxes.
- **Surface Layer**: Revised MM5 scheme for near-surface atmospheric interactions.
- **Initial Conditions**: Derived from **ERA5 reanalysis** data, provided by the **European Centre for Medium-Range Weather Forecasts (ECMWF)**.

The model's computational domain included multiple nested grids to capture both regional and local scale variations.

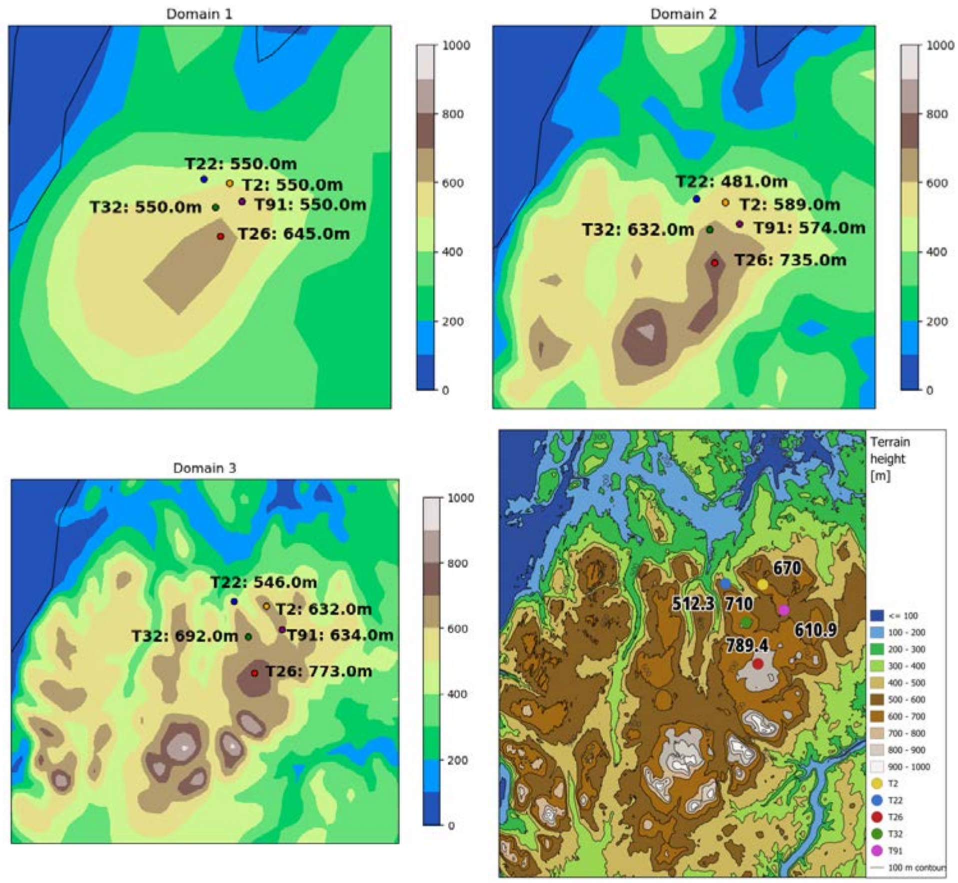


Figure 3: WRF model terrain height.

Makkonen Model for Ice Accretion

Ice accretion on wind turbines is assessed using the **Makkonen model**, which calculates the **ice mass** accumulating over time. This model captures key physical processes influencing **in-cloud icing** and **freezing rain**.

Model Validation and Observational Comparison

Model outputs were validated using observational data from the **Banak Weather Station**, located near the wind farm. Statistical analysis was conducted on:

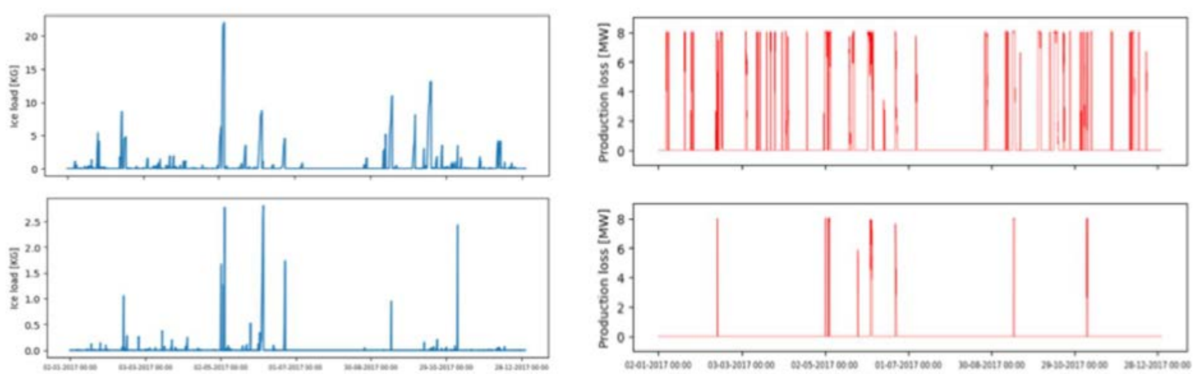
- **Mean Temperature**: Evaluating seasonal variations across turbine locations.
- **Liquid Water Content**: Measuring the availability of supercooled water for ice formation.
- **Wind Speed and Wind Rose**: Analyzing wind patterns to understand turbine exposure.

Results indicated that model outputs align closely with observed data, providing confidence in the WRF model's ability to capture **atmospheric icing events**.

Icing Severity and Production Loss

Annual icing intensity was calculated for five turbine locations (T2, T22, T26, T32, T91). Key findings include:

1. **Terrain Influence**: Higher terrain correlates with increased **icing severity** due to **lower temperatures** and **greater liquid water content**.
2. **Most Affected Turbine**: **T26** experienced the most severe icing with **1555 hours** above **10 g/h**, corresponding to **17.75% annual meteorological icing**.
3. **Least Affected Turbine**: **T22** had **276 hours** of icing above **10 g/h**, equating to **3.17% annual icing**.
4. **Production Loss**: Turbines with higher icing rates experienced **significant energy production loss—19.86% at T26** and **4.16% at T22**.



Ice load at Turbine T26, T22

Prduction loss at Turbine T26, T22

Figure 4: *Annual icing hours and production loss across turbine locations.*

Wake Effect on Icing

Wind turbines downstream from other turbines experienced a **wake effect**, reducing wind speed and increasing local turbulence. This led to:

- A maximum mean wind speed difference of **1.425 m/s** between affected and unaffected areas.
- An icing rate difference of **113 hours** above **10 g/h** between turbine locations.

This suggests that wind farms with closely spaced turbines may experience **reduced icing** compared to isolated turbines.

Conclusion

The WRF model effectively simulated **atmospheric icing** and **production**, highlighting:

- **Higher Terrain Increases Icing Severity**: Elevated areas experience more significant icing due to lower temperatures and increased liquid water content.
- **Production Loss Variability**: Turbines in regions with greater icing experienced substantial energy output reductions.
- **Wake Effect Reduces Icing**: Downstream turbines showed lower icing rates due to the shielding effect of upstream turbines.

These findings have practical implications for **wind farm design** and **icing mitigation strategies**, offering a robust framework for future assessments of **atmospheric icing** using advanced **numerical models** like WRF.

5.5 Air Quality Monitoring & Modelling

Prince Vijay, Ph.D. Student, IIT Bombay

Introduction

Air pollution modeling plays a crucial role in assessing air quality in a region based on emissions and atmospheric processes. The primary concern in air pollution dispersion lies within the Planetary Boundary Layer (PBL), which is influenced by surface heating, friction, and stratification. The depth of the PBL varies from a few hundred meters at night to around one to two kilometres during the day. Dispersion processes in this layer are highly complex due to the influence of terrain and meteorological factors, making the accurate prediction of pollution dispersion a challenging task.

Air Pollution Models

Air pollution models are classified based on their scale of application. Short-range models are used for distances up to ten kilometers, while urban and long-range transport models cover larger scales. Among these, Gaussian diffusion-based models are the most widely used. The Gaussian plume model assumes that pollutants emitted from a point source disperse in the atmosphere following a Gaussian distribution in both vertical and horizontal directions. However, these models have limitations. They are unsuitable for dispersion studies under low wind conditions or for distances below 100 meters. Furthermore, their assumptions regarding meteorological homogeneity make them less effective for far-field modeling.

Models serve as mathematical abstractions of reality and are essential tools for environmental regulations, research, and Environmental Impact Assessments (EIA). Line source dispersion models have gained significance in understanding air pollution impacts, energy consumption, and public health. Despite their limitations, Gaussian plume models remain widely used due to their simplicity and ease of application.

Gaussian Plume Model

The Gaussian plume model is based on a mathematical equation that incorporates several variables, including source strength, horizontal and vertical dispersion coefficients, wind speed, receptor height, and plume height. The model assumes that:

- The equation of continuity holds.
- Steady-state conditions exist during the modeling period (usually one hour).
- Wind speed remains constant.
- Diffusion in the direction of transport is negligible.
- Pollutant concentrations follow a Gaussian distribution in both crosswind and vertical directions.
- Wind direction is consistent with height.

- Diffusion parameters depend only on the distance from the source.

AERMOD and Its Components

AERMOD is a widely used air quality dispersion model developed by the American Meteorological Society (AMS) and the United States Environmental Protection Agency (EPA). It consists of multiple components:

1. AERMET: A meteorological pre-processor that provides the dispersion model with necessary meteorological data. It processes routine meteorological measurements, surface characteristics (such as Albedo, Bowen Ratio, and Surface Roughness Length), and upper-air sounding data.
2. AERMAP: A terrain pre-processor that characterizes the land surface using Digital Elevation Models (DEM). It generates receptor grids and computes terrain-influence height.
3. AERMOD View: A software tool that estimates pollutant concentrations based on meteorological data quality and surface characteristics at observation sites. It is designed for short-range pollutant dispersion (up to 50 kilometers) from stationary industrial sources.

AERMOD requires various input files, including meteorological data, terrain features, receptor data, traffic emissions, and source parameters. The output provides pollutant concentrations, helping researchers and policymakers evaluate air quality impacts.

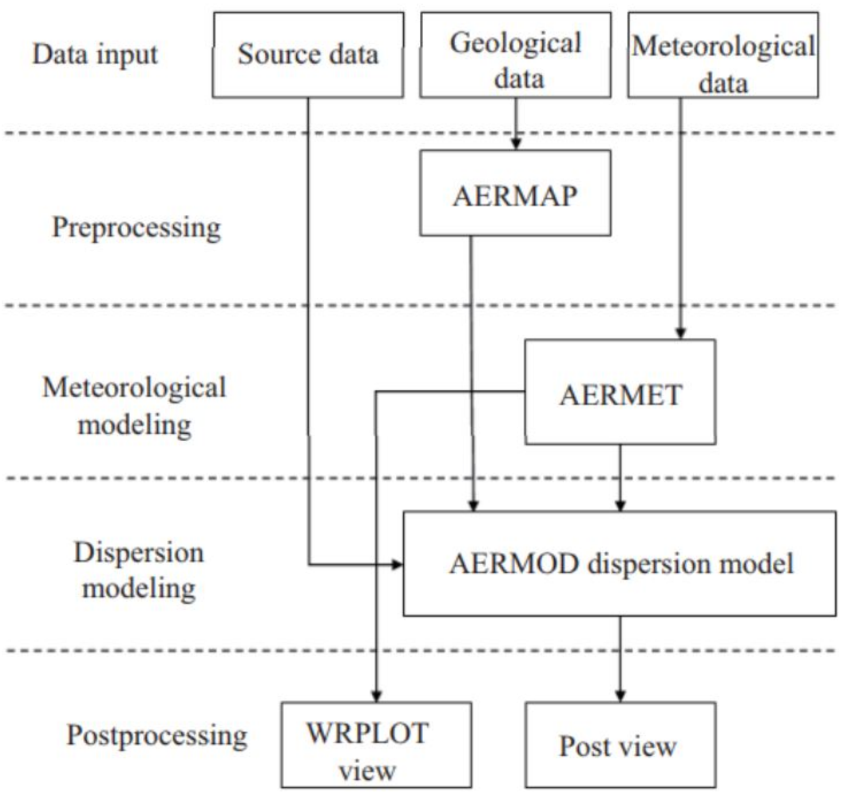


***Figure 1:** Components of AERMOD*

Sources of Error and Limitations

AERMOD's accuracy is highly dependent on the selection of land use parameters, particularly surface roughness length, which can introduce errors of up to 20%. Gaussian-type models, including AERMOD, require meteorological data that is spatially and temporally representative of the study area. The validity of model assumptions is crucial; as Gaussian models do not retain memory of past emissions. This limitation is especially significant for modeling morning inversion break-up, fumigation, and diurnal pollutant recycling in urban areas.

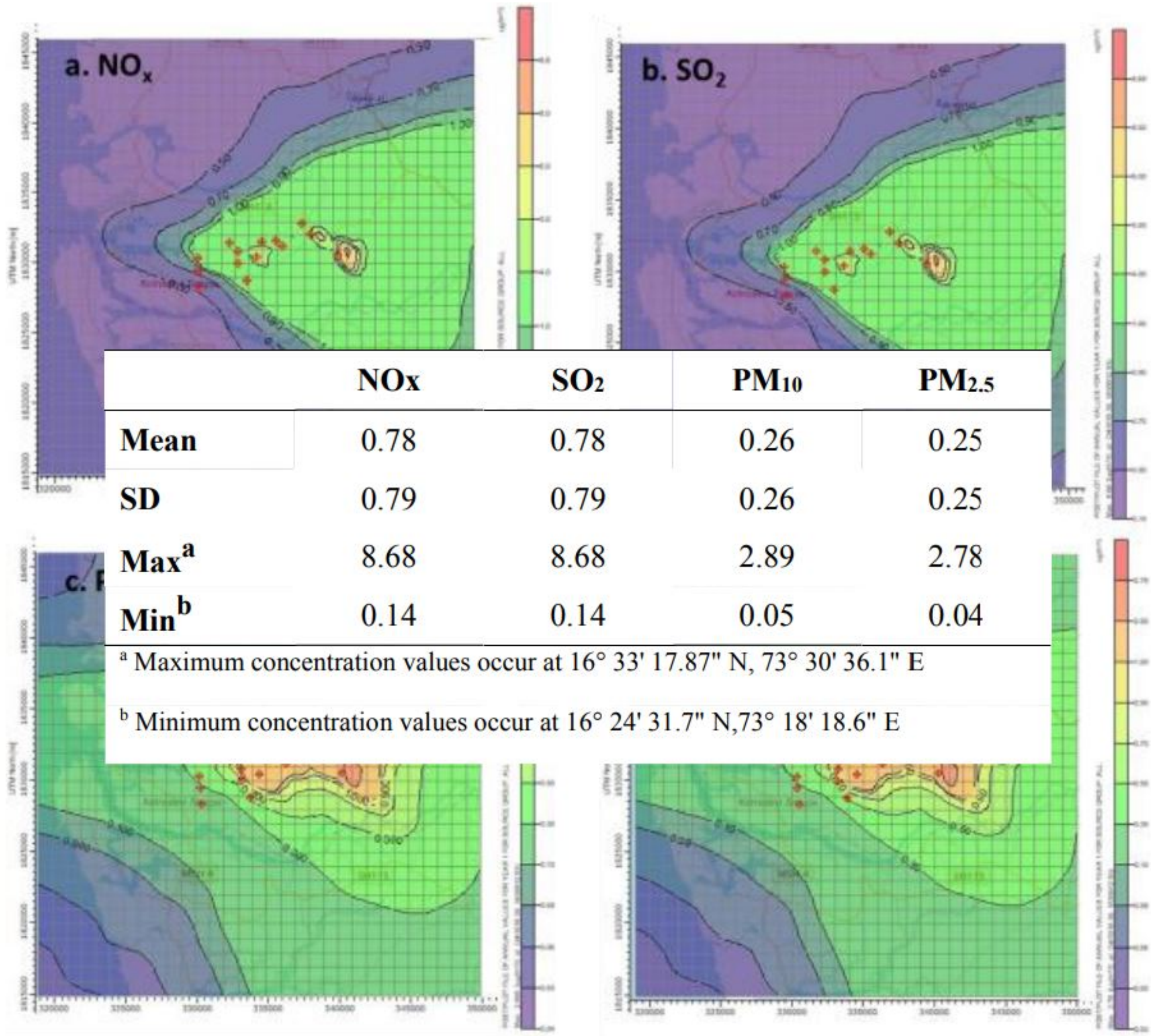
Additional challenges arise when using deterministic models for short time intervals, as they assume steady-state conditions. Gaussian models also struggle with zero wind speeds, making them unsuitable for extreme value predictions. While these models are ideal for long-term planning, they are less reliable for short-term forecasting.

Case Studies and Model Implementation

A case study involving an industrial power plant highlights the model's application in real-world scenarios. Key emission parameters considered include:

- Stack characteristics (diameter, height, emission exit velocity).
- Pollutant emission rates (NOx, SO2, PM10, and PM2.5).
- Meteorological data obtained from external sources.

The model was run for one year using emissions and meteorological inputs. Land-use parameters such as Albedo, Bowen Ratio, surface roughness, water bodies, and grasslands were included in the data processing. The results indicated that pollutant concentrations were highest near Stack 1, due to the large proportion of emissions (approximately 36%) originating from this source and the influence of meteorological factors.



	NOx	SO_2	PM_{10}	$PM_{2.5}$
Mean	0.78	0.78	0.26	0.25
SD	0.79	0.79	0.26	0.25
Max[a]	8.68	8.68	2.89	2.78
Min[b]	0.14	0.14	0.05	0.04

[a] Maximum concentration values occur at 16° 33' 17.87" N, 73° 30' 36.1" E

[b] Minimum concentration values occur at 16° 24' 31.7" N,73° 18' 18.6" E

Figure 2: *1x1 km gridded annually averaged predicted concentration plots for the four pollutants*

Comparison with Regulatory Standards

To assess compliance with environmental regulations, the modeled pollutant concentrations were compared against industrial standards. The results indicated that:

- NO2 concentrations were below the annual and 24-hour limits.
- SO2 levels remained within permissible limits.
- PM10 and PM2.5 concentrations were also below regulatory thresholds.

These findings suggest that the proposed industrial activities are unlikely to cause significant adverse impacts on ambient air quality. Given that the project site is predominantly rural and forested, actual background pollutant concentrations may be lower than the model estimates.

Performance Evaluation and Sensitivity Analysis

Model performance was evaluated using statistical metrics such as:

- Index of Agreement (IA): Measures how well the model predictions match observed values.
- Fractional Bias (FB): Indicates over prediction or under prediction tendencies.
- Normalized Root Mean Square Error (NRMSE): Estimates overall deviations between observed and predicted values.
- Geometric Mean Bias (MG) and Variance (VG): Assess model performance when data follows a log-normal distribution.

Sensitivity analyses revealed discrepancies in model predictions, likely due to uncertainties in the emission inventory. Variations in traffic data, meteorological conditions, and background pollution levels can influence model accuracy. The assumption of constant traffic flow, for example, may reduce the correlation between observed and predicted values.

Discussion and Key Findings

The study identified several factors that affect model accuracy. Differences between estimated and actual emissions may arise due to variations in vehicle usage patterns and seasonal changes in pollution levels. Emission inventories rely on averaged data, which does not always reflect real-world fluctuations. Additionally, meteorological data processing, particularly variations in boundary layer depth, may impact model outcomes.

Despite these challenges, AERMOD remains a valuable tool for air quality assessment, particularly when used in conjunction with receptor models. The integration of background concentration data and improved emission inventories could enhance model reliability.

Conclusion

This study demonstrates the applicability of air quality modeling in assessing industrial and urban pollution impacts. AERMOD effectively predicts pollutant dispersion patterns, though its accuracy depends on the quality of input data and the validity of model assumptions. The results indicate that air quality at the project site remains within regulatory limits, with minimal adverse environmental impacts expected. Future research should focus on refining emission inventories and incorporating real-time meteorological data to improve model performance.

6 *Technical Session 2*: Remote sensing of the environmental status (Day 3)

6.1 Remote Sensing of the Urban Environment: Connecting Scales from North to South

Dr. Victoria Miles, Senior Scientist, Nansen Center (NERSC), Bergen, Norway

Introduction

Urbanization is accelerating globally, transforming landscapes and posing significant environmental challenges. More than **55% of the world's population** now lives in urban areas, a figure projected to rise to **68% by 2050**. This rapid growth requires extensive investment—approximately **$6.3 trillion annually** by 2030—to maintain urban infrastructure and address environmental impacts. Urban areas, though covering only **3% of the Earth's surface**, contribute to **67-76% of global energy use** and **75% of CO_2 emissions**, making cities a primary driver of climate change.

Remote sensing offers a comprehensive way to monitor urban environments by measuring variables like **land surface temperature (LST)**, **urban heat islands (UHI)**, and **vegetation cover**. This report explores how remote sensing technology is applied to analyze urban transformations, mitigate urban heat islands, and support sustainable urban development across scales, from **North to South**.

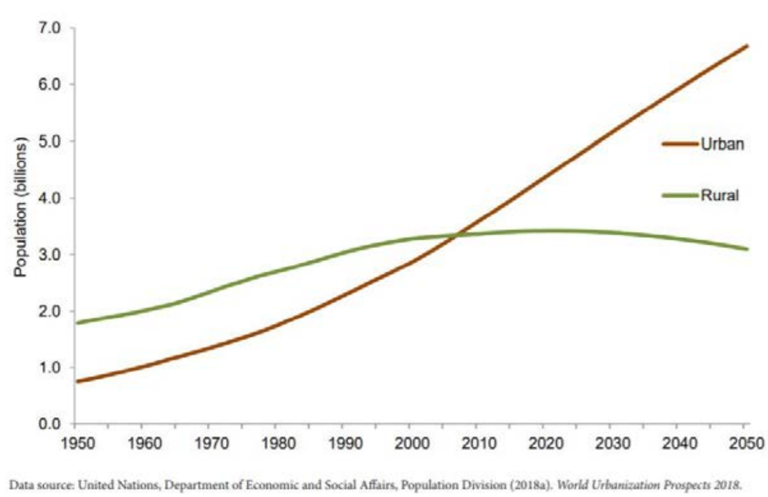


Figure 1: *Global urban population growth from 1950 to 2050, with projections showing an increase to 68% by 2050.*

Urbanization and Its Environmental Impact

Urbanization leads to drastic changes in **land use** and **land cover**, which directly impact local climates. Increased **impervious surfaces** like concrete and asphalt absorb more heat, intensifying the **urban heat island** effect. For instance, the **Pearl River Delta's** rapid urbanization, as captured by NASA's Landsat satellite, demonstrates the scale of such transformation.

The consequences of urban expansion are visible through **heat anomalies** and **heat waves**. Heat anomalies refer to deviations from normal temperatures, while heat waves are prolonged periods of extreme heat. Urban residents experience these phenomena more severely due to heat-retaining surfaces and reduced green spaces.

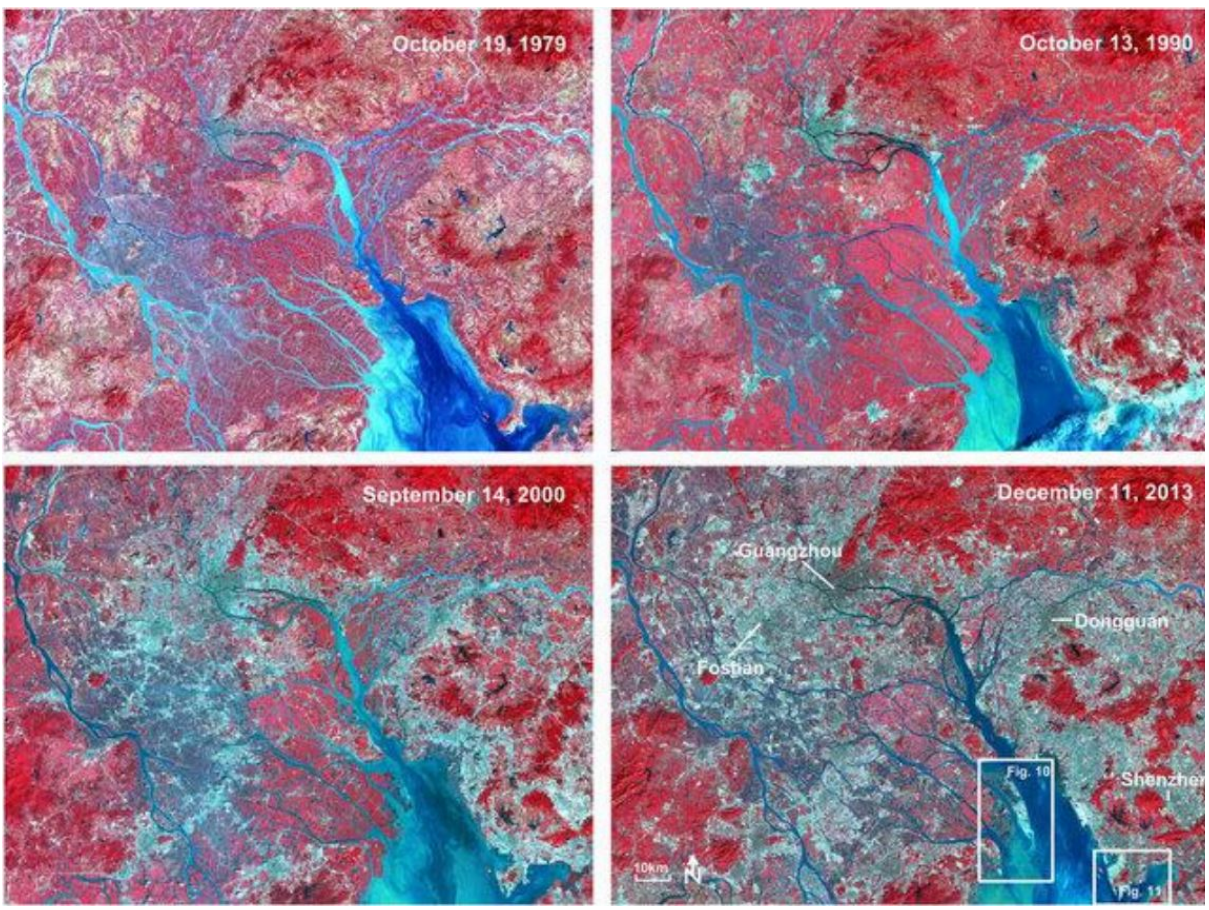


Figure 2: *NASA Landsat image showing the transformation of the Pearl River Delta over time.*

Urban Heat Islands (UHI) and Surface Urban Heat Islands (SUHI)

An **Urban Heat Island (UHI)** is a region where temperatures are higher than surrounding rural areas due to urban infrastructure. This temperature difference arises from the **thermal properties** of impervious surfaces and reduced vegetation. There are two main types of UHI:

1. **Atmospheric UHI** – Air temperature differences between urban and rural areas.
2. **Surface UHI** – Temperature differences at the Earth's surface, which are more pronounced during the day.

Remote sensing technologies, like those from **Landsat satellites**, provide detailed measurements of these temperature differences, aiding in monitoring and developing mitigation strategies.

Measuring Urban Climate Across Scales

Remote sensing enables the study of urban environments at multiple spatial scales:

1. **Pan-Arctic Scale** – Broad regional assessments, including climatic patterns across multiple cities.
2. **Urban Scale** – In-depth analysis of a single city's thermal and vegetative variability.
3. **Neighborhood Scale** – Fine-scale observations of microclimates in local areas such as parks and residential zones.
4. **Building Scale** – Examining how building size, density, and materials influence local temperatures.

Each scale provides insights into **urban transformation**, **climate adaptation**, and **sustainability**. For example, the Arctic city of **Rovaniemi, Finland**, demonstrates strong seasonal variations between urban and rural land surface temperatures (LST).

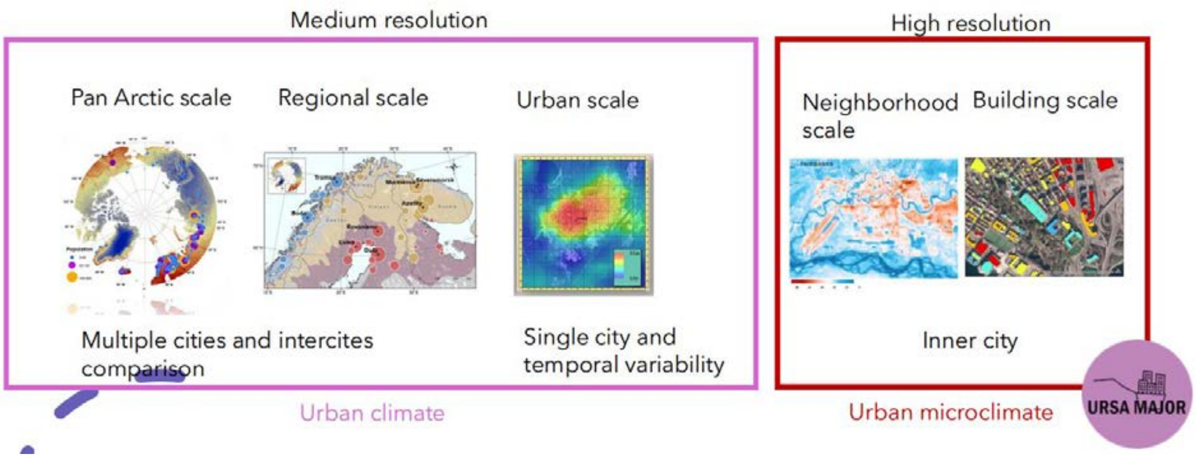


Figure 3: *Illustration showing how urban climates vary across Pan-Arctic, urban, neighbourhood, and building scales.*

Land Surface Temperature (LST) and Its Importance

Land Surface Temperature (LST) refers to the temperature of the Earth's solid ground or terrain, excluding water bodies. It reflects how hot or cold the Earth's surface feels at a given time and is influenced by **solar radiation**, **land cover**, and **weather conditions**.

Monitoring LST through **satellite data** is essential for tracking **urban heat islands**, evaluating the effectiveness of mitigation strategies, and understanding **urban microclimates**.

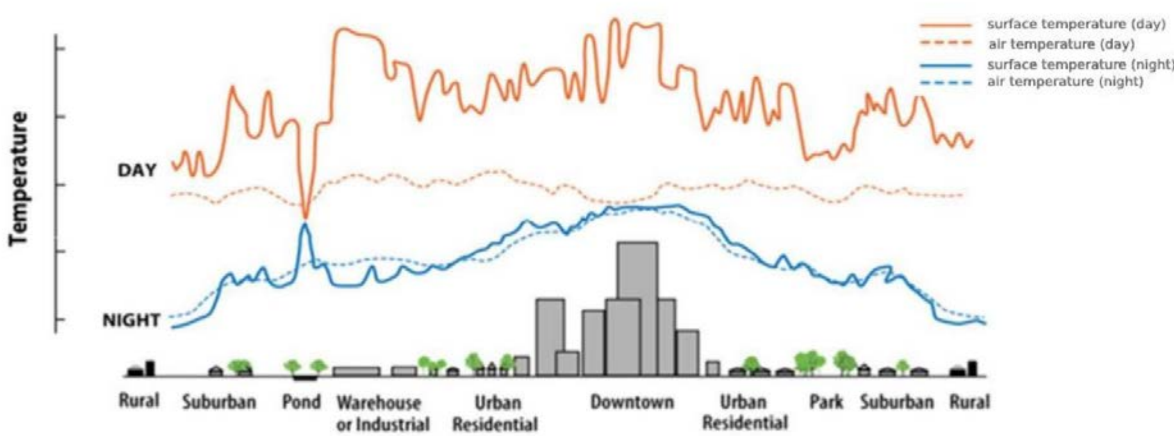


Figure 4: *Visualization of LST variations in different land use types over different times of the day.*

The Role of Vegetation in Mitigating Urban Heat

Vegetation is crucial for **regulating urban temperatures** through **shade** and **evaporative cooling**. The **Normalized Difference Vegetation Index (NDVI)**, derived from satellite imagery, quantifies vegetation health by measuring how plants reflect **near-infrared** and **red light**.

In **Tromsø, Norway**, areas with higher NDVI values show significantly cooler temperatures, highlighting the role of green spaces in mitigating the urban heat island effect. Research in **Bergen** shows how urban densification reduces vegetation and exacerbates heat risks.

Socio-Spatial Inequities in Green Space Distribution

Green space distribution is often **uneven** across urban areas, leading to **socio-spatial inequities**. Wealthier neighborhoods typically have better access to green spaces, while industrial and high-density residential areas have limited vegetation.

For instance, in **Tromsø**, approximately **55%** of urban greenery is found in residential areas, while industrial and commercial zones contain less vegetation. This disparity impacts public health, as areas with less greenery are more vulnerable to heat stress.

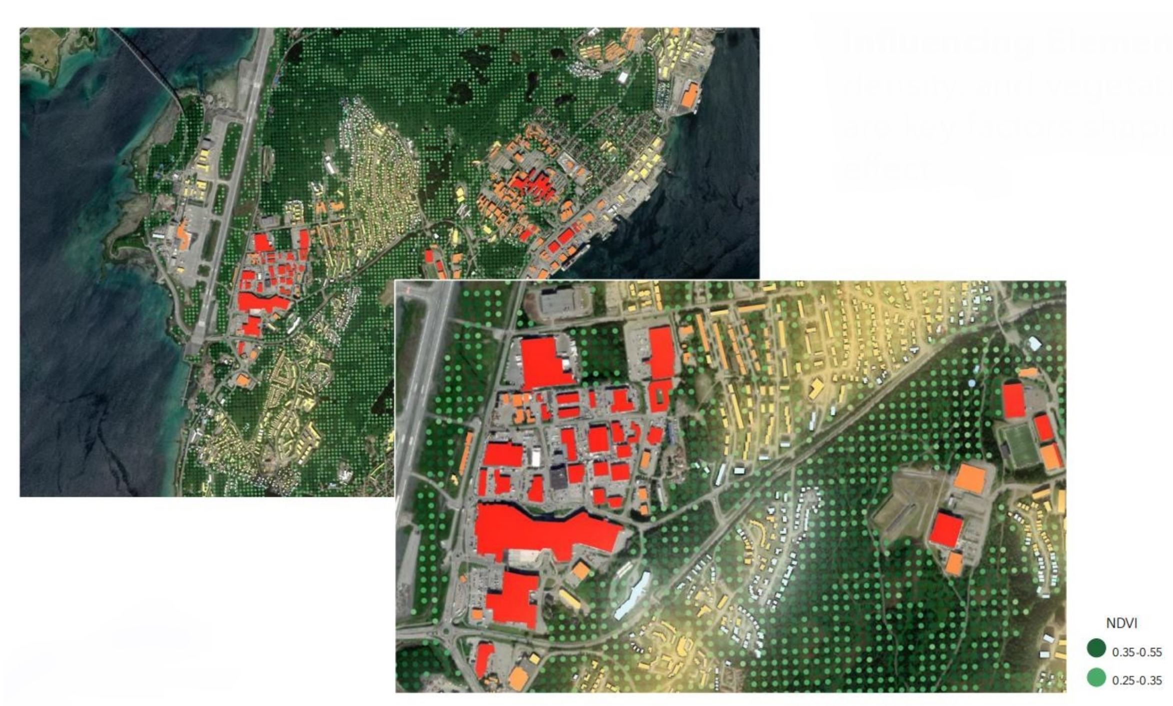


Figure 5: *Distribution of vegetation across various land uses in Tromsø.*

Building Morphology and Its Impact on Urban Heat

Building design affects urban microclimates. Larger buildings with increased **surface areas** absorb and retain more heat, resulting in **higher local temperatures**. This phenomenon is particularly evident in dense urban environments where thermal inertia slows heat release.

Remote sensing reveals that **building density** and **surface materials** significantly influence the intensity of **surface urban heat islands**. Cities like **Tromsø** demonstrate how larger, denser buildings create warmer microclimates.

Green and Blue Infrastructure for Climate Regulation

Green (vegetation) and **blue** (water bodies) infrastructures are effective strategies to combat urban heat. For example, areas with high tree cover can be **2-5°C cooler** than those dominated by impervious surfaces. Water bodies further mitigate heat through **evaporative cooling**.

Case studies from **New York City** and **Tromsø** demonstrate how increased vegetation and water features reduce local temperatures, improving **thermal comfort** and **public health**.

Streets as Public Spaces for Climate Adaptation

Streets can serve as **public spaces** that foster **social interaction** and **thermal comfort**. Incorporating vegetation and water features into street designs reduces heat and enhances the urban experience. Remote sensing data can assess how different urban designs affect **temperature** and **liveability**. For instance, asphalt-covered streets without vegetation create **heat traps**, while green streets with shade trees lower temperatures and improve urban aesthetics.

Active Learning and Web-GIS for Urban Transformation

Web-GIS storytelling is an innovative approach used in the **URSA MAJOR** research initiative to engage students and stakeholders in urban climate adaptation. Through interactive GIS platforms, users can explore urban scenarios, co-create solutions, and assess the impact of sustainable urban development.

A case study from **Trondheim, Norway**, demonstrated how students collaborated to design green infrastructure solutions that mitigate the urban heat island effect.

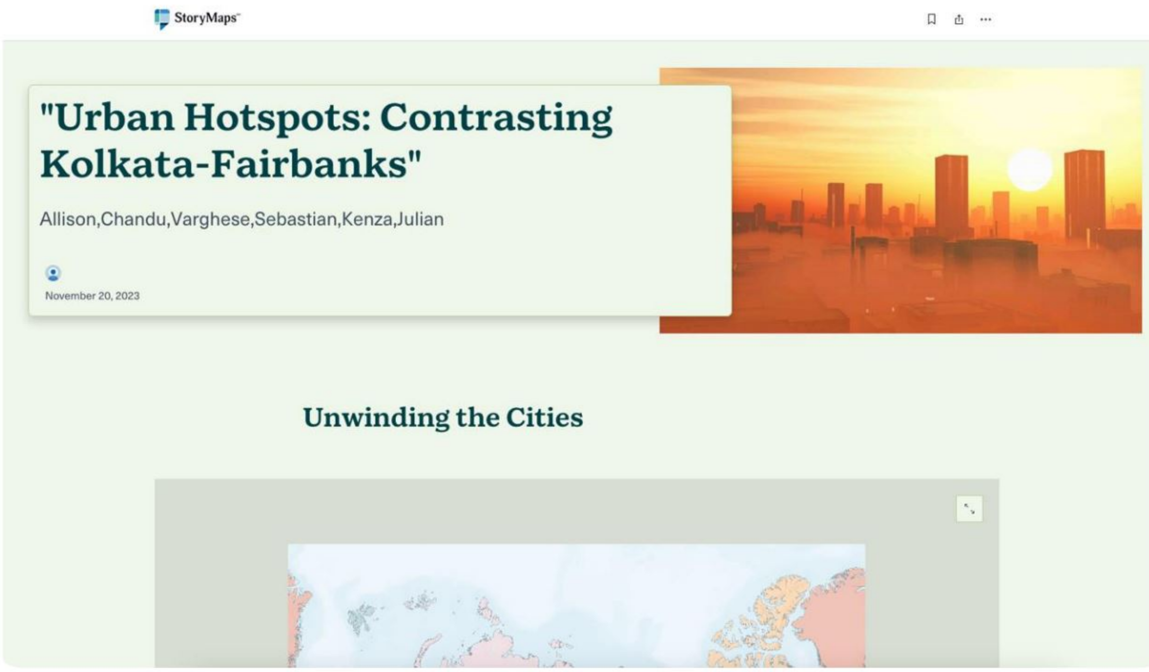


Figure 6: *Screenshot of the URSA MAJOR Web-GIS storytelling platform showcasing a mini student project. Access here; https://arcg.is/8SDjj*

Conclusion

Remote sensing is a powerful tool for understanding and addressing the environmental impacts of urbanization. By analyzing urban climates across multiple scales, researchers can track **urban heat islands**, identify **socio-spatial inequities**, and develop effective **mitigation strategies**. As urban populations continue to grow, leveraging remote sensing technologies is crucial for building **sustainable**, **equitable**, and **climate-resilient** cities. Through ongoing research and initiatives like **URSA MAJOR**, we can develop actionable solutions to shape the future of urban environments.

6.2 Advancements in Air Quality Monitoring and Remote Sensing

Dr. Ranith Raj, Scientist, Nansen Environmental Research Centre (India), Madavana, Kochi, Kerala

1. Introduction to Sustainable Development Goals (SDGs) and Air Quality

Sustainable Development Goal (SDG) 11.6.2 focuses on making cities and human settlements inclusive, safe, resilient, and sustainable, with a specific indicator being the concentration of fine particulate matter (PM2.5). This goal is closely aligned with SDG 7, which aims to ensure access to clean energy, and SDG 3.9.1, which seeks to reduce deaths and illnesses caused by air pollution.

Researchers are working to integrate national reference-grade ground measurements, satellite data, chemical transport models, and population statistics to derive population-weighted air pollution concentrations. These combined data sets contribute to calculating the disease burden from both household and ambient air pollution. The World Health Organization (WHO) plays a crucial role in coordinating global efforts to monitor and address air pollution through these SDGs.

2. Air Quality: A Critical Issue

Air pollution is the leading environmental and occupational risk factor worldwide, contributing to approximately seven million premature deaths annually. In addition to its severe health impacts, air pollution also poses significant economic challenges, including losses in agricultural productivity, increased healthcare costs, and reduced worker efficiency.

Improving air quality offers several co-benefits, including reducing greenhouse gas emissions. Addressing air pollution is vital for both public health and climate change mitigation efforts.

3. Health Impacts of Air Pollution

Fine particulate matter (PM2.5) is particularly dangerous due to its ability to penetrate the respiratory system and enter the bloodstream. Research indicates that a 10 $\mu g/m^3$ increase in PM2.5 is associated with a 0.40% rise in non-accidental mortality, a 0.63% increase in cardiovascular mortality, and a 0.75% increase in respiratory mortality. Even at low exposure levels, PM2.5 has been linked to significant health complications, including respiratory and cardiovascular diseases.

Household air pollution affects approximately 2.4 billion people annually and caused an estimated 3.2 million deaths in 2020. Ambient air pollution contributes to 4.2 million deaths globally each year. According to the Lancet Commission on Pollution and Health, an estimated nine million deaths annually are linked to pollution, with air pollution accounting for 6.67 million of these.

Efforts to reduce air pollution require a combination of policy changes, regulatory enforcement, and global collaboration. Addressing pollution at its source and implementing stricter air quality standards is essential to protecting public health and minimizing long-term environmental impacts.

4. Challenges in Air Quality Data Collection

One of the most significant challenges in air quality monitoring is the lack of sufficient data coverage, particularly in densely populated and economically disadvantaged regions. Most areas have fewer than ten regulatory air quality monitors per million people, with even fewer monitors tracking pollutants beyond PM2.5. This disparity is especially pronounced in regions with higher pollution levels, which are often the least monitored.

While low-cost sensors have improved data coverage in some areas, they remain insufficient to capture the full variability of pollution. Pollutants can vary greatly on small spatial scales due to differences in their sources and atmospheric lifetimes. Economic and technical limitations further complicate accurate and consistent data collection.

A significant proportion of the global population, particularly in Africa, South Asia, and South America, lives in areas with minimal ground station coverage. This lack of data hinders efforts to understand the full impact of air pollution and to design effective mitigation strategies.

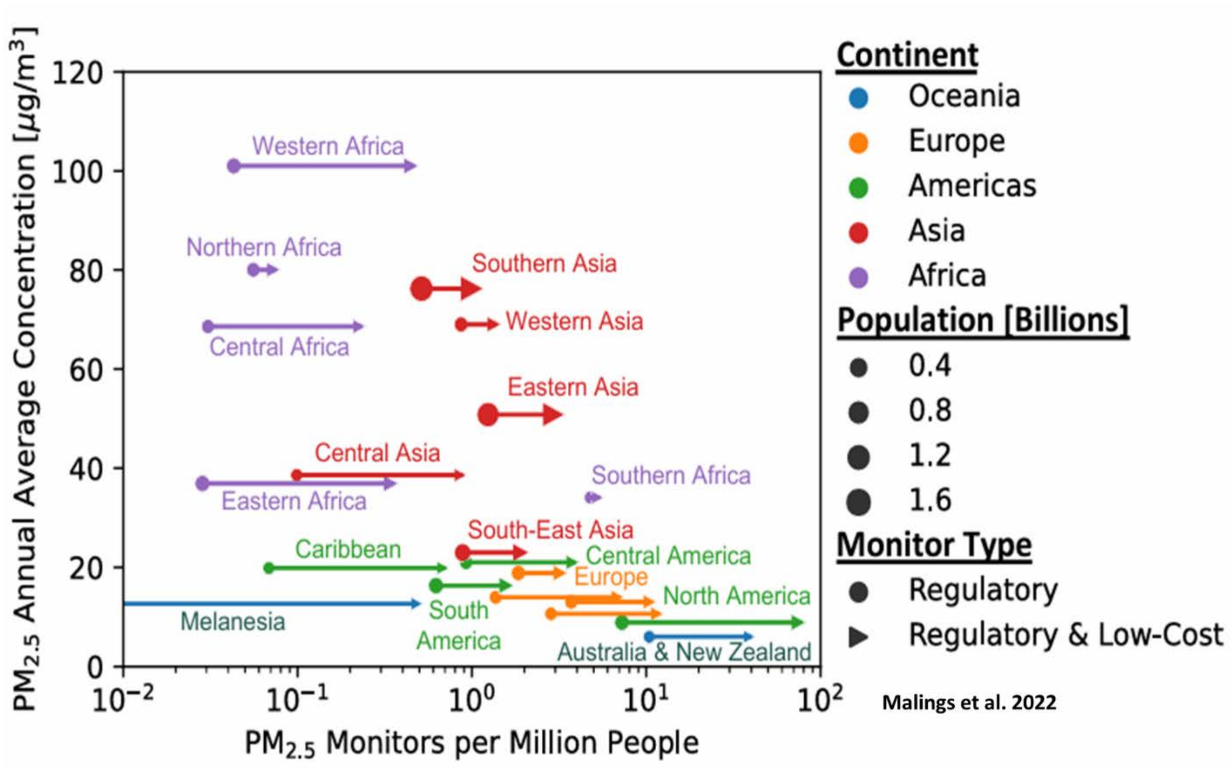


Figure 1: *The graph shows the annual average concentration of PM2.5 (μg/m^3) plotted against the number of PM2.5 monitors per million people for various continents. The size of the points represents the population of each region, and the colour indicates the continent. The shape of the point signifies the type of monitor used (regulatory or regulatory & low-cost).*

5. Satellite Remote Sensing in Air Quality Monitoring

Satellite remote sensing is a valuable tool for addressing spatial gaps in ground-based air quality monitoring. Satellites provide continuous spatial information at a global scale, often without acquisition costs, making them particularly useful in regions with limited or no ground stations.

Since 1998, satellite observations from platforms such as MODIS (Moderate Resolution Imaging Spectroradiometer), MISR (Multi-angle Imaging SpectroRadiometer), and SeaWiFS (Sea-viewing Wide Field-of-view Sensor) have been used to assess global air quality. These data sets have been crucial for organizations like WHO and Greenpeace to evaluate the health impacts of air pollution.

One example of the effectiveness of satellite data is the global annual mean geophysical PM2.5 estimates for 2015, which demonstrated the potential of satellite technology to monitor air quality.

Satellite data also play a critical role in identifying air pollution hotspots and guiding policy decisions for air quality improvement.

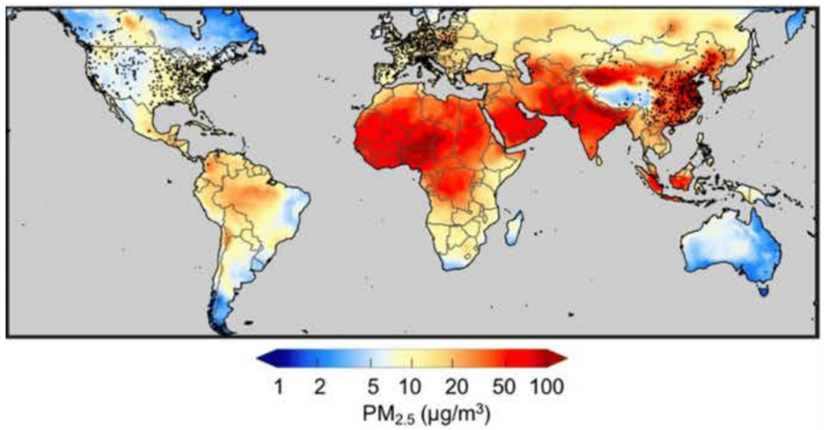


Figure 2: *Global annual mean of geophysical PM2.5 estimates for the year 2015 based on advances in satellite observations. Black dots represent ground stations. (Hammer et al., 2020).*

6. Sentinel-5P and GEMS: Advances in Satellite Monitoring

The Sentinel-5P satellite, part of the European Commission's Copernicus initiative, is dedicated to atmospheric monitoring. The TROPOMI (Tropospheric Monitoring Instrument) onboard Sentinel-5P maps various trace gases, including nitrogen dioxide (NO_2), ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), methane (CH_4), and aerosols. With a swath width of 2,600 km and a resolution of 7 km × 3.5 km, it provides near-daily global coverage.

During the COVID-19 pandemic, Sentinel-5P data revealed clear evidence of reduced anthropogenic emissions worldwide. A case study over Bangkok in 2021 demonstrated how the TROPOMI instrument provides detailed spatial representations of pollutant concentrations.

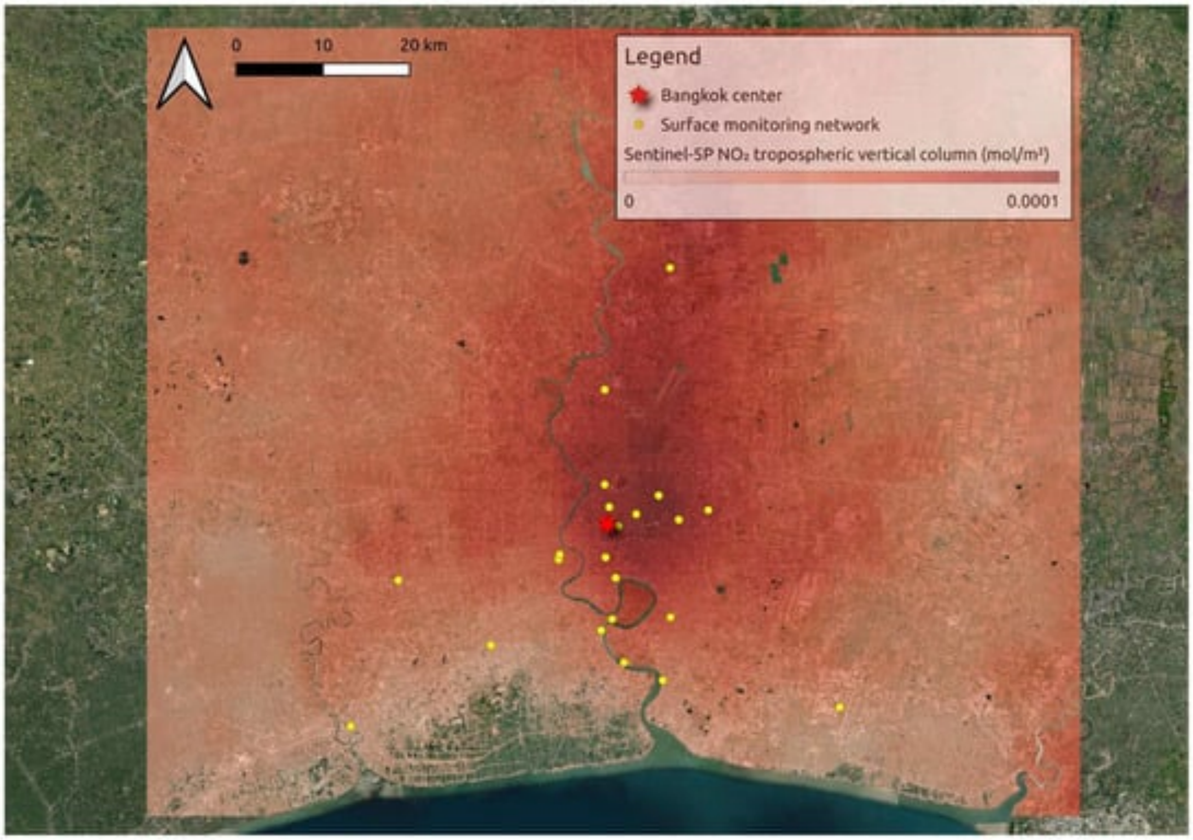


***Figure 3:** Annual mean of the tropospheric vertical column of NO2 for the year 2021 retrieved from Sentinel-5P satellite over Bangkok, Thailand. The blue dots represent the locations of the regulatory-grade ground stations available in this region. The layers are superimposed over a natural-color satellite image of the city of Bangkok.*

The Geostationary Environment Monitoring Spectrometer (GEMS) monitors atmospheric conditions over Asia with hourly updates. Launched by South Korea's National Institute of Environmental Research (NIER) in 2020, GEMS offers detailed measurements of key pollutants and has significantly improved air quality monitoring in the region.

7. Applications of Satellite Data in Air Quality Assessment

Satellite-derived Aerosol Optical Depth (AOD) is a reliable proxy for monitoring PM2.5 concentrations. Research shows a strong correlation between MODIS AOD data and ground-based particulate matter measurements.

Integrating multiple sensors, such as OMI (Ozone Monitoring Instrument) and Sentinel-5P, enhances the accuracy and resolution of pollutant estimations. However, satellite data are susceptible to interference from clouds and aerosols, which can limit their reliability. Researchers address these limitations using advanced spatial interpolation techniques, including inverse distance weighting, kriging, and mixed-effects models.

8. Machine Learning in Air Quality Monitoring

Machine learning (ML) has emerged as a powerful tool for enhancing air quality estimation. Unlike traditional empirical models, which rely on linear assumptions, ML methods can handle complex, nonlinear relationships in large datasets.

Studies, such as those by Gupta et al. (2009), have successfully used artificial neural networks (ANN) to estimate PM2.5 concentrations by combining MODIS AOD and meteorological data. Other ML techniques, including back-propagation neural networks (BPNN), random forests (RF), support vector machines (SVM), and deep learning (DL), have also demonstrated effectiveness in modeling air pollutant concentrations.

A recent case study by Li et al. (2024) utilized ML models to estimate six primary air pollutants, including PM2.5, PM10, O_3, CO, NO_2, and SO_2, providing high-resolution maps of pollutant distribution.

9. Challenges and Future Directions in Remote Sensing

Remote sensing for air quality faces challenges such as limited spatial and temporal resolution, interference from atmospheric conditions, and the complexity of data processing. Many satellite sensors lack the fine resolution required to capture pollution at the street level, while cloud cover can obstruct accurate readings.

Future advancements in remote sensing will focus on improving sensor resolution, integrating multiple data sources (satellite, airborne, and ground-based), and expanding the range of pollutants detected. Additionally, the development of digital platforms and web-based GIS tools will make remote sensing data more accessible to policymakers and the public.

10. Conclusion

Remote sensing has become a critical tool for monitoring global air quality, filling data gaps where ground measurements are sparse. Technological advancements in satellite sensors and machine learning have improved the precision and reliability of air quality assessments.

Despite challenges such as data interpretation and environmental interference, continued innovation in sensor technology and data integration holds promise for enhancing air quality monitoring. These advancements are essential for shaping policy, protecting public health, and mitigating the effects of air pollution globally.

7 *Technical Session 3*: Barriers for Smart City Development (Day 4)

7.1 From Barriers to Opportunities in Smart Cities: Creating Value Through Data and Digital Technologies

Dr. Sobah Abbas Petersen, SINTEF Digital, Trondheim, Norway

Introduction

Smart city development, driven by digital technologies and data-driven approaches, holds the potential to transform urban spaces. This transformation hinges on understanding the barriers and opportunities inherent in leveraging Information and Communication Technology (ICT) to address urban challenges. Central to this exploration is the role of ICT in enhancing citizen engagement and promoting sustainable development. By examining how digital tools and data-driven strategies are implemented, we can better understand their impact on creating more efficient, responsive, and liveable urban environments.

Understanding Smart Cities

The concept of smart cities encompasses various definitions, but they all converge on the idea that technology, particularly ICT, plays a central role in improving urban life. According to the Smart Cities Council (2014), a smart city uses ICT to enhance livability, workability, and sustainability. The European Union defines it as a city where traditional networks and services become more efficient through digital and telecommunication technologies. Other definitions, such as those from Batty et al. (2012) and ISO (2015), emphasize the integration of digital technologies with traditional urban infrastructure to improve quality of life, urban efficiency, and socio-economic outcomes.

Smart cities are not just about technology but also about improving social, environmental, and economic benchmarks. They represent a shift toward "Future Cities"—encompassing eco-cities, smart grids, and sustainable urban environments. The digital transformation focus of smart cities, as discussed by Hämäläinen (2020), highlights how data and advanced technologies are reshaping urban living.

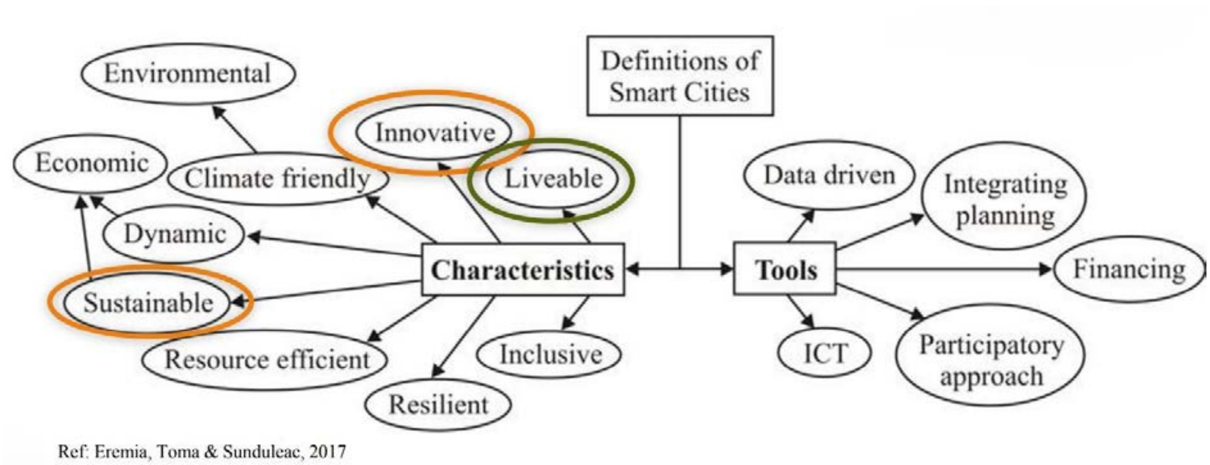


Figure 1: *Smart Cities: Future Cities and Future of cities (Eremia, Toma and Sunduleac, 2017).*

Characteristics and Challenges of Smart Cities

The primary characteristic of smart cities is their desire to improve the social, environmental, and economic well-being of their inhabitants. However, practical implementation faces numerous challenges. These include technical issues related to integrating new technologies with existing infrastructure, ensuring data security, and maintaining public trust. Social challenges also persist, such as fostering citizen engagement and addressing digital literacy gaps. Additionally, governance challenges involve developing regulatory frameworks and ensuring the ethical use of data.

A major concern is the sustainability "debt"—the accumulation of unintended long-term consequences from present decisions. This concept suggests that urban planning should consider future impacts, including those on the environment and society, and make sustainable decisions accordingly.

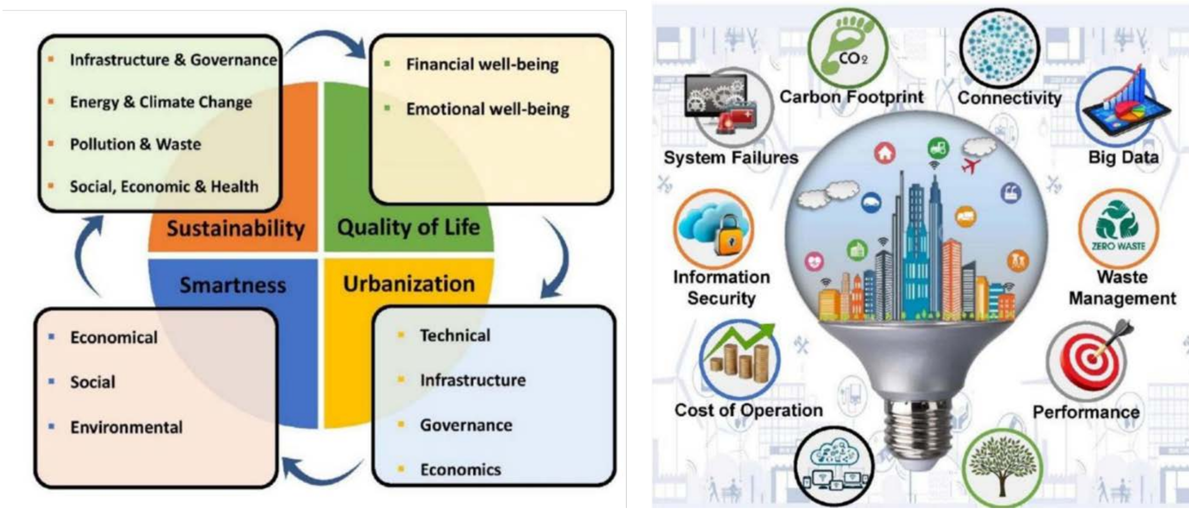


Figure 2: *Smart Cities; Characteristics & Challenges*

Citizen Participation and Responsibility

Citizen engagement is a crucial element of smart cities. The presentation emphasizes the importance of empowering citizens with knowledge and tools to act on issues such as air quality and environmental sustainability. Effective communication strategies are essential to convey complex sustainability issues in a way that both citizens and policymakers can understand.

Innovative approaches like visualization, interactivity, and immersive technologies are being used to engage citizens. For instance, in Trondheim, virtual reality (VR) has been employed to visualize air quality and wind speed. This immersive and interactive solution helps raise public awareness and facilitates data-driven decision-making.

Another example is the "Gaia Vesterålen" project, which uses augmented reality (AR) and object tracking for multi-user interaction. Such initiatives demonstrate how technology can bridge the gap between scientific data and public understanding, encouraging broader participation in environmental monitoring and urban planning.

Digital Tools and Citizen Science

A range of digital tools and participatory methods are being developed to foster citizen engagement. The "Maker Movement," for instance, encourages public involvement in environmental monitoring through low-cost sensors. This approach enables citizens to contribute to scientific research and promotes a sense of collective responsibility.

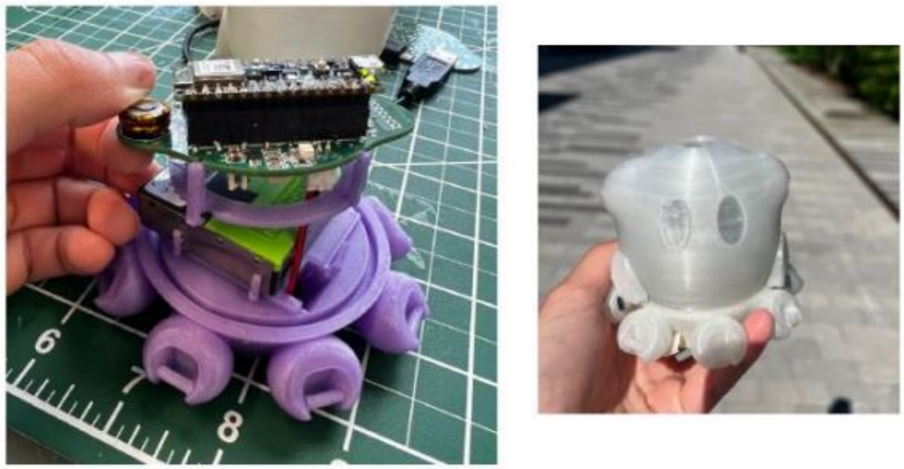


Figure 3: *low cost sensors to check air quality cheaply*

"Thermal walks," pioneered by the Building and Urban Data Science (BUDS) Lab at the National University of Singapore, combine environmental data with people's perceptions to provide a comprehensive understanding of urban heat and microclimates. Similarly, gesture recognition and machine learning technologies are being used to create interactive museum exhibits, enhancing visitor engagement and learning through AI and edge computing.

Figure 4: *Illustration of Thermal walk*

The Smiling Earth Project

One of the most impactful initiatives discussed is the "Smiling Earth" mobile app. This gamified app is designed to raise awareness about carbon footprints and motivate behavioral change. By integrating energy and transport data, the app provides real-time feedback on individual CO_2 emissions. Users can track their environmental impact through intuitive visual indicators, including a circular gauge that represents the distribution of energy consumption across various activities.

The app offers "estimation buttons," allowing users to visualize the potential carbon savings from adopting sustainable behaviors such as using electric vehicles or installing solar panels. Data visualization is a key feature, with bar and continuous graphs illustrating short- and long-term emission trends. This user-centered approach encourages individuals to make more sustainable choices by providing actionable insights and feedback.

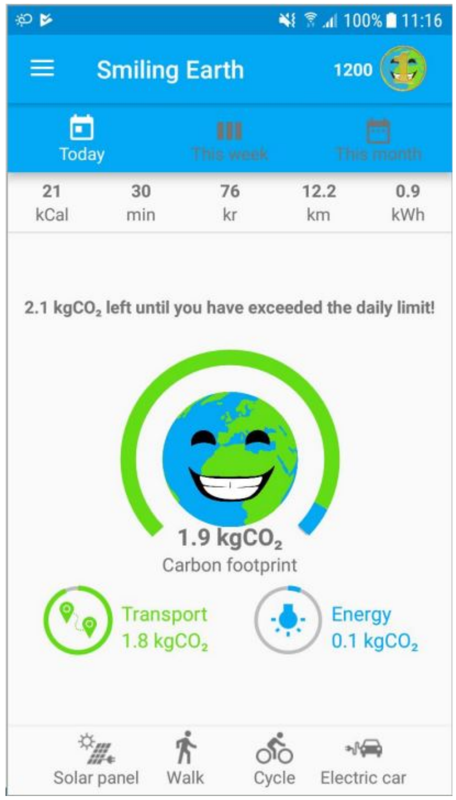


Figure 5: *Smiling Earth Application- User Interface*

Circular Economy and Urban Sustainability

The presentation highlights the importance of transitioning from a linear to a circular economy. Circular cities aim to reduce environmental impact, optimize resource use, and enhance social and economic well-being. This model emphasizes responsible production and consumption, waste reduction, and sustainable urban design.

A circular city applies these principles to urban planning and management, fostering a regenerative system where resources are reused and recycled. This approach not only addresses environmental challenges but also creates new economic opportunities and enhances community resilience.

Multi-Stakeholder Collaboration and the Quintuple Helix

Successful smart city development requires collaboration across diverse sectors. The "Quintuple Helix" model, which extends beyond traditional partnerships between government, academia, and industry to include civil society and the natural environment. This model fosters innovation through interdisciplinary collaboration and ensures that diverse perspectives are incorporated into urban planning and policy-making.

Moreover, the "Triple Transition" framework underscores the need to balance social, environmental, and economic sustainability. It emphasizes that design decisions must account for their future consequences, advocating for a holistic and forward-thinking approach to urban development.

The Sustainability Analysis Diagram (SusAD)

To guide sustainable decision-making in IT systems design, the presentation references the Sustainability Analysis Diagram (SusAD). This tool helps designers consider the long-term social and environmental impacts of their decisions. For example, platforms like Airbnb and Uber illustrate how digital innovations can disrupt traditional industries and create unforeseen social consequences. SusAD encourages a comprehensive analysis of these effects to ensure sustainable and ethical outcomes.

Conclusion and Future Directions

Overcoming smart city barriers requires a multidimensional approach. This involves integrating advanced digital technologies, fostering citizen engagement, and adopting sustainable urban planning practices.

Future smart cities should prioritize transparency, inclusivity, and long-term sustainability. Digital tools like virtual reality, citizen science initiatives, and gamified applications can play a pivotal role in educating and empowering citizens. Collaboration through the Quintuple Helix model and adopting circular economy principles will be essential for creating resilient and sustainable urban environments. Ultimately, the transition from barriers to opportunities in smart city development relies on combining technology for societal benefit while maintaining a strong commitment to sustainability and equity.

7.2 Digitisation of Urban Governance opportunities, Challenges and Way forward: Cochin Smart Mission Limited

Mr. Clipson, Cochin Smart Mission Limited (CSML)

Introduction

The Smart Cities Mission, launched on **25th June 2015** by the Ministry of Housing and Urban Affairs (MoHUA), aims to enhance urban living by providing core infrastructure and a decent quality of life to citizens. This mission promotes the creation of a **clean and sustainable environment** through the implementation of smart solutions. A unique aspect of the Smart Cities Mission is its "lighthouse" approach, where selected cities serve as models to inspire similar developments across the nation. Through pilot projects, the mission fosters the replication of successful initiatives, creating a connected network of smart cities throughout India.

Kochi, under the **Cochin Smart Mission Limited (CSML)**, is a key participant in this national initiative. The city's vision aligns with the principles of making urban areas **inclusive, accessible, safe, green, and identity-preserving**. By integrating technology with governance, Kochi is transforming itself into a smart and sustainable urban hub.

Smart Cities Mission – Strategy and Progress

The Smart Cities Mission follows a comprehensive strategy to integrate advanced technology and efficient governance for urban development. This approach focuses on enhancing public service delivery, improving infrastructure, and fostering community engagement.

A significant part of the strategy involves adopting **Integrated Command, Control, and Communication Centre (IC4)** systems. These platforms combine data from multiple sources to provide real-time analytics, enabling quick decision-making and improving operational efficiency. Over the years, the Smart Cities Mission has demonstrated tangible progress in areas such as public safety, traffic management, energy efficiency, and digital governance.

Figure 1: *Smart Cities mission - progress*

Digital Opportunities in Urban Governance

India is on a trajectory to become a **$1 trillion digital economy by 2025-2026**, with digital innovation driving growth across various sectors. Some of the key focus areas include quality education and universal healthcare, e-governance for efficient service delivery, advanced IT infrastructure, next-generation financial services, and the promotion of the "Make in India, Make for the World" initiative.

Digital platforms in urban governance have revolutionized how city administrations manage resources and respond to public needs. Kochi, through CSML, has adopted a range of digital projects that streamline processes, enhance service delivery, and provide valuable data for decision-making. These projects are improving public services and contributing to economic growth while fostering a culture of technological advancement.

Integrated Command, Control, and Communication Centre

Integrated Command, Control, and Communication Centre (IC4) in Kochi is a centralized platform that integrates data from various smart systems, providing a comprehensive decision-support framework for city administration. It combines inputs from diverse functional services, allowing the aggregation of city-level information in real-time. This system is crucial for urban governance as it enables rapid response to emergencies, enhances transparency, and facilitates continuous monitoring of city operations.

The IC4 platform operates across multiple layers and components, allowing it to analyze data from smart utilities and transform it into actionable insights. These insights aid in planning, monitoring, and managing urban services more effectively. By offering a unified view of urban operations, IC4 supports better resource management and proactive governance.

Key outcomes of the IC4 platform include real-time situational monitoring, fostering transparency and accountability, continuous citizen engagement, and rapid emergency response. This system also provides a foundation for future innovations in urban governance by enabling the monitoring of city functions, controlling field assets, and identifying inefficiencies.

***Figure 2**: Integrated Command, Control, and Communication Centre (IC4), Kochi*

Smart Elements Integrated with IC4

Several smart city solutions are integrated into the IC4 platform to enhance the efficiency of urban services. These include smart LED street lights for better energy management, smart energy meters for accurate real-time power monitoring, and smart water meters to track consumption patterns. Additionally, the system includes intelligent city surveillance for public safety, grievance management modules for addressing citizen complaints, and intelligent traffic management systems (ITMS) for optimizing traffic flow and ensuring pedestrian safety.

The integration of these smart elements ensures that city administration can monitor and manage critical services from a centralized location. This integration facilitates faster response times, data-driven decision-making, and improved public service delivery.

Energy Efficiency Initiatives

One of the significant advancements under the Smart Cities Mission is the deployment of **Smart LED Street Lights**. In the Area-Based Development (ABD) region of Kochi, **3,054 LED streetlights** have been installed. This project, with a total cost of **₹32.38 crores**, is expected to deliver **53% electricity bill savings** and **41% energy efficiency**. The centralized monitoring system via IC4 ensures that streetlights function optimally, enhancing public safety and reducing energy consumption.

The **Pan-City LED Street Light** initiative further extends energy efficiency across the city, with **32,000 lights installed** and a proposed expansion to **40,400 lights**. This project, with an estimated cost of **₹42 crores**, aims to deliver annual energy savings of **₹1.54 crores**, contributing to long-term sustainability.

The introduction of **Smart Energy Meters** is another crucial development. With **24,000 smart meters** already installed, Kochi leads Kerala in real-time energy monitoring. These meters improve billing accuracy, reduce resource wastage, and minimize energy theft.

***Figure 3**: Smart LED Street Light System Overview*

Intelligent City Surveillance System (ICSS)

The **Intelligent City Surveillance System (ICSS)** in Kochi enhances public safety through an extensive network of **464 cameras** at **141 locations**. This project, costing **₹42.61 crores**, employs fixed and pan-tilt-zoom (PTZ) cameras to provide comprehensive surveillance coverage.

ICSS delivers real-time monitoring, facilitates faster crime detection, and helps ensure the cleanliness of public spaces. The system also provides real-time alerts and supports continuous data analysis to improve city-wide safety measures.

Integrated Traffic Management System (ITMS)

The **Integrated Traffic Management System (ITMS)**, with a project cost of **₹27.44 crores**, is designed to streamline traffic flow and improve road safety. With **104 cameras** across **21 strategic**

locations, the system includes specialized features like **red light violation detection**, **pelican signals** for pedestrian crossings, and **variable message displays** for real-time traffic updates.

ITMS enhances pedestrian safety, provides green corridors for emergency vehicles, and supports law enforcement through automated traffic rule enforcement. This system plays a pivotal role in reducing congestion and improving urban mobility.

***Figure 4:** Traffic Management Dashboard*

Open Spaces and Tourism Development

Under the Smart Cities Mission, **11 parks and open spaces** in Kochi have been upgraded, with work ongoing in **15 additional locations**. Key projects include the **Marine Drive Walkway**, spanning **2.45 km** and developed at a cost of **₹1.07 crores**, and the **Rajendra Maidan**, which has been revitalized to enhance public recreation.

These projects are not only improving the city's aesthetic appeal but also generating revenue through advertisement spaces and user fees. By creating accessible green spaces, the initiative promotes physical well-being, social interaction, and environmental sustainability.

Figure 5: *Redeveloped Marine Drive Walkway*

Challenges and Barriers in Digital Transformation

Implementing smart city solutions presents several challenges. One major obstacle is the **lack of technological competency** among project stakeholders, including consultants and service providers. Additionally, many departments continue to evaluate progress based on physical outputs rather than project outcomes, limiting the realization of long-term benefits.

Resistance to adopting new systems and lack of departmental integration further complicate the implementation process. Moreover, sustaining smart projects beyond the initial deployment phase remains a concern, particularly during ongoing maintenance and operation.

Way Forward

To advance urban transformation, it is essential to establish **Centers of Excellence** for sector-specific innovations and strengthen **Public-Private Partnerships (PPP)**. Capacity-building programs are vital to enhance government personnel's technological expertise, while robust cybersecurity measures and open data policies will ensure the integrity of digital systems.

By bridging the **digital divide** between urban and rural areas and fostering digital literacy, the Smart Cities Mission can continue to drive sustainable urban development.

Conclusion

The Smart Cities Mission has transformed urban governance in India by leveraging technology to improve infrastructure, enhance public safety, and promote energy efficiency. Kochi's progress under the **CSML** serves as a model for other cities, demonstrating the potential of integrated digital solutions to create sustainable, livable urban environments.

7.3 Barriers for Smart City Development: Literature Review and Way Forward

Prof. Alenka Temeljotov Salaj, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

1. Introduction

The development of smart cities is a complex process driven by the need for sustainability, resilience, health, and well-being. These cities rely heavily on technological innovations and smart solutions to enhance urban living and resource management. However, despite the growing emphasis on smart urban transformation, several barriers hinder the effective implementation of smart city initiatives. This report explores the key challenges identified through a literature review and proposes ways to overcome these obstacles to facilitate sustainable urban development.

2. Defining Smart Cities

There is no single, universally accepted definition of a smart city, but multiple organizations offer perspectives on what constitutes one. According to the International Organization for Standardization (ISO), a smart city is an innovative urban area that uses Information and Communication Technologies (ICT) to enhance the quality of life, improve urban service efficiency, and address the socio-economic and environmental challenges posed by urbanization. The European Union describes a smart city as one where digital and telecommunication technologies make traditional networks and services more efficient, benefiting both inhabitants and businesses. Beyond these definitions, a smart city connects physical, social, business, and ICT infrastructures to create a more intelligent and responsive urban environment.

Smart city governance goes beyond technological adoption—it involves creating new forms of human collaboration through digital technologies. The effective implementation of smart cities requires a political understanding of technology, a systematic process for managing emerging innovations, and a balanced focus on economic benefits and broader public values. This perspective underscores that technology alone is insufficient to make a city "smart"; rather, it is the thoughtful integration of technology with governance and citizen participation that drives meaningful transformation.

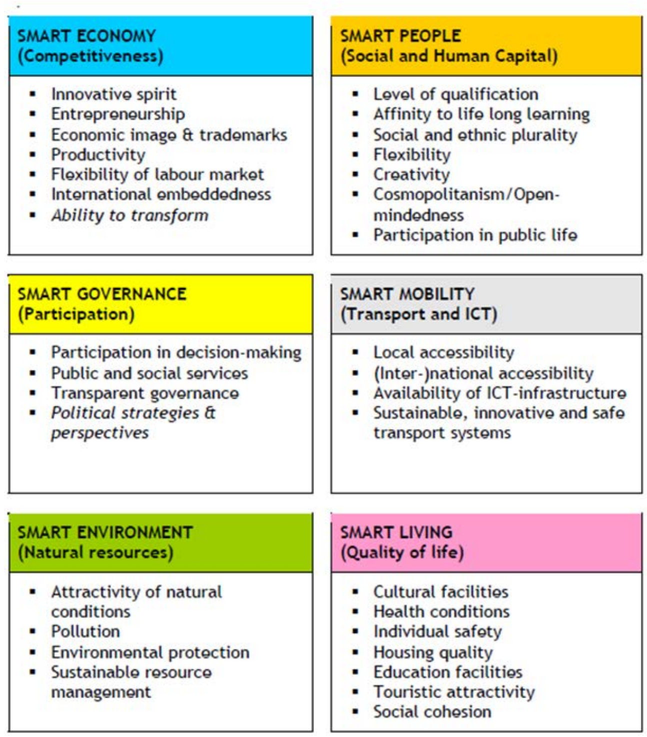


***Figure 1**: Characteristics and factors of smart city*

3. Key Aspects of a Smart City

Smart cities can be categorized across three main dimensions: social, technological, and environmental. Socially, a smart city fosters citizen participation, supports the education and technological engagement of its residents, and focuses on improving the overall quality of life. This involves creating people-centered processes that prioritize public welfare and well-being. From a technological perspective, smart cities require a robust and adaptable infrastructure that manages and utilizes data effectively while respecting privacy concerns. The environmental dimension emphasizes reducing the carbon footprint through advanced resource management and sustainable urban practices. A successful smart city integrates these three dimensions to create a holistic and sustainable urban ecosystem.

4. Barriers to Smart City Development

4.1 Smart Governance Barriers

One of the most significant challenges in smart city development is the lack of a clearly defined digital or smart city strategy. Many cities struggle to integrate agile technology pilots with long-term strategic projects and procurement processes. This disconnect slows the socio-economic progress necessary for smart city development. Furthermore, there is a limited understanding of the interaction between smart governance and the emerging socio-technological landscape. Without clear value creation strategies, it becomes difficult to improve stakeholder satisfaction and assess how smart city governance contributes to economic growth and public values. Another major gap lies in the absence of well-defined goals for public participation. While smart cities promise citizen empowerment, there is often no structured framework to transition from basic information-sharing to genuine co-management and decision-making.

4.2 Smart People-Oriented Barriers

Smart cities often adopt advanced digital solutions but fail to address the digital literacy gap among their citizens. The successful implementation of smart governance relies on public participation, yet there is a lack of tools and frameworks to encourage meaningful citizen engagement. Most studies evaluating smart city initiatives focus on technological outputs rather than citizen-centric outcomes. Few emphasize the importance of co-creating knowledge with local communities, limiting the potential for inclusive urban development. Moreover, many smart city projects lack a "By People, For People" orientation, resulting in technological innovations that do not adequately address real community needs. Another critical barrier is the poor understanding of sustainability goals and their long-term social, environmental, and economic consequences among the public and policymakers.

5. Sustainable Urban Development and Smart Cities

A sustainable smart city must align with the United Nations Sustainable Development Goals (SDGs) by addressing social, technological, and environmental challenges through integrated frameworks. Two overarching perspectives guide sustainable urban development. First, co-production serves as a means to bridge the gap between research and real-world action by actively involving citizens in the knowledge-production process. Second, successful smart city strategies must incorporate multiple dimensions of urban sustainability to ensure long-term, equitable outcomes. This requires the active involvement of local communities in shaping the city's future through participatory methods.

6. Findings from Research Projects

6.1 Urban Green Spaces and Social Perceptions

Research highlights that cities function as ecosystems where social, ecological, and technological systems are interconnected. Green infrastructure plays a crucial role in maintaining these ecosystems, alleviating urban stress, and improving citizens' well-being. However, the perception and use of green spaces differ across social and demographic groups. These differences must be considered when planning and implementing urban sustainability projects to ensure equitable access and benefit for all residents.

6.2 Local Knowledge as a Democratic Tool

Local knowledge plays a pivotal role in promoting democratic participation and enhancing the legitimacy of smart city initiatives. Co-production with local communities generates practical and policy-relevant knowledge that reflects diverse lived experiences. Digital participatory methods, such as Public Participation GIS (PPGIS), help integrate community perspectives into urban planning by capturing the meanings and values that residents attach to specific places. However, challenges remain in ensuring data accuracy, establishing trust between stakeholders, and maintaining long-term citizen engagement.

6.3 Digital Participation Tools

Digital tools offer new possibilities for citizen engagement in smart cities. For instance, citizen science initiatives empower residents to collect environmental data, such as air quality measurements, contributing to evidence-based policymaking. Interactive innovation platforms foster collaboration between citizens, businesses, and government officials to identify urban problems and co-design solutions. Despite these advances, technical and social challenges persist, including data calibration, privacy concerns, and aligning the diverse motivations of citizens and city officials.

6.4 Balancing Public Engagement and Expectations

A critical aspect of smart city development is balancing public engagement with realistic expectations. New participatory methods, such as citizen science, participatory budgeting, and digital tools, aim to include previously disengaged residents in urban decision-making. However, it is essential to clearly communicate the scope of public influence to avoid disillusionment. If these tools are not implemented with transparency, they risk generating frustration rather than empowerment among citizens.

7. Case Studies and Innovative Solutions

Several case studies demonstrate innovative approaches to addressing smart city challenges. In Oslo's Fjordbyen and Furuset projects, urban transformation initiatives focused on sustainable strategies and citizen inclusiveness. The "FjordbyAppen" project developed a digital voting application to allow residents to choose between various sustainable development options while providing feedback on how their choices impact different user groups. Other initiatives, such as "ByBøddy," created an online platform to collect citizen input across different life stages, while "FUTUREset" introduced interactive, multilingual kiosks to engage underrepresented groups. Mobile solutions like "ByBilen" brought participation opportunities directly to citizens, offering digital services and administrative support. Meanwhile, the "ToolBoxen" platform provided municipalities and private organizations with customized methods to facilitate public participation. These case studies underscore the value of technology in fostering citizen engagement while highlighting the importance of addressing social and technical barriers.

Figure 2: Illustration of FjordbyAppen, ByBøddy & FUTUREset

8. Conclusion and Way Forward

Overcoming the barriers to smart city development requires a comprehensive and collaborative approach. Cities must develop clear digital strategies and integrate agile technology initiatives with long-term urban planning. Enhancing digital literacy and fostering a citizen-centric approach are essential for ensuring public participation and co-creation. Embracing participatory methods that leverage local knowledge can strengthen community engagement and improve policy outcomes. Furthermore, technological solutions should be inclusive and adaptable to the diverse needs of urban populations. By addressing these barriers and fostering a holistic approach to smart city governance, cities can achieve sustainable development while improving the quality of life for their residents.

7.4 Urban Heritage Facility Management (UHFM): Navigating Sustainability Challenges

Dr. Bintang Noor Prabowo, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

Introduction

Urban heritage sites are vital to preserving the cultural identity of cities while simultaneously adapting to the demands of modern urban living. These sites are more than historical artifacts; they represent living environments that must evolve to accommodate contemporary challenges such as climate change, over-tourism, and gentrification. Managing these sites requires a delicate balance between **cultural preservation** and **modernization**.

Urban Heritage Facility Management (UHFM) is an emerging framework that integrates **traditional facility management (FM)** with the complex demands of **urban heritage conservation**. This approach seeks to maintain the historical and cultural significance of heritage sites while addressing the operational and sustainability challenges associated with modern urban development.

Figure 1: *A juxtaposition of historic and modern architecture, reflecting the balance required between cultural preservation and urban growth.*

The Tension Between Cultural Heritage Conservation and Modernization

Urban development often clashes with the preservation of cultural heritage. The tension between these two forces is particularly evident when new infrastructure and commercial interests threaten the historical integrity of urban heritage sites. An example of this tension can be seen in the

Liverpool Maritime Mercantile City, which was removed from UNESCO's **World Heritage List** in 2021 due to large-scale modernization projects, including the construction of **Everton Stadium**. This case demonstrates how urban growth can sometimes overshadow the commitment to preserving cultural identity.

On the other hand, successful models of **adaptive reuse** showcase how modern architecture can coexist with historical structures. For instance, the **Louvre Pyramid** in Paris and the **Royal Ontario Museum** in Canada demonstrate that responsible and thoughtful design can integrate contemporary structures into historic settings without compromising cultural values. These examples highlight that modernization and cultural conservation are not mutually exclusive when managed through effective UHFM frameworks.

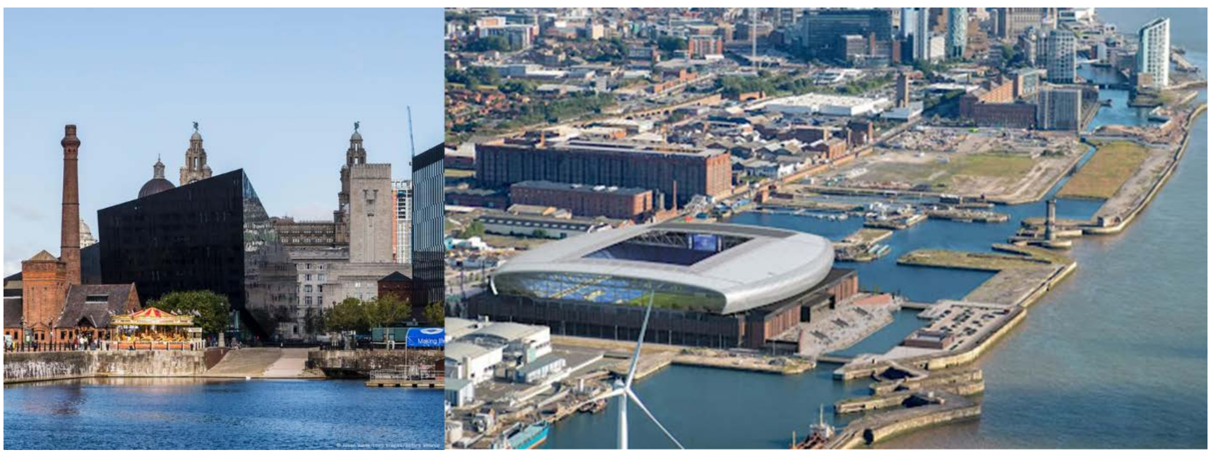


Figure 2: *Liverpool's waterfront development that led to the city's removal from UNESCO's World Heritage List.*

Understanding the Evolution from Facility Management (FM) to Urban Heritage Facility Management (UHFM)

Traditional **Facility Management (FM)** focuses on providing effective and efficient operational services, including maintenance, resource management, and infrastructure support. However, urban heritage sites require a more specialized approach due to the need to balance operational efficiency with the **preservation of cultural and historical assets**.

The transition from FM to **Urban Heritage Facility Management (UHFM)** reflects a shift from basic operational maintenance to a more nuanced, multidisciplinary model. For instance:

- **Simple Structures (Cabin/Hytta)** require minimal intervention and are often self-maintained.
- **Residential Buildings** involve more complex systems, with some outsourced support for maintenance.
- **Student Villages** demand centralized facility management for efficiency and large-scale operational support.
- **World Heritage Sites (e.g., Røros, Norway)** require comprehensive UHFM frameworks to manage the interplay between modern needs and historical preservation.

Figure 3: *An example of UHFM practices at the Røros World Heritage Site.*

The UHFM Organizational Framework

The **UHFM framework**, as proposed by **Prabowo et al. (2024)**, builds on the **Historic Urban Landscape (HUL)** approach to provide a structured methodology for managing urban heritage sites. The UHFM framework involves six critical steps:

1. **Identify and Map Heritage Assets** – Systematically document cultural, physical, and historical assets to understand their value and vulnerabilities.
2. **Evaluate Risks and Opportunities** – Identify environmental and urbanization risks while exploring opportunities for integrating sustainable practices.
3. **Stakeholder Engagement** – Involve local communities, policymakers, and private sectors to ensure a collaborative decision-making process.
4. **Integrate Sustainable Management Strategies** – Embed heritage conservation plans within broader urban policies and development initiatives.
5. **Continuous Monitoring and Evaluation** – Implement systems for ongoing assessment to adapt to changing conditions and emerging challenges.
6. **Public Awareness and Education** – Promote public engagement through educational programs and initiatives that highlight the value of cultural heritage.

This framework not only facilitates efficient facility management but also ensures that cultural identity is preserved while enabling heritage sites to evolve alongside urban environments.

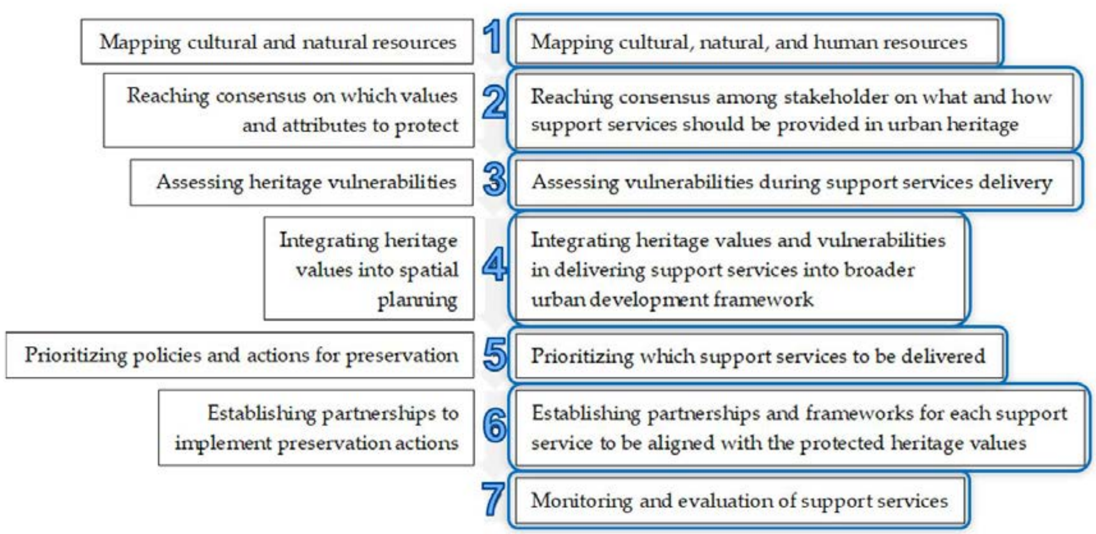


***Figure 4**: Diagram illustrating the six-step UHFM framework.*

Cultural Dynamics in Urban Heritage Management

Cultural dynamics refer to the ongoing process of **cultural formation, transformation, and adaptation** over time. These dynamics play a crucial role in **UHFM**, where the objective is to strike a balance between **cultural continuity** and **modern urban demands**.

Urban heritage sites are shaped by both **internal** and **external** cultural factors. Internal factors include local traditions, community identity, and historical narratives, while external factors encompass economic pressures, urban development policies, and globalization. Successful UHFM practices account for these dynamics by integrating local knowledge and ensuring cultural narratives remain central to urban development strategies.

One of the central dilemmas in UHFM is the **tension between preservation and modernization**. While preserving historical buildings protects cultural authenticity, modernization offers improved environmental efficiency and economic benefits. Effective UHFM policies seek to harmonize these competing objectives through **adaptive reuse** and **sustainable retrofitting** practices.

Sustainability Challenges in Urban Heritage Areas

Urban heritage sites face complex sustainability challenges across four key dimensions: **social**, **environmental**, **economic**, and **cultural**.

Social Sustainability Challenges include issues like **gentrification** and **displacement**, where rising property values threaten to displace long-standing communities. Furthermore, heritage management plans often adopt a **top-down** approach, excluding local residents from decision-making processes. Modernizing infrastructure to ensure accessibility without compromising cultural value is another persistent challenge.

Environmental Sustainability Challenges revolve around the **climate change** threat, which poses significant risks to the physical integrity of heritage sites. For instance, rising temperatures and extreme weather events can accelerate the decay of historic materials. Retrofitting heritage buildings to improve **energy efficiency** without compromising their architectural integrity is a delicate process.

Economic Sustainability Challenges include the need for **diversified funding models** to support ongoing maintenance and conservation. Over-tourism exacerbates physical wear on heritage sites while fostering economic inequity by concentrating financial benefits within specific stakeholder groups.

Cultural Sustainability Challenges highlight the potential **loss of authenticity** due to modernization. As urban areas evolve, there is a risk of **eroding cultural identity** and **weakening the intergenerational transfer of knowledge**.

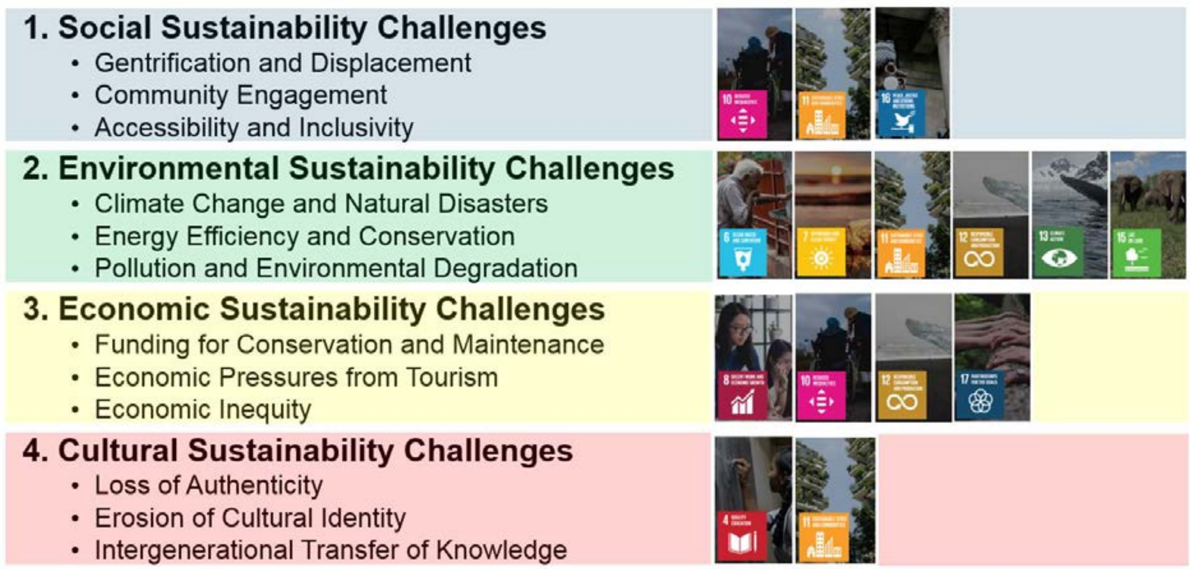


***Figure** 5: Sustainability challenges affecting urban heritage management.*

Integrating UHFM with the UN Sustainable Development Goals (SDGs)

UHFM practices align closely with the **UN Sustainable Development Goals (SDGs)** by fostering inclusive, resilient, and sustainable urban development. Specifically:

- **SDG 11** (Sustainable Cities and Communities) emphasizes the protection of cultural and natural heritage.
- **SDG 13** (Climate Action) encourages proactive measures to protect heritage sites from climate-related hazards.
- **SDG 8** (Decent Work and Economic Growth) promotes sustainable tourism practices that balance economic growth with cultural conservation.

By embedding UHFM strategies within the broader SDG framework, urban heritage sites can be sustainably managed to benefit both present and future generations.

Conclusion

Urban Heritage Facility Management (UHFM) represents a crucial framework for addressing the **sustainability challenges** faced by heritage sites. By integrating **cultural preservation** with **modernization**, UHFM supports the long-term protection of cultural identities while allowing urban environments to evolve.

The successful implementation of UHFM requires a **holistic and collaborative** approach that balances social, environmental, economic, and cultural priorities. As urban landscapes continue to change, UHFM offers a viable pathway to ensure that heritage sites remain vibrant, accessible, and resilient for future generations.

8 Summaries of the Group Projects

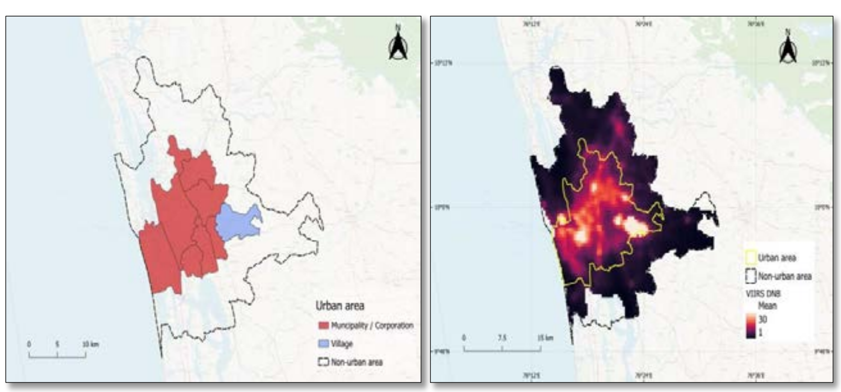
8.1 Group 1: *Assessing Urban Growth and its impacts on Surface Urban Heat Island in the Kochi City, Kerala*

Authors*: Ajaya Indrani, Anagha Satheesan K., Anjaly P. S., Madhuraj P. K., Peediyakkathodi Sajna, Pravin Punde, Rakhi K. Raj, Sneha K. S., Sruthy Robert, Vishnu N. G., Alexander Baklanov, Bindu G., Igor Esau, Jayanarayanan Kuttippurath, and Prince Vijay*. See Annex 2 for affiliations.

1. Introduction

Urbanization is a defining characteristic of the 21st century, with more than half of the global population currently residing in cities. This proportion is expected to increase to nearly 70% by 2050, driven by rapid economic growth, infrastructural development, and migration from rural to urban areas (United Nations, 2018). While urbanization brings economic and social benefits, it also introduces environmental challenges, including the Urban Heat Island (UHI) effect. UHIs occur when urban areas exhibit significantly higher temperatures than their surrounding rural regions, primarily due to the replacement of natural vegetation with impervious surfaces like asphalt, concrete, and buildings (Oke, 1982). These materials absorb and retain heat more efficiently than natural landscapes, leading to temperature disparities (Santamouris, 2015).

Kochi, located on the southwest coast of India in the state of Kerala, is a rapidly growing metropolitan city recognized for its strategic economic and industrial significance. The city serves as a major economic hub, having its own Special Economic Zone (SEZ) (Government of Kerala, 2021). Kochi's industrial landscape includes key establishments such as the Cochin Shipyard, one of the largest shipbuilding and maintenance facilities in India, and the Cochin Port, which facilitates extensive maritime trade (Kumar, 2020). The city also houses Infopark Kochi, a premier Information Technology (IT) park, hosting numerous global and domestic technology firms (Infopark, 2022). Kochi is also a leading tourism destination, known for its rich cultural heritage, including historic sites like Fort Kochi and Mattancherry (Kerala Tourism, 2023). This dynamic growth across industries, coupled with increasing urban sprawl and population density, has intensified the demand for infrastructure and posed significant environmental challenges. The interaction between industrial expansion, tourism, and urbanization makes Kochi an ideal subject for studying urban heat islands for developing sustainable urban planning strategies.



Left: The administrative boundary of the city of Kochi and nearby rural regions. Right: The Visible and Infrared Imaging Suite (VIIRS) Day Night Band (DNB) on the Joint Polar-orbiting Satellite System (JPSS).

2. Objective

To assess the urban heat island and urban sprawl of the city of Kochi, Kerala.

3. Methodology

In this study, **MODIS Land Surface Temperature (LST) data** (MOD11A2.0061) for the period March, 2023– February, 2024 was utilized to analyze both daytime and nighttime surface temperatures across Kochi and its surrounding rural regions. This dataset offers an 8-days composite of surface temperatures with a spatial resolution of 1 km, ensuring accurate and high-quality thermal observations over large areas.

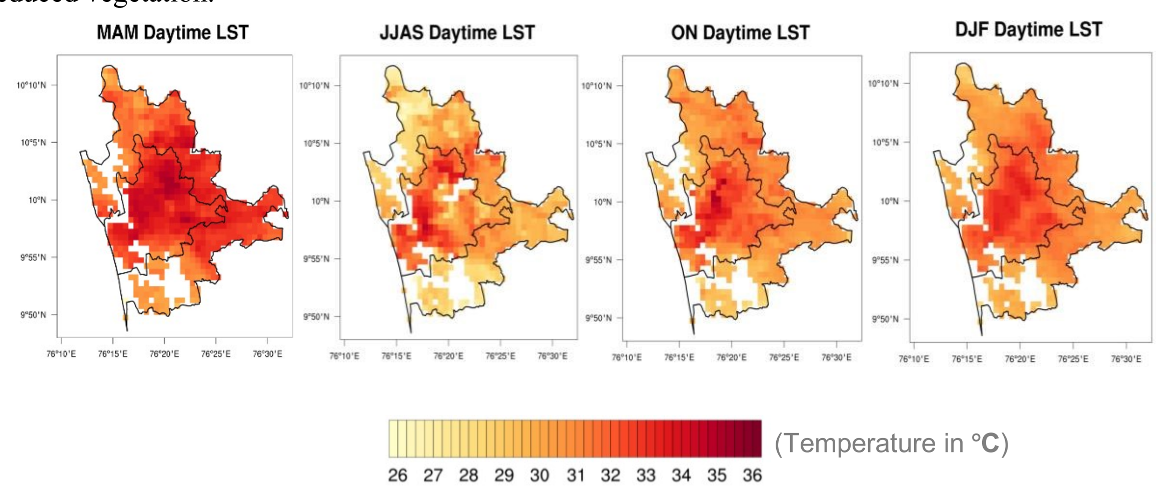
The Surface Urban Heat Island (SUHI) index was calculated using the formula:

SUHI = LSTurban – meanLST non-urban

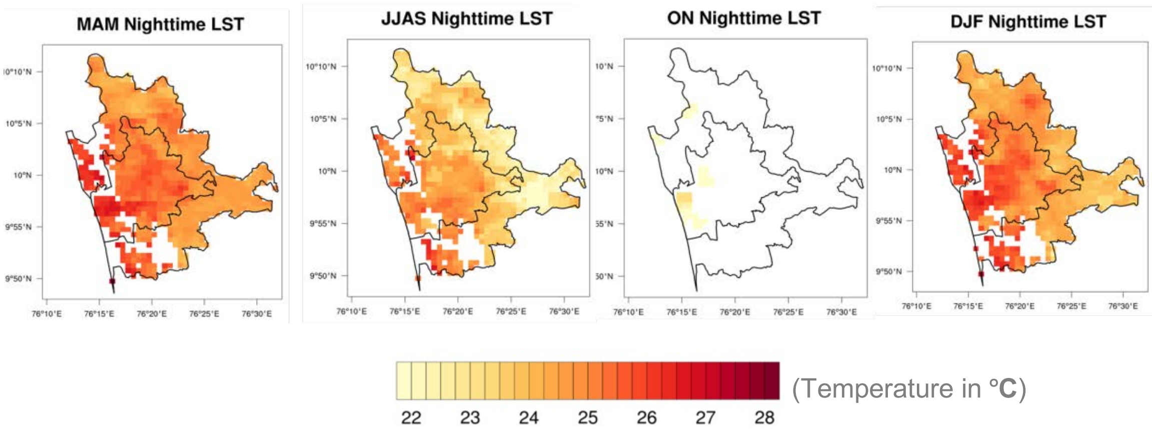
In addition, the study incorporated a range of datasets and analytical methods to assess the UHI and urban sprawl. MODIS Land Use and Land Cover (LULC) product (MCD12Q1.061) for the years 2003 and 2023 were used to analyze historical changes in land use. Normalized Difference Vegetation Index (NDVI) values were calculated using Sentinel-2 data. The GHSL-POP R2023A and Global Building Volume (P2023A) datasets were integrated to analyze urban growth patterns and evaluate their influence on surface temperature dynamics. Meteorological data were sourced from ERA5 reanalysis datasets and supplemented with ground-based observations to ensure accuracy. The analysis was conducted using R, QGIS, Python, Google Earth Engine, and the NCAR Command Language (NCL).

4. Results and Discussion

The annual daytime Land Surface Temperature (LST) for Kochi was 30.68°C, with significant seasonal variations. The highest daytime LST was recorded during MAM (March to May) at 33.29°C, followed by DJF (December to February) at 32.02°C. The JJAS (June to September) and ON (October and November) recorded lower temperatures, 31.31°C and 31.77°C, respectively. The central region of Kochi exhibited the highest UHI index during the day, highlighting the intensity of urban heat due to dense infrastructure and reduced vegetation.

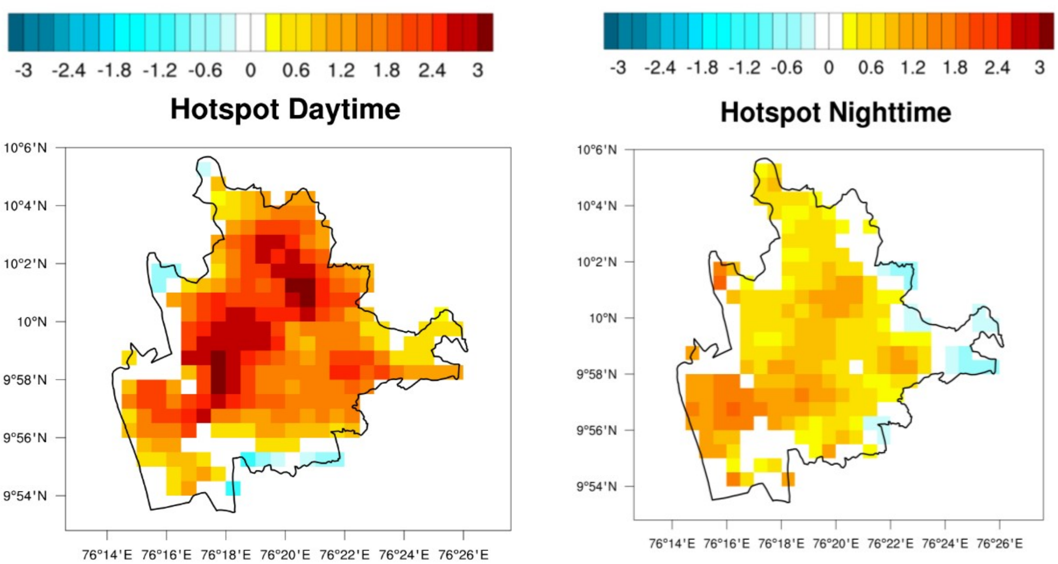


Daytime LST

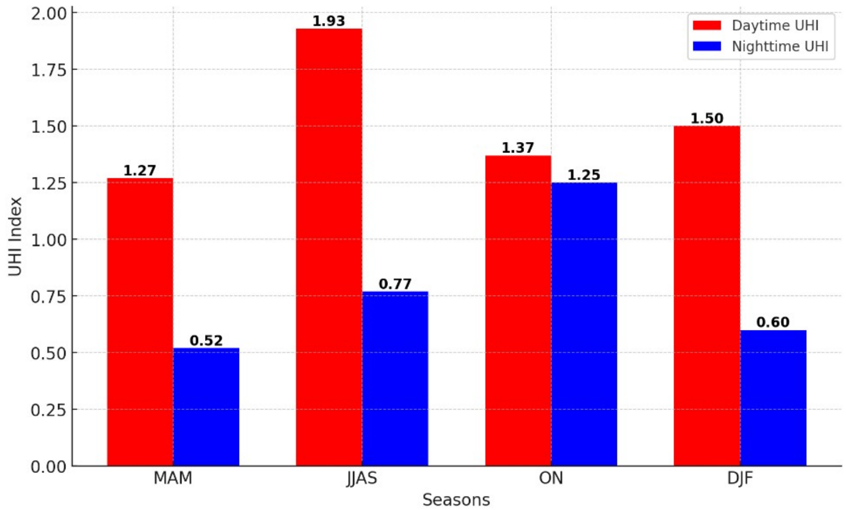


Nighttime LST

The annual nighttime LST averaged 24.44°C, with seasonal maxima recorded in the MAM at 25.37°C. The lowest nighttime temperatures were observed in ON at 20.38°C. Unlike daytime patterns, the maximum nighttime UHI index was observed in coastal regions, likely influenced by thermal retention in built-up areas and proximity to water bodies. The mean annual UHI index was 1.51°C during the daytime and 0.78°C at night, demonstrating the persistent thermal disparity between urban and rural areas.

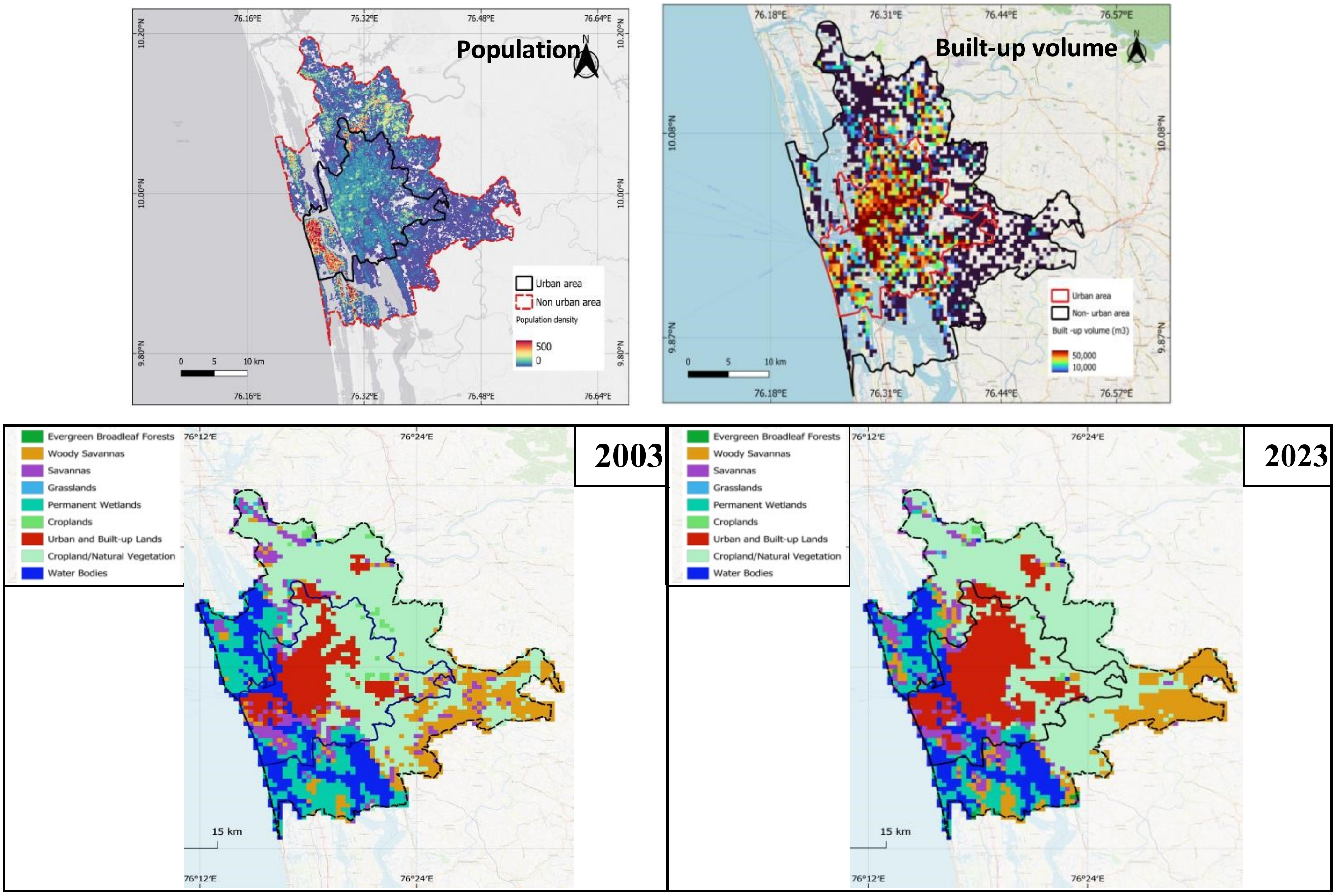


UHI between day and night



Average UHI between day and night across seasons

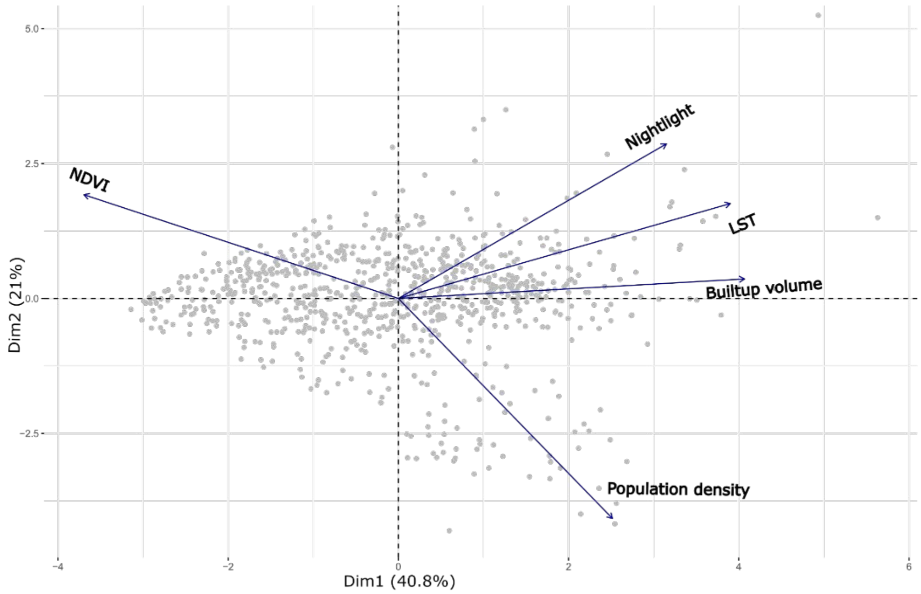
Urban sprawl has led to a noticeable decline in Normalized Difference Vegetation Index (NDVI), reflecting reduced vegetation cover and its associated cooling effects. From the built-up volume data, it was observed that the city is expanding predominantly in the northeast direction. This trend is indicated by the presence of high building volume pixels spreading extensively in that direction.



The analysis of Land Use and Land Cover (LULC, lower panel) changes from 2003 to 2023 reveals significant transformations in Kochi's landscape, driven by urbanization and shifts in land management practices. Built-up areas exhibited a substantial 48.38% increase, marking the most significant positive change among all LULC categories (upper right).

This reflects the rapid urbanization and expansion of infrastructure in Kochi. Croplands experienced the steepest decline, with a 60.00% reduction over the 20-year period. A 20.34% reduction in permanent wetlands was observed, indicating significant environmental degradation, possibly due to land reclamation for construction and infrastructure development.

The PCA results indicated that built-up volume and nightlight intensity are positively associated with Land Surface Temperature (LST), suggesting that urban features contribute to an increase in surface temperatures. Conversely, Normalized Difference Vegetation Index (NDVI) is negatively associated with LST, highlighting the cooling effect of vegetation in mitigating urban heat.



PCA biplot showing the relationship between LST and Related Variables.

4.1 Mitigation of Urban Heat Island (UHI)

Addressing the Urban Heat Island (UHI) effect in Kochi requires a combination of structural interventions, urban planning strategies, and the promotion of green infrastructure. The following mitigation strategies were identified and discussed to reduce the intensity of UHI and enhance urban resilience:

Reflective and White Roofs: Applying reflective or white paint to rooftops can significantly reduce the amount of heat absorbed by buildings, lowering surface temperatures and reducing indoor cooling demands. These coatings reflect sunlight and minimize heat retention, making them a cost-effective solution for managing UHI in densely built areas.

Green Roofs and Terrace Gardens: Implementing green roofs, where vegetation is grown on rooftops, offers dual benefits: reducing rooftop temperatures and improving urban aesthetics. Green roofs not only reduce heat absorption but also enhance evapotranspiration, which cools the surrounding air. Terrace gardens, another effective intervention, utilize vacant rooftop spaces to grow plants, further reducing building temperatures and improving air quality.

Community Gardens: Establishing community gardens in vacant urban spaces encourages sustainable land use and increases vegetation cover in the city. These gardens not only reduce localized temperatures but also promote community engagement and enhance food security.

Promotion of Green Infrastructure: Integrating green infrastructure into urban development projects can have long-term benefits. Materials like laterite and compressed earth blocks offer sustainable and thermally efficient solutions, particularly suited to the climatic and environmental conditions of regions like Kochi.

5. Conclusion

The analysis of the Urban Heat Island (UHI) effect and urban sprawl in Kochi reveals the profound impact of rapid urbanization on the city's thermal and ecological balance. The study highlights a significant increase in built-up areas over the past two decades, accompanied by a decline in vegetative cover, croplands, and wetlands. These changes have intensified the UHI effect, with elevated Land Surface Temperatures (LST) observed in densely urbanized regions and coastal areas. The results demonstrate a positive correlation between LST and urban features like built-up volume and nightlight intensity, while vegetation indices such as NDVI show a negative association, underscoring the critical role of vegetation in mitigating urban heat.

Mitigation strategies, including the adoption of reflective and green roofs, urban greening, community gardens, and sustainable land-use planning, have been identified as essential steps to combat the UHI effect. Furthermore, the use of traditional construction materials such as laterite and compressed earth blocks presents an eco-friendly alternative for reducing heat absorption and promoting thermal regulation.

Kochi's rapid urban growth, particularly in the northeast direction, reflects the need for proactive urban planning that integrates green infrastructure and preserves natural ecosystems. Policies promoting the use of sustainable building practices, tree planting, and the conservation of wetlands and other green spaces are critical to ensuring long-term environmental sustainability.

References

1. Government of Kerala. (2021). Special Economic Zones in Kerala. Retrieved from https://kerala.gov.in
2. Infopark. (2022). Infopark Kochi Overview. Retrieved from https://infopark.in Kerala Tourism. (2023). Tourism in Kochi. Retrieved from https://www.keralatourism.org
3. Kumar, R. (2020). Economic Importance of Cochin Shipyard and Port. Journal of Maritime Studies, 14(3), 45-60.
4. Oke, T. R. (1982). The Energetic Basis of the Urban Heat Island. Quarterly Journal of the Royal Meteorological Society, 108(455), 1–24.
5. Santamouris, M. (2015). Analyzing the Heat Island Magnitude and Characteristics in Urban Areas: A Novel Methodology for Global Applications. Advances in Building Energy Research, 9(1), 21–39.
6. United Nations. (2018). World Urbanization Prospects: The 2018 Revision. Department of Economic and Social Affairs, Population Division.

8.2 Group 2: *Assessing Urban Air Quality: A Comparative Study of Pollutant Trends in Delhi and Kochi*

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Abstract

This study investigates the temporal and spatial variations in air pollutant concentrations, including carbon monoxide (CO), nitrogen dioxide (NO_2), aerosols, formaldehyde (HCHO), sulfur dioxide (SO_2), and aerosol optical depth (AOD) over the cities of Delhi and Kochi from 2019 to 2023. Satellite-derived data from Sentinel-5 Precursor (TROPOMI) and Terra and Aqua (MODIS) sensors were utilized to analyze pollutant trends, with a particular focus on the effects of the COVID-19 lockdown periods. The methodology involved extracting monthly pollutant data from 20-30 random points within each city, averaging the data to identify temporal trends, and performing spatial analysis within city boundaries. A Generalized Linear Model (GLM) was applied to assess the relationships between pollutants and other environmental variables, providing insights into the statistical significance and direction of changes in pollutant concentrations. The study quantifies the relative change in pollutant levels from the baseline year of 2019 and explores how pollution dynamics varied across different regions and time periods. This report aims to contribute valuable insights for urban air quality management, particularly in the context of policy-making and environmental monitoring.

1. Introduction

Air pollution has emerged as one of the most pressing environmental challenges faced by urban populations around the world. With profound implications for human health, climate change, and ecosystem sustainability, the escalating levels of pollutants in urban areas have become a major concern. Rapid urbanization, industrialization, and the increasing number of vehicles have exacerbated the concentration of harmful pollutants in the atmosphere, significantly affecting air quality in cities globally. In India, major urban centers such as Delhi and Kochi are witnessing deteriorating air quality, which not only threatens public health but also compromises the quality of life for millions of residents. The management and mitigation of air pollution are crucial for safeguarding public health, and a comprehensive understanding of its spatial and temporal dynamics is essential for effective air quality control measures.

This study aims to investigate the temporal and spatial variations in the concentration of key air pollutants, including carbon monoxide (CO), nitrogen dioxide (NO_2), aerosols, formaldehyde (HCHO), sulfur dioxide (SO_2), and aerosol optical depth (AOD), in the cities of Delhi and Kochi. The primary goal of this research is to evaluate how the concentrations of these pollutants have evolved over time from 2019 to 2023, with particular emphasis on the impact of the COVID-19 lockdowns on air quality. To achieve this, the study leverages remote sensing data from the Sentinel-5 Precursor (TROPOMI) and Terra and Aqua (MODIS) satellites, which offer valuable insights into the atmospheric composition and pollutant levels over the study period.

The methodology employed includes advanced spatial and temporal analysis techniques, such as Generalized Linear Model (GLM) analysis and relative change calculations, to explore pollutant trends and their contributing factors. The temporal analysis identifies pollutant concentration trends over the years, while the spatial analysis offers a detailed understanding of the distribution and intensity of pollution across both cities. Additionally, the relative change analysis quantifies the variations in pollutant levels relative to baseline data from 2019, highlighting the effects of environmental factors, regulatory measures, and external events such as the pandemic.

This report aims to provide a thorough analysis of the pollutant dynamics in Delhi and Kochi, offering insights that can guide future air quality management strategies. By examining the spatial and temporal trends of pollutants, this study contributes to the ongoing efforts to improve air quality, mitigate health risks, and promote sustainable urban development in Indian cities. Through this research, we hope to inform policy decisions that can lead to more effective and targeted actions to address air pollution and protect public health.

2. Data and Methodology

This study aims to analyze the temporal and spatial variations in pollutant concentrations, including CO, NO_2, aerosols, HCHO, SO_2, and AOD, using satellite data from Sentinel-5 Precursor and Terra and Aqua (MODIS sensors). The study period spans from 2019 to 2023, incorporating the COVID-19 lockdown lock-down periods. The methodology for data collection, analysis, and interpretation is outlined below.

2.1 Data Acquisition

Pollutant concentration data were downloaded from the Sentinel-5 Precursor (TROPOMI) and Terra and Aqua (MODIS) satellites for the selected timeframe (2019-2023). The details of the datasets, including satellite, instrument, resolution, and band information, are provided in Table 2.1.

#	Pollutant	Satellite	Instrument	Resolution		Band	Description
				Spatial	Temporal		
1	CO (carbon monoxide)	Sentinel-5 Precursor (Sentinel-5P)	TROPOspheric Monitoring Instrument (TROPOMI)	7 km x 7 km	Daily	CO_column_number_density	Total column of carbon monoxide (in mol/m²)
2	NO_2 (Nitrogen Dioxide)	Sentinel-5 Precursor (Sentinel-5P)	TROPOspheric Monitoring Instrument (TROPOMI)	7 km × 3.5 km	Daily	NO_2_column_number_density	Total NO_2 column density (mol/m²)
3	Aerosol Index (AI)	Sentinel-5 Precursor (Sentinel-5P)	TROPOspheric Monitoring Instrument (TROPOMI)	0.01°	Daily	absorbing_aerosol_index	Measures the presence of aerosols in the atmosphere, specifically absorbing aerosols like desert dust or biomass burning particles (unitless)

#	Pollutant	Satellite	Instrument	Resolution		Band	Description
				Spatial	Temporal		
4	Formaldehyde (HCHO)	Sentinel-5 Precursor (Sentinel-5P)	TROPOspheric Monitoring Instrument (TROPOMI)	0.01°	Daily	tropospheric_HCHO_column_number_density	Tropospheric formaldehyde column density (mol/m²)
5	SO_2 (Sulphur Dioxide)	Sentinel-5 Precursor (Sentinel-5P)	TROPOspheric Monitoring Instrument (TROPOMI)	7 km × 3.5 km	Daily	SO_2_column_number_density	Total SO_2 column density in the atmosphere (mol/m²)
6	Aerosol Optical Depth (AOD)	Terra and Aqua (MODIS sensors)	MODIS (Moderate Resolution Imaging Spectroradiometer)	1 km	Daily	Optical_Depth_047	Aerosol optical depth over land retrieved in the MODIS Blue band (0.47 µm)

Table 2.1: Details of Satellite-Derived Air Pollutant Datasets and Instruments.

2.2 Temporal Analysis

To examine the temporal trends of the pollutants, 20-30 random points were selected for each city within the study area. Using Python scripts, the pollutant concentrations for each selected point were extracted on a monthly basis for each year. For each city, the data for these points were averaged to calculate the mean pollutant concentration for each month. A bar diagram was then generated to illustrate the temporal changes in pollutant concentrations, providing a clear indication of how the levels varied over time, including during the COVID-19 lockdown periods.

2.3 Spatial Analysis

For precise spatial analysis, the satellite data was clipped to the city boundaries using the respective city shapefiles or geoJSON files. Monthly averaged pollutant data were analyzed for each pixel within the clipped area. The following statistical measures were calculated for each city and pollutant: mean, median, minimum, and maximum pollutant concentrations. These values provided insight into the spatial distribution and intensity of pollution across the study area.

2.4 Calculation of Relative Change

To quantify the relative change in pollutant concentrations over time, the baseline data for each pollutant was set as the 2019 data. The relative change for each pollutant was calculated using the following equation:

$$(Final\ data - Baseline\ data)/\ Baseline\ data$$

This equation allowed for a comparative analysis of how pollutant levels varied in subsequent years (2020-2023) relative to the baseline (2019) data.

2.5 Generalized Linear Model (GLM) Analysis

A Generalized Linear Model (GLM) was employed to explore the relationships between various pollutants and their temporal trends. The GLM allowed for the estimation of the correlation between pollutants and other environmental variables, providing statistical significance values for each pollutant. Trend analysis was conducted for each year, and p-values and slope coefficients were calculated to assess the significance and direction of changes in pollutant concentrations over time.

3. Results

3.1 Relative Change of Pollutants Over Delhi and Kochi

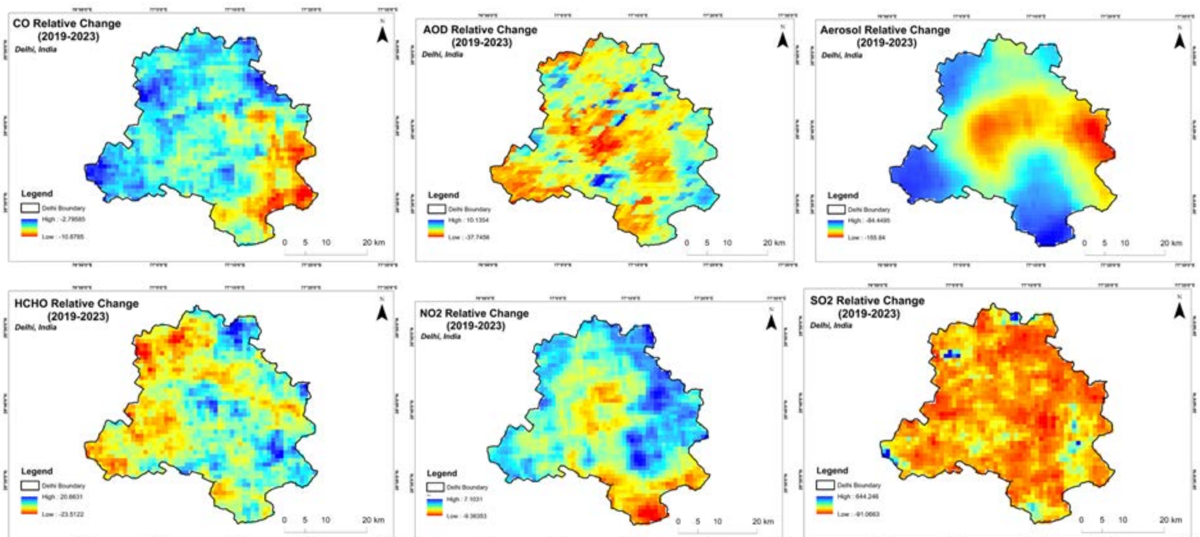


Fig. 3.1.1: Relative change of six essential air pollutants over Delhi during 2019 to 2023

The spatial analysis of pollutants over Delhi reveals significant variations in their relative changes across the city. Aerosol concentrations have shown a widespread decrease, with most areas experiencing a decline of over -100%, particularly in the central and southern regions, likely due to targeted pollution mitigation efforts. Similarly, Aerosol Optical Depth (AOD) levels have significantly reduced, with most areas showing positive relative changes, though the northern and western regions exhibit higher concentrations, indicating localized aerosol sources.

Carbon monoxide (CO) levels have generally declined by over -5%, yet some central and eastern pockets exhibit increases, suggesting persistent emission sources. Formaldehyde (HCHO) concentrations, on the other hand, have risen significantly, with a relative change exceeding 10% across most areas. This increase is most prominent in the central and eastern parts, potentially linked to vehicular and industrial emissions.

Nitrogen dioxide (NO_2) levels have decreased across Delhi, with most areas showing a reduction of over -5%. The most substantial decreases are observed in the central and southern regions, reflecting possible improvements in traffic management and emission controls. Sulfur dioxide (SO_2) concentrations also show a significant decline, with reductions exceeding -50% across most of Delhi, particularly in the western and southern regions, likely due to reduced industrial emissions.

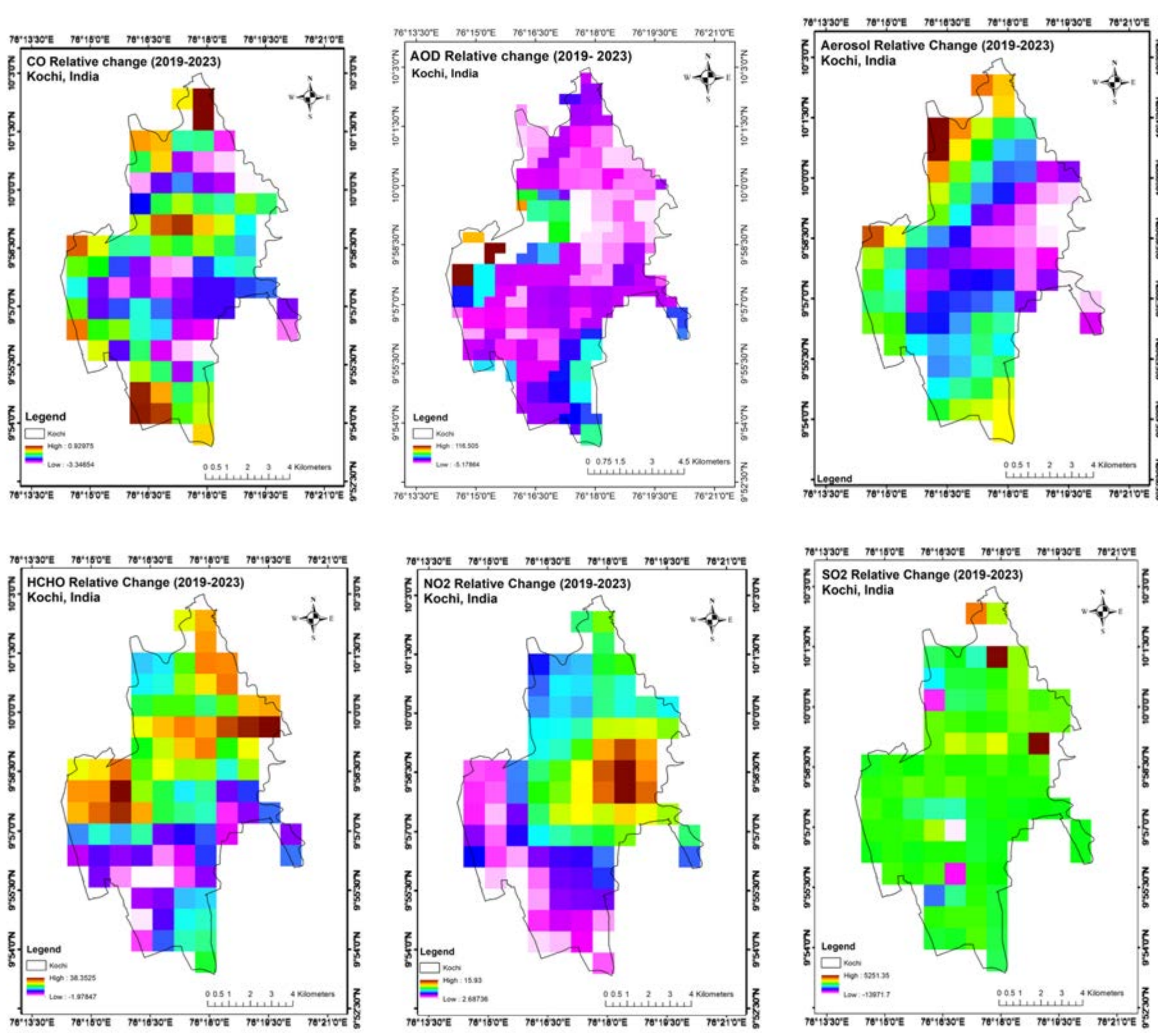


Fig. 3.1.2: Relative change of six essential air pollutants over Kochi during 2019 to 2023

From 2019 to 2023, aerosol concentrations in Kochi showed a general decrease across most areas, with significant reductions in the central and northwestern regions, while increases were observed in the eastern and southeastern regions. AOD exhibited a mixed trend, with increases in the central and northwestern areas and decreases in the eastern and southeastern regions. CO concentrations showed a significant overall decline, particularly in the central and northeastern parts of Kochi. HCHO concentrations decreased notably in the central and northern regions, with a slight increase in the southernmost areas. NO_2 levels demonstrated an overall increase, with pronounced rises in the central region and moderate increases in the northern and eastern regions. SO_2 concentrations displayed a mixed trend, with significant increases in the central region and decreases in the northwestern and southeastern areas. These findings indicate spatially varied trends in pollutant concentrations across Kochi over the study period.

3.2 Time Series Analysis of Monthly Average Values of air pollutants at Delhi and Kochi from 2019-2023

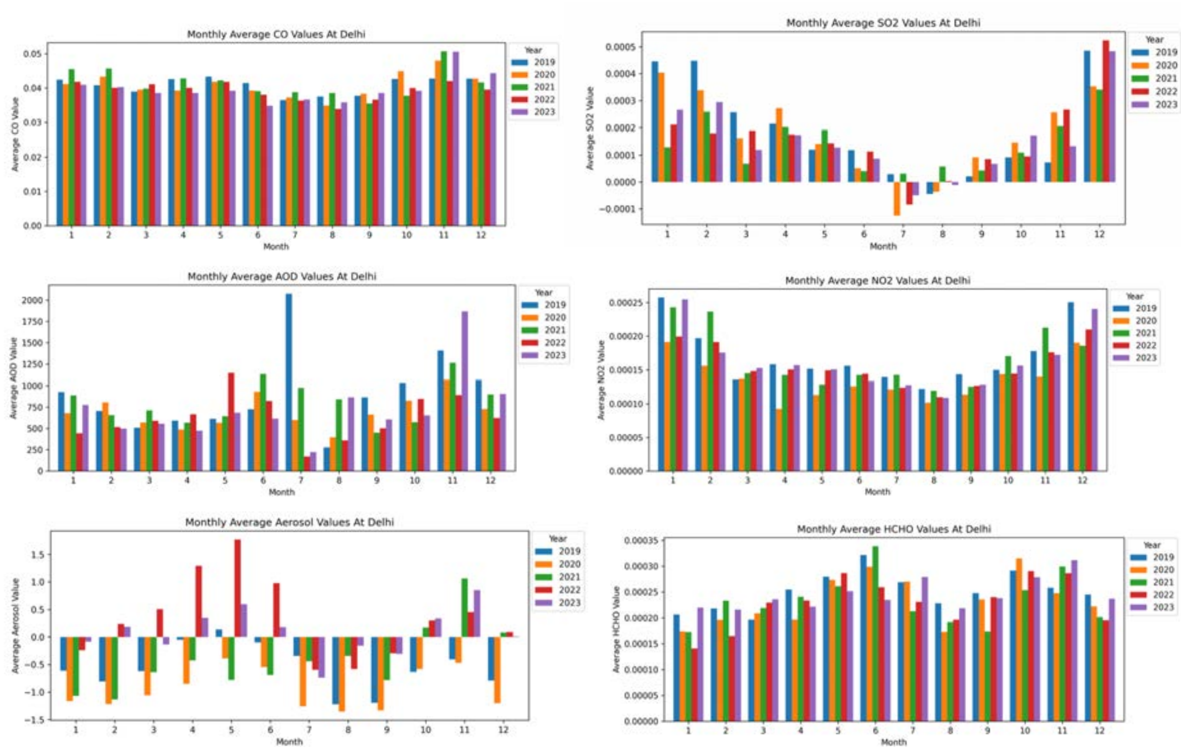


Fig. 3.2.1: Monthly Averages of Different pollutants in Delhi

The time series analysis of monthly average pollutant concentrations over Delhi from 2019 to 2023 reveals distinct seasonal patterns and inter-annual variations. Aerosol levels exhibit a clear seasonal cycle, peaking in May, with the highest values recorded in 2022, while lower concentrations are observed during the monsoon months (June to September). A general increase is noted during the winter months (October to February). Similarly, Aerosol Optical Depth (AOD) values are significantly higher in the winter months, particularly in 2019, 2021, and 2022, with a notable peak in July 2019, indicating an anomaly during this period.

Carbon monoxide (CO) concentrations are consistently elevated during the winter months, with peaks typically occurring in November. A noticeable dip in CO levels during the monsoon season (July–August) suggests reduced pollution during this period. Formaldehyde (HCHO) follows a similar seasonal pattern, with higher concentrations in winter and a pronounced peak in November across all years, aligning with winter pollution trends.

Nitrogen dioxide (NO_2) levels are also higher during the winter months, peaking in November and December, with a slight reduction during the monsoon season. This trend mirrors the behavior of CO and HCHO, underscoring the seasonal impact on pollutant concentrations. Sulfur dioxide (SO_2), though comparatively lower in concentration throughout the year, demonstrates a strong seasonal pattern, with peaks observed during the winter months. The highest recorded SO_2 levels occurred in December 2022.

These results highlight a recurring seasonal cycle in pollutant levels, with elevated concentrations during winter months and reductions during the monsoon season, reflecting temporal variations in air quality over Delhi.

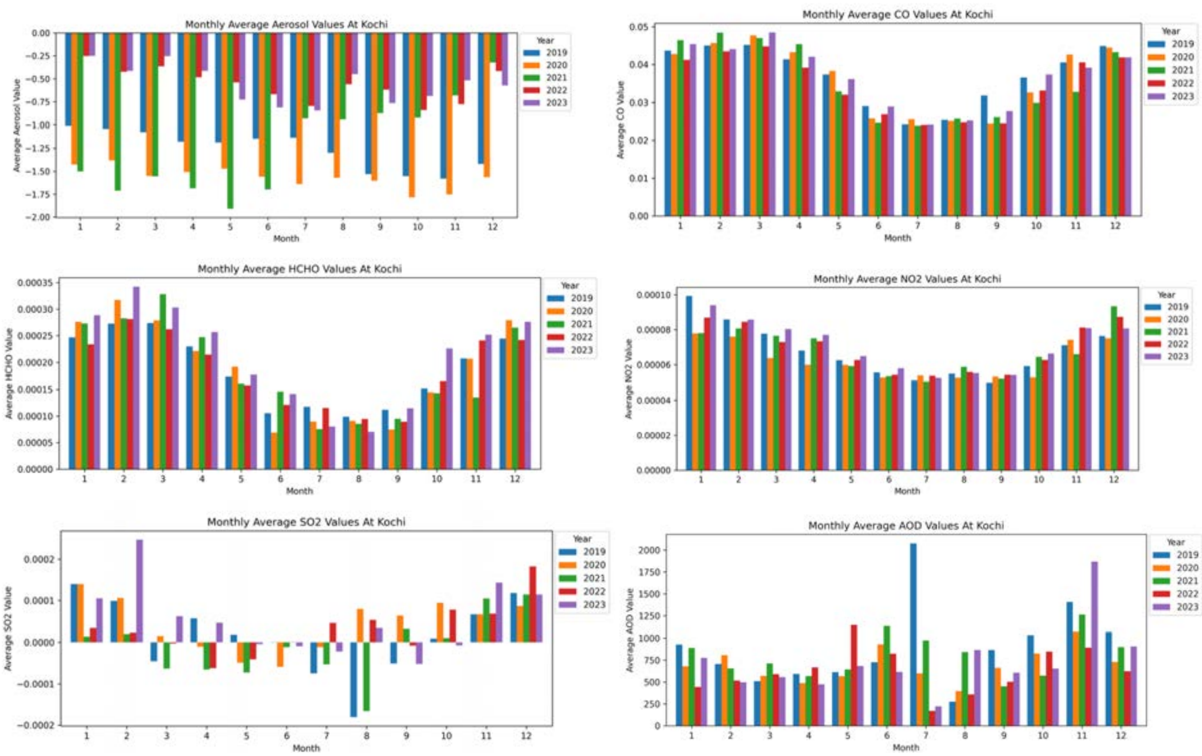


Fig. 3.2.2: Monthly Averages of Different pollutants in Kochi

From 2019 to 2023, aerosol values in Kochi displayed a consistent seasonal pattern, with higher levels during the winter months (December-February) and lower levels during summer (June-August), indicating the influence of seasonal factors. Year-on-year, there was a slight decrease in average aerosol values, suggesting an improvement in air quality. AOD values showed a distinct peak in July, likely linked to monsoon patterns, though the year-on-year trend was inconsistent with significant fluctuations. CO levels peaked in January, gradually decreased until June, and showed a slight rise in October, with a consistent year-on-year decrease, indicating improved air quality. HCHO values peaked in February and exhibited a gradual decline from 2019 to 2023, reflecting improving air quality. NO_2 levels peaked in January, correlating with vehicle emissions and industrial activities, and showed a slight year-on-year decrease, suggesting better air quality over time. SO_2 levels showed spikes in February and November, likely due to seasonal and industrial factors, and displayed a gradual decrease year-on-year, indicating overall improvement in air quality concerning SO_2.

3.3 Statistical Trends of Air Pollutants in Delhi and Kochi (2019-2023)

3.3.1 Analysis of CO Trends in Delhi (2019-2023)

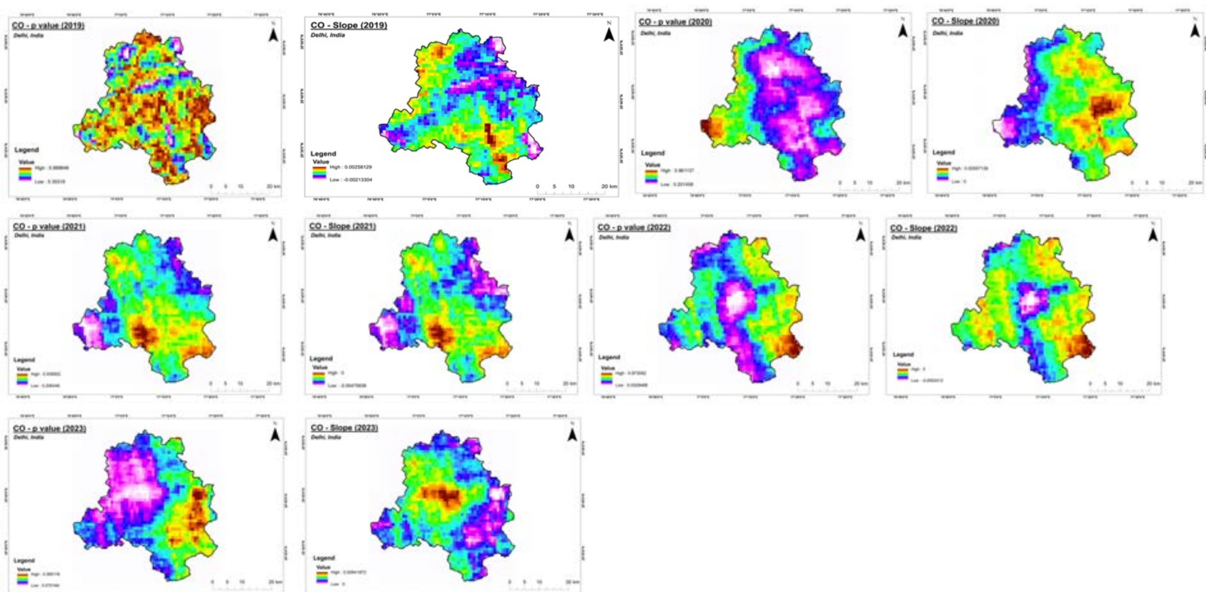


Fig. 3.3.1: Annual CO Analysis of Delhi (2019- 2023)

The spatial analysis of CO levels in Delhi from 2019 to 2023 reveals significant spatial and temporal variability based on p-value and slope maps. Areas with low p-values indicate a statistically significant relationship between CO concentrations and the factors analyzed, while high p-values suggest weak significance, pointing to potential influences from other variables not included in the model. Regions with positive slopes represent increasing CO levels, whereas negative slopes indicate a decrease in concentrations over time.

In 2019, central and eastern Delhi showed low p-values and significant slopes, indicating a strong influence of the analyzed factors on CO levels, while western and southwestern regions displayed high p-values and weaker slopes, suggesting the need for additional variables to explain CO variations. Similar trends persisted through subsequent years, with regional differences becoming more pronounced. For instance, in 2021 and 2022, the southwestern regions exhibited high positive slopes and p-values, reflecting rapid increases in CO levels likely driven by local sources such as vehicular emissions and industrial activities. Conversely, northern and eastern regions generally displayed lower p-values and less pronounced slopes, suggesting more stable or declining CO levels.

By 2023, areas with low p-values and negative slopes, particularly in central and eastern Delhi, highlighted statistically significant reductions in CO concentrations, potentially indicating the impact of pollution control measures. Simultaneously, regions with high p-values and positive slopes, predominantly in the southern and western parts, pointed to weaker but increasing trends in CO levels, requiring further scrutiny.

These findings underscore the heterogeneous nature of CO trends across Delhi and emphasize the need for targeted air quality management strategies tailored to specific regional characteristics.

3.3.2 Analysis of NO_2 Trends in Delhi (2019-2023)

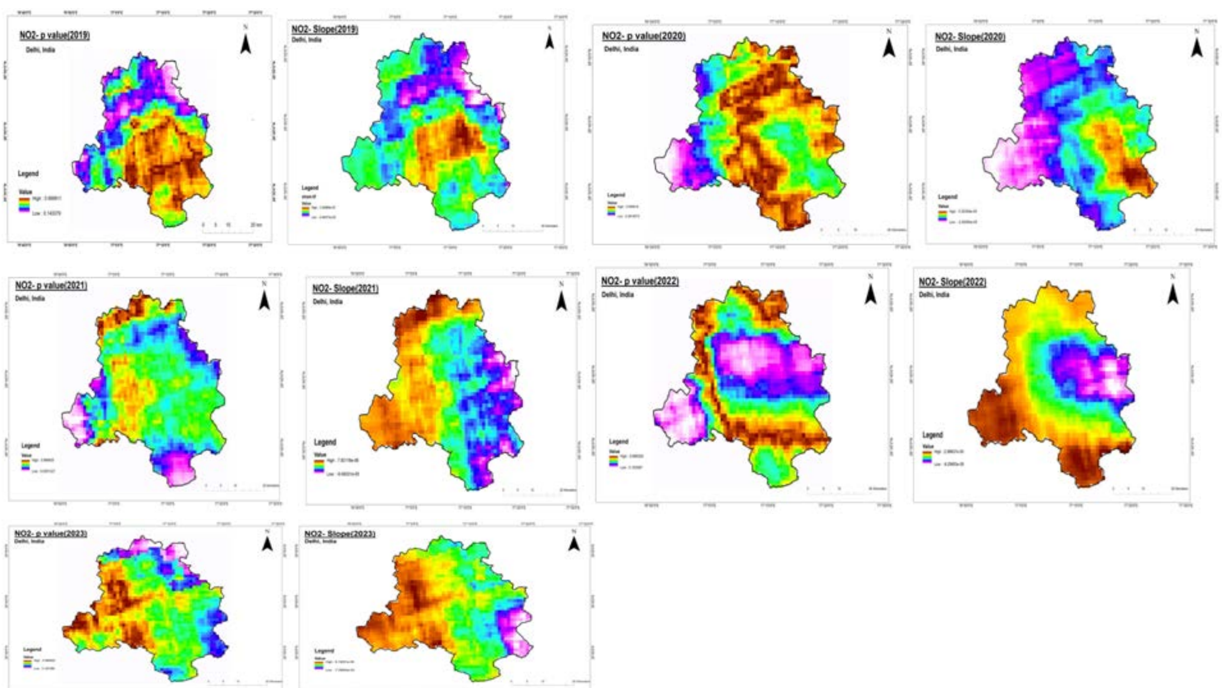


Fig. 3.3.2: Annual NO_2 Analysis of Delhi (2019- 2023)

The spatial and temporal analysis of NO_2 concentrations in Delhi from 2019 to 2023 highlights significant regional variations and trends. In 2019, the NO_2 p-value map revealed higher values in the eastern and central regions, signifying greater concentrations of NO_2 in these areas, while the western and northwestern regions showed lower p-values. The NO_2 slope map for the same year displayed predominantly low values across Delhi, indicating a stable or slow change in NO_2 concentrations, except for pockets in the central and eastern regions, where a faster increase was observed.

In 2020, high NO_2 p-values were concentrated in the central and southern parts of Delhi, while the northern and western regions exhibited the steepest increases in NO_2 levels, as reflected by higher slope values. Conversely, the eastern and southern regions showed shallower changes, indicating slower variations in NO_2 levels. By 2021, the NO_2 p-value map highlighted the highest values in the central and eastern regions, such as ITO and Connaught Place, while the lowest values were observed in the northwest and southwest regions, including Dwarka and Rohini. The NO_2 slope map for 2021 showed a sharp increase in NO_2 levels from west to east, with areas like Dwarka exhibiting relatively uniform concentrations.

In 2022, the spatial variation in p-values indicated significant temporal changes in NO_2 concentrations, with higher values in the eastern and southern parts of Delhi and lower values in other regions. The slope map revealed a mixed pattern, with positive slopes concentrated in the central and western regions, indicating an increase in NO_2 concentrations, while the eastern and southern regions exhibited both positive and negative slopes, reflecting complex temporal changes.

By 2023, the NO_2 p-value map depicted heterogeneous patterns, with high values in central Delhi and lower values in the southwest and northwest outskirts. The slope map showed a pronounced spatial gradient, with steeper increases in NO_2 levels in the eastern regions, indicating a rapid rise in concentrations. Overall, central Delhi consistently emerged as a hotspot for NO_2, with elevated concentrations and significant increases over the years, while the outskirts exhibited lower levels and more gradual changes.

3.3.3 Analysis of Aerosol Trends in Delhi (2019-2023)

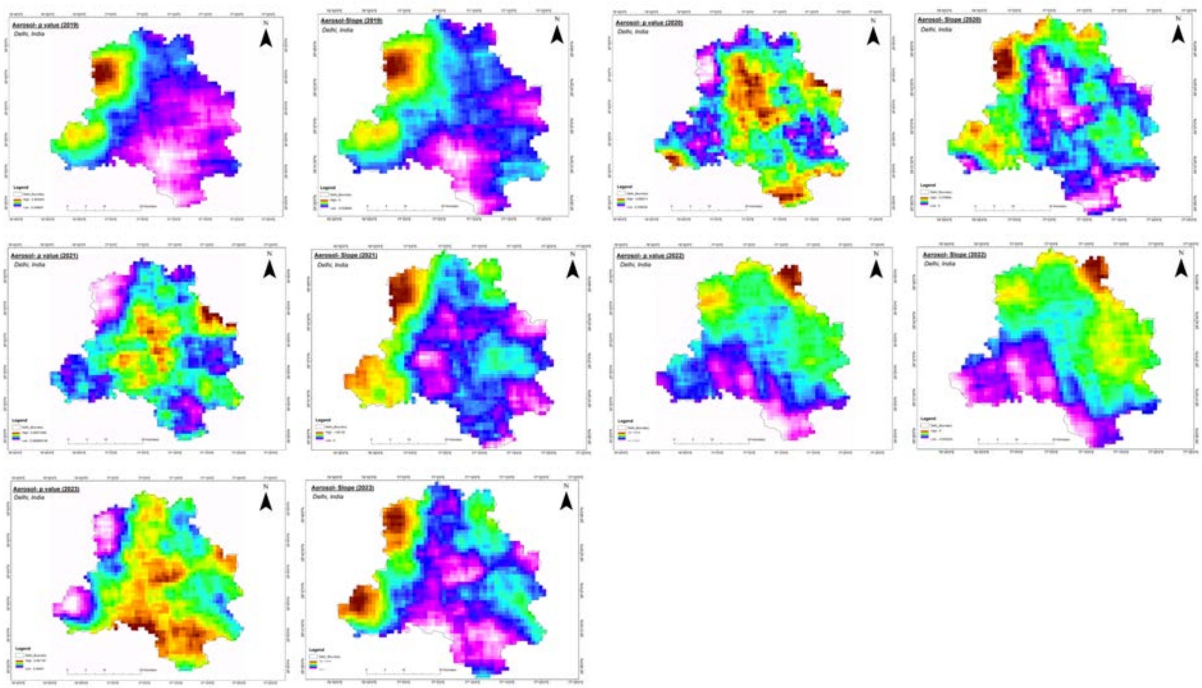


Fig. 3.3.3: Annual Aerosol Analysis of Delhi (2019- 2023)

In 2019, high p-values were observed in the central and southern parts of Delhi, indicating a higher probability of significant aerosol concentration differences, while low p-values were found in the northern and western areas, suggesting lower aerosol variation. Positive slopes in the eastern and southern regions indicated increasing aerosol concentrations over time, whereas negative slopes in the northern and western areas signaled decreasing trends.

In 2020, high p-values in the western and southern regions suggested less confidence in aerosol trend detection, while low p-values in the eastern and northern regions indicated more statistically significant trends. Positive slopes in the western and southern areas showed an increasing trend in aerosol concentrations, while negative slopes in the eastern and northern regions reflected decreasing trends.

In 2021, high p-values were found in the central and eastern regions, indicating weaker aerosol signals, while low p-values in the western and northern parts pointed to stronger aerosol signals. Positive slopes in the western and northern areas suggested a steeper increase in aerosol concentrations, and negative slopes in the central and eastern regions indicated a gentler increase.

In 2022, high p-values and positive slopes in certain regions indicated consistent aerosol trends, while low p-values and negative slopes reflected localized aerosol patterns. The northern and western regions showed consistent high aerosol concentrations, while the central and eastern areas exhibited more variable aerosol levels.

In 2023, high p-values in yellow to red areas indicated higher uncertainty in aerosol measurements, while low p-values in blue to purple areas suggested more reliable aerosol patterns. Higher slope values in some areas indicated rapid increases in aerosol concentrations, while lower slope values indicated more stable aerosol levels.

3.3.4 Analysis of formaldehyde (HCHO) Trends in Delhi (2019-2023)

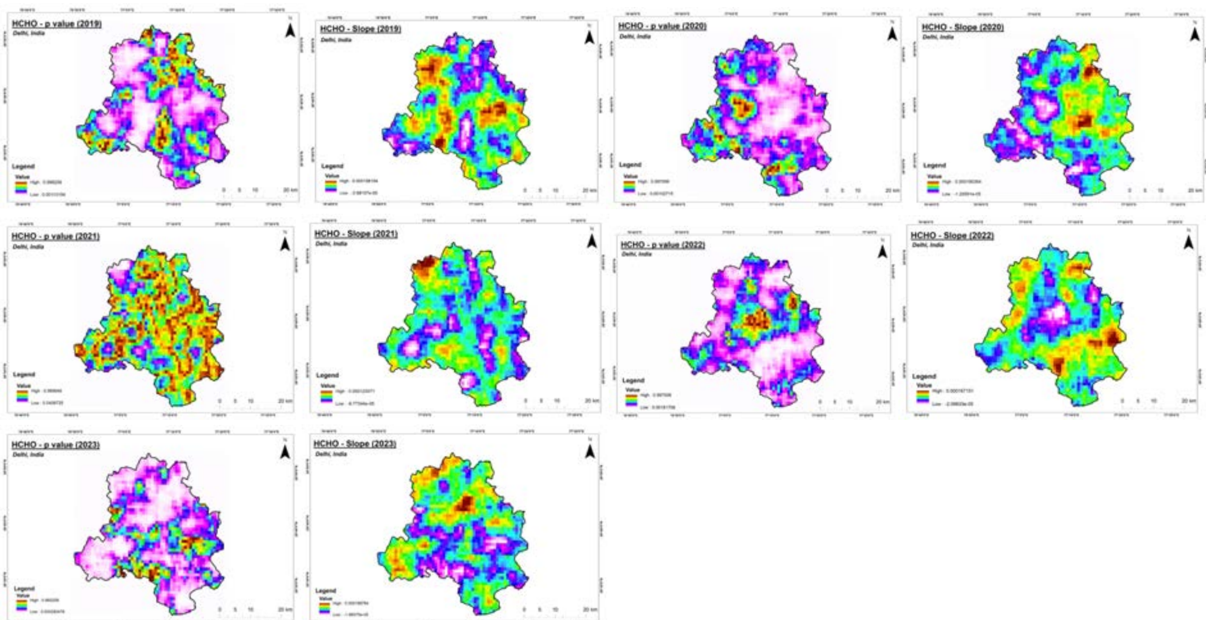


Fig. 3.3.4: Annual HCHO Analysis of Delhi (2019- 2023)

From 2019 to 2023, the spatial distribution of HCHO concentrations in Delhi revealed distinct trends in p-values and slopes, highlighting both the statistical significance and temporal changes in HCHO levels across the city. In 2019, high p-values were observed in central and eastern Delhi, indicating weak statistical significance, while low p-values in the western and northern regions suggested significant HCHO presence. The slope map indicated both positive and negative slopes across the city, with positive slopes in areas like the southern and western regions, suggesting an increasing trend in HCHO concentrations, and negative slopes in parts of the northern and eastern areas, implying a decrease in HCHO levels.

In 2020, high p-values were concentrated in regions with lower HCHO concentrations, while low p-values indicated areas with statistically significant levels, such as the southwestern and central parts. Positive slopes were observed in areas with rising HCHO concentrations, notably in the southwestern and central regions, while negative slopes, suggesting improving air quality, were present in the northern and eastern regions. This spatial heterogeneity highlighted the importance of localized factors in determining HCHO distribution and trends.

By 2021, the p-value map revealed weak statistical significance in the north-western and eastern regions, while low p-values in the southern and central parts indicated more significant HCHO trends. The slope map showed positive slopes in the southern and western areas, pointing to an increase in HCHO concentrations, and negative slopes in the northern and eastern parts, suggesting a decrease. These trends suggested potential increases in HCHO emissions in the southern and central areas, with a possible improvement in air quality in the northern and eastern regions.

In 2022, higher p-values were observed in the northwestern and western parts, suggesting weaker statistical significance, while lower p-values in the south and east indicated stronger evidence of HCHO presence. Positive slopes in the south and east regions aligned with higher p-values, indicating increasing HCHO concentrations, while negative slopes in the north-western and western parts pointed to decreasing trends. The combination of these maps indicated that HCHO levels were rising in the southern and eastern parts of Delhi.

In 2023, the spatial distribution of HCHO concentrations showed a strong correlation between high levels of HCHO and significant slopes in areas like central, south-west, and west Delhi, suggesting major emission sources from traffic, industrial activities, and dense urban development. Lower HCHO levels and moderate slopes were observed in the north-east and south-east regions, which may be attributed to green spaces, lower urban density, and less intense anthropogenic activities.

3.3.5 Analysis of SO_2 Trends in Delhi (2019-2023)

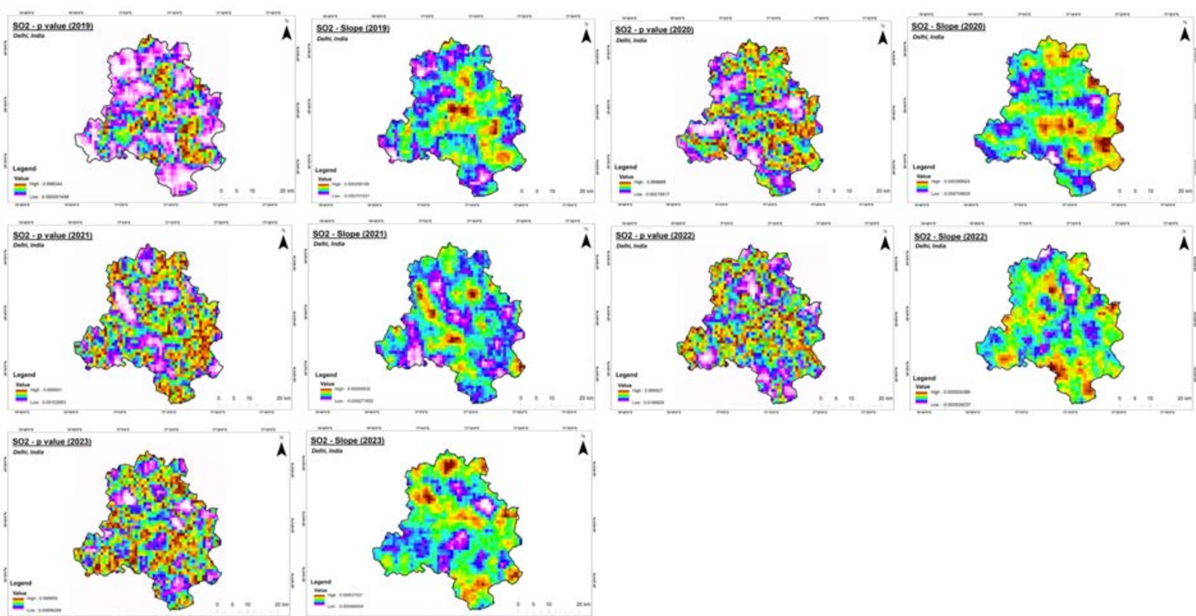


Fig. 3.3.5: Annual SO_2 Analysis of Delhi (2019- 2023)

The analysis of SO_2 p-value and slope in Delhi from 2019 to 2023 revealed significant spatial patterns and trends. In 2019, areas with higher p-values, concentrated in the southern and eastern parts, indicated a strong statistical significance of SO_2 levels, while lower p-values in the northern and western parts suggested weaker significance. The slope map for 2019 showed mostly positive slopes, with the steepest slopes in the eastern and southern regions, indicating a rapid increase in SO_2 levels. Conversely, the north-western regions had shallow negative slopes, suggesting a slower decline in SO_2 levels.

In 2020, the p-value and slope analysis indicated that regions with high p-values showed statistically insignificant increases in SO_2 concentrations, while areas with low p-values demonstrated statistically significant trends. Positive slopes in certain regions highlighted an upward trend in SO_2 concentrations, while negative slopes in other areas pointed to a decrease. In 2021, a similar pattern emerged, with high p-values and positive slopes suggesting insignificant increases in SO_2 levels, and low p-values with positive slopes indicating significant increases. Negative slopes in some areas signaled a decrease in SO_2 levels, contributing to a clearer understanding of spatial and temporal changes.

In 2022, the analysis highlighted areas in the southern and eastern parts of Delhi with high p-values and positive slopes, suggesting a strong positive relationship between SO_2 levels and independent variables, indicating a significant increase in SO_2 levels. Conversely, areas with low p-values and negative slopes in the northern and western regions suggested a weak decrease in SO_2 levels. By 2023, the spatial distribution showed high p-values in the central and southern regions, indicating a lack of statistically significant trends. Areas with low slopes suggested more gradual changes in SO_2 levels, reflecting a more homogeneous distribution across the city.

3.3.6 Analysis of Aerosol Optical Depth (AOD) Trends in Delhi (2019-2023)

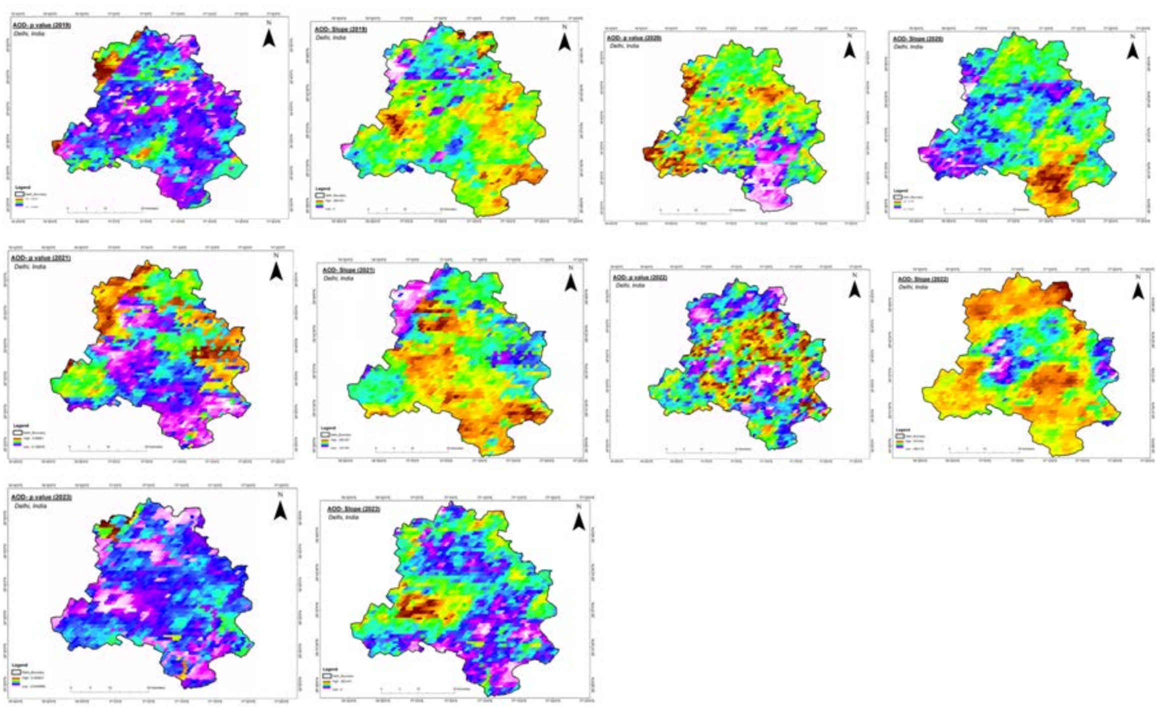
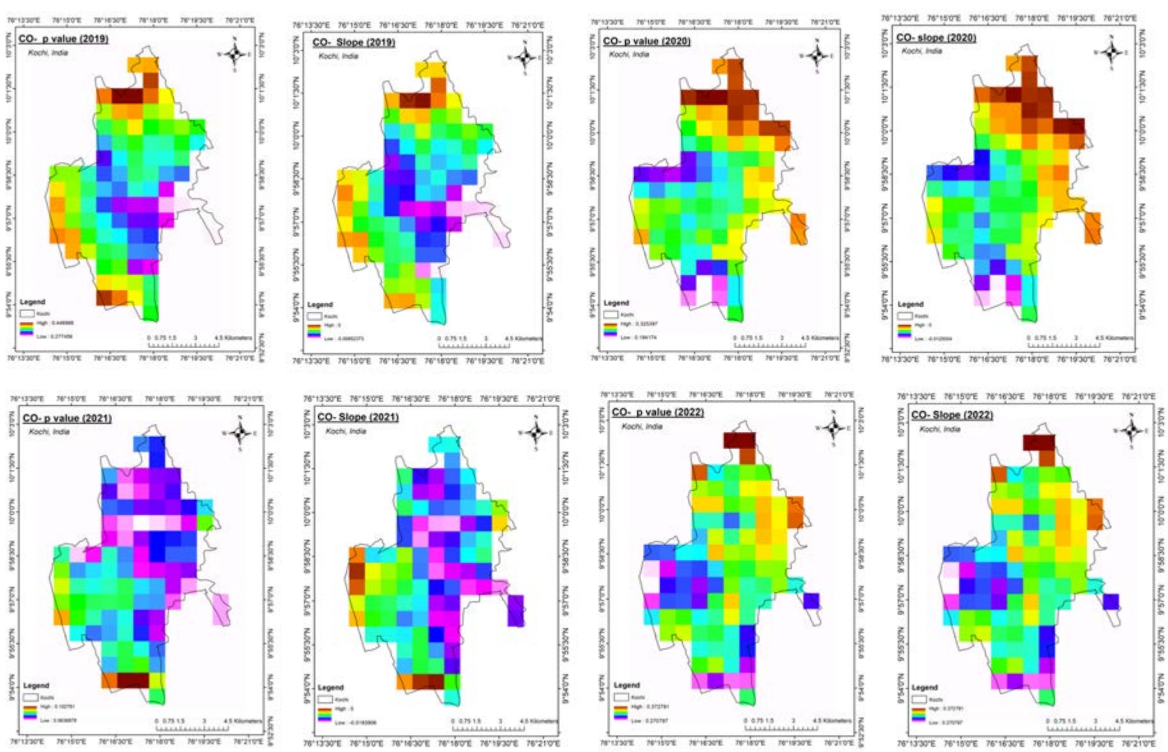


Fig. 3.3.6: Annual AOD Analysis of Delhi (2019- 2023)

In 2019, the spatial distribution of the p-value and slope of Aerosol Optical Depth (AOD) in Delhi showed a strong positive relationship between AOD and time in the central and southern parts of the city, where high p-values and high slopes were observed. This indicates a significant increase in AOD over time in these regions. Conversely, the northern and western parts exhibited a weaker but positive trend, with lower slopes and mixed p-values, suggesting a less pronounced increase in AOD. In 2020, central and eastern Delhi displayed higher p-values and steeper slopes, reflecting a significant and rapid increase in AOD with altitude, while western and southern parts showed weaker relationships and more gradual changes. The 2021 data revealed areas with high p-values and high slopes along Delhi's outer edges, suggesting potential measurement uncertainties and significant spatial variability in AOD, while central Delhi displayed low p-values and more homogeneous AOD levels. In 2022, the southern and eastern regions had both high p-values and high slopes, signifying a statistically significant increase in AOD over time. These areas likely experienced higher pollution levels, driven by industrial activities, vehicular emissions, and construction. The 2023 data highlighted the central and southwestern parts of Delhi as areas of rapid AOD increase, with higher p-values and steeper slopes, indicating a statistically significant and fast rise in AOD in these regions compared to the northern and eastern parts, where trends were less significant.

3.3.7 Analysis of CO Trends in Kochi (2019-2023)



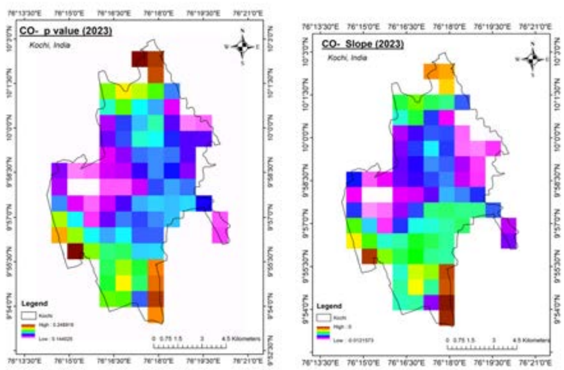


Fig. 3.3.7: Annual CO Analysis of Kochi (2019- 2023)

From 2019 to 2023, the spatial and temporal trends of CO concentrations in Kochi demonstrated notable variations. In 2019, high p-values were observed in the central and eastern regions, indicating significant trends in CO levels, while lower p-values were prevalent in the western regions, suggesting weaker trends. Positive slopes, representing increasing CO levels, were prominent in the central and eastern regions, while negative slopes, indicating decreasing levels, were observed in the western regions. In 2020, the central and eastern parts of Kochi displayed the highest p-values, suggesting significant increasing trends, while lower p-values and weaker trends were evident in the northern and western regions. The slope map highlighted a dominant positive trend in the central and eastern areas, with minimal or negative trends in the western and northern parts. In 2021, high p-values were concentrated in the central and western regions, reflecting minimal changes in CO levels, while low p-values in the eastern regions indicated statistically significant trends. Positive slopes were observed in the eastern and southern areas, indicating rising CO concentrations, whereas negative slopes dominated the northern and western parts, suggesting declining trends. In 2022, high p-values were concentrated in the northern and eastern parts of Kochi, while low p-values were prevalent in the central and southern regions. Positive slopes, representing increasing trends, were scattered across the city, while negative slopes were concentrated in the southwestern region. Finally, in 2023, high p-values in certain regions indicated weak evidence of significant changes, while low p-values suggested localized significant increases in CO levels. Positive slopes dominated many areas, indicating increasing CO trends, whereas negative slopes, indicating decreasing trends, were confined to specific regions. These findings highlight dynamic spatial and temporal patterns in CO concentrations, emphasizing areas with increasing or decreasing trends over time.

3.3.8 Analysis of NO_2 Trends in Kochi (2019-2023)

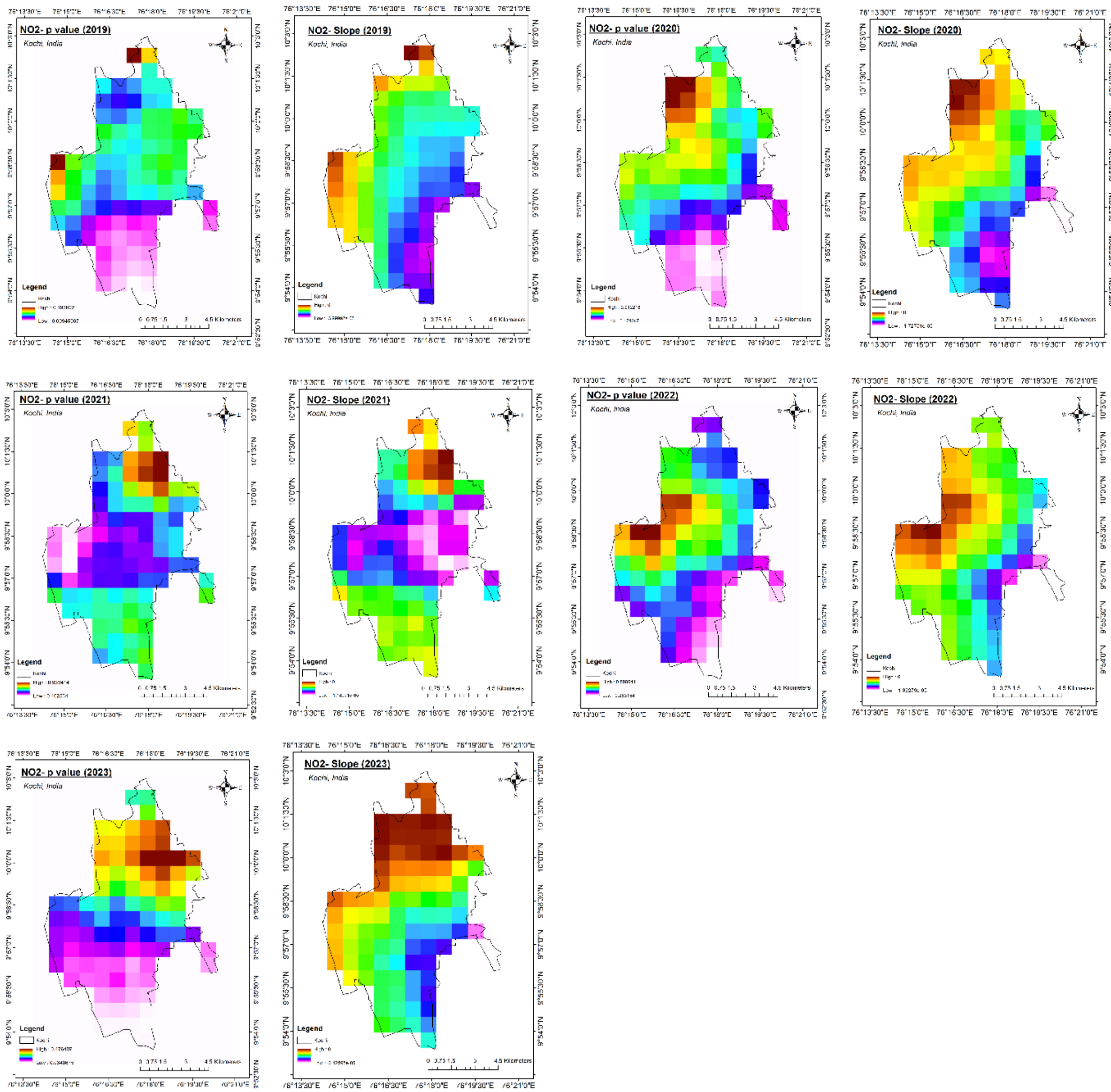


Fig. 3.3.8: Annual NO_2 Analysis of Kochi (2019- 2023)

From 2019 to 2023, the spatial and temporal trends of NO_2 concentrations in Kochi exhibited notable variations. In 2019, high p-values in the northern and central parts indicated significant NO_2 presence, while low p-values in the southern and eastern areas reflected weaker statistical significance. Positive slopes, indicating increasing NO_2 levels, were observed in the north-central and western regions, while negative slopes, denoting a decline, dominated the southeastern areas. In 2020, the eastern parts of Kochi showed the highest p-values, suggesting a significant deviation in NO_2 levels, while the slope map revealed stable concentrations across the city, with minimal changes over time. In 2021, higher p-values and positive slopes in the central and eastern regions indicated increasing NO_2 concentrations, likely due to urban activities, while the western and northern regions exhibited lower p-values and negative slopes, implying reduced concentrations. In 2022, high p-values dominated most of the city, suggesting minimal statistically significant changes, but pockets of low p-values and positive slopes indicated increasing NO_2 levels in localized areas. Finally, in 2023, high p-values were concentrated in the north-central regions, while low p-values in the southern and western areas reflected statistically significant trends. Positive slopes were predominant across Kochi, indicating an overall increase in NO_2 levels, with a small negative slope observed in the northwestern part of the city. These findings highlight the dynamic spatial and temporal changes in NO_2 concentrations in Kochi, with areas of increasing trends requiring closer attention for air quality management.

3.3.9 Analysis of Aerosol Trends in Kochi (2019-2023)

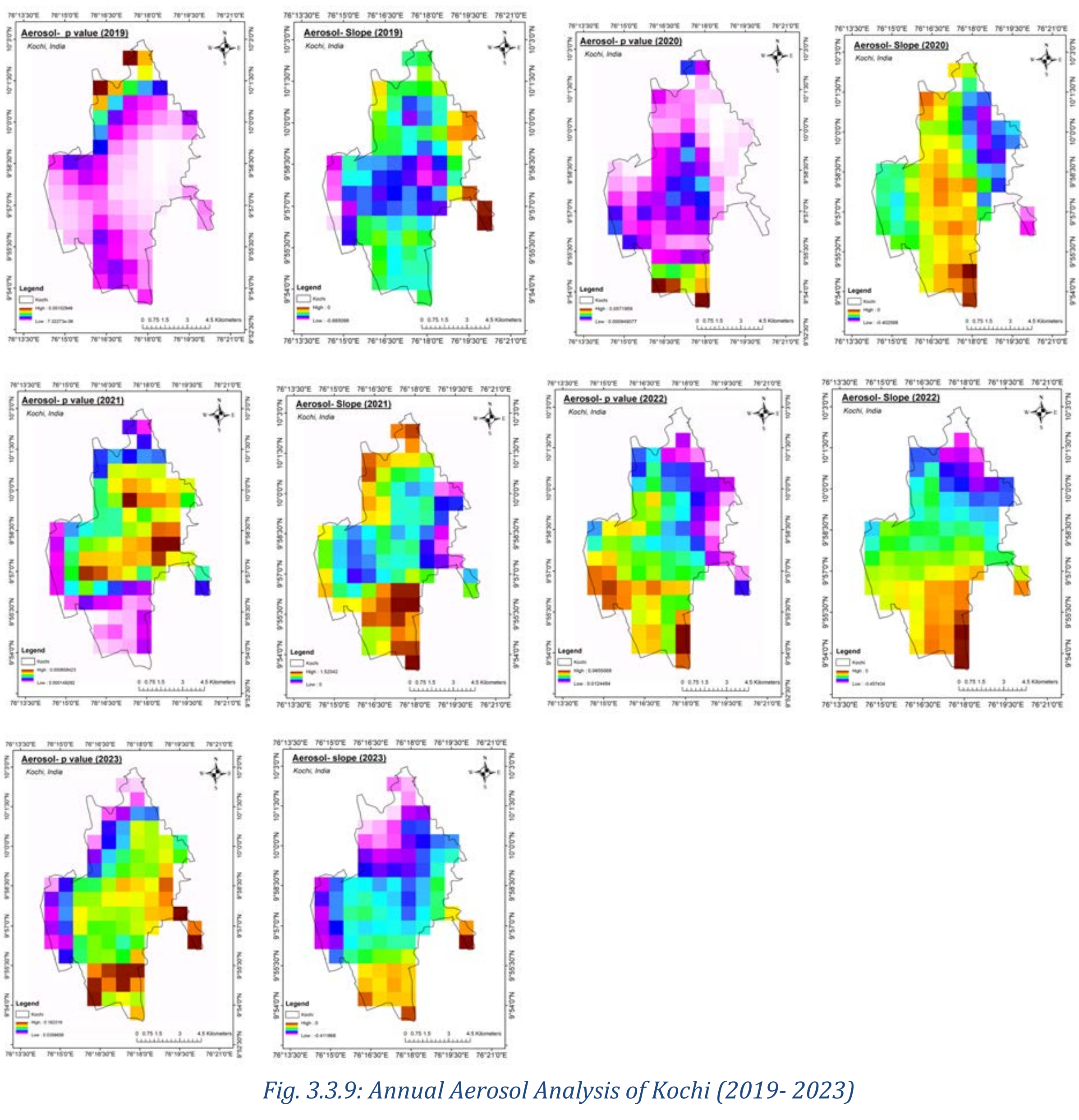
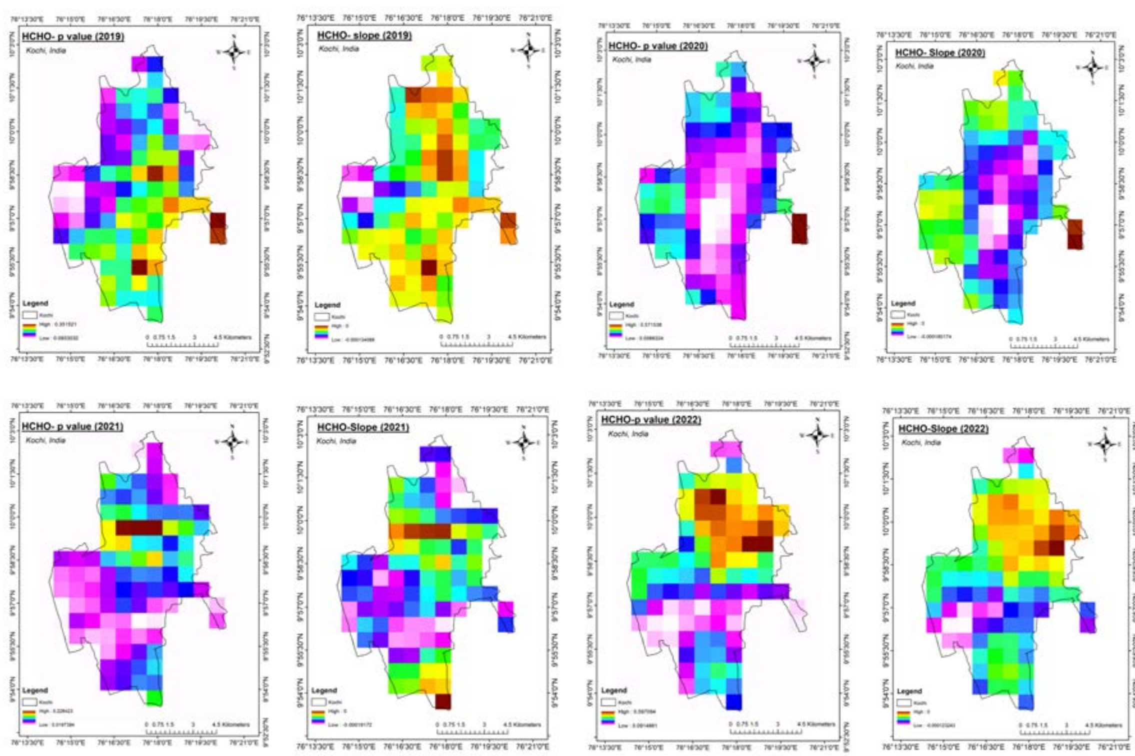


Fig. 3.3.9: Annual Aerosol Analysis of Kochi (2019- 2023)

From 2019 to 2023, aerosol concentration in Kochi exhibited distinct spatial and temporal trends. In 2019, high p-values indicated significant aerosol presence in the central and eastern regions, with the slope map showing mixed trends of increasing concentrations in the eastern regions and decreasing levels in the central areas. In 2020, most areas displayed significant trends in aerosol concentration, with the slope map highlighting an overall increasing trend, particularly in the eastern and northeastern regions. By 2021, the spatial variation became more pronounced, with high p-values in the central region suggesting stable aerosol levels, while lower p-values in the northern and southern areas indicated significant changes. The slope map revealed a steep increase in aerosol concentrations in the eastern regions and slower changes in the western parts. In 2022, the p-value and slope maps identified an increasing trend in aerosol levels in the western and northern regions, while parts of the central area showed decreasing trends. By 2023, a mix of significant and non-significant trends emerged, with positive slopes dominating most areas, particularly in the southern and eastern regions, indicating rising aerosol levels, while the northern and western parts experienced declining trends. These findings underscore the dynamic nature of aerosol concentration in Kochi, likely influenced by factors such as industrial activity, urbanization, and meteorological conditions.

3.3.10 Analysis of formaldehyde (HCHO) Trends in Kochi (2019-2023)



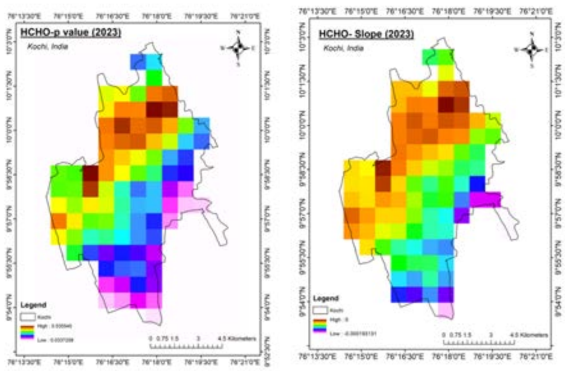
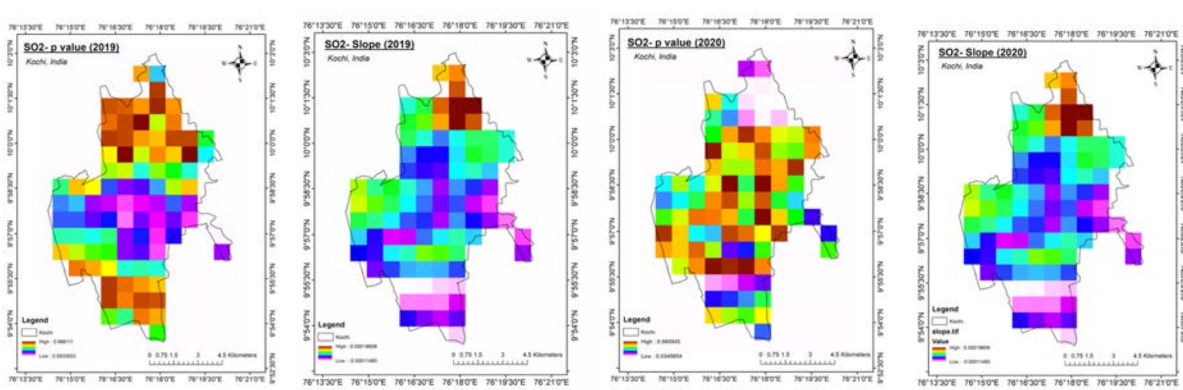


Fig. 3.3.10: Annual HCHO Analysis of Kochi (2019- 2023)

In 2019, the p-value map indicated higher HCHO concentrations in the southern and eastern parts of Kochi, with a peak p-value of 0.351521, while the northern and western parts exhibited lower values, with a minimum of 0.0933032. The slope map showed a uniform distribution, with slightly higher values in the central and eastern regions and lower values in the western and northern areas. The highest slope value was 0.000134089, suggesting a slightly higher rate of HCHO increase in the central and eastern parts of Kochi. In 2020, the p-value map revealed significant HCHO presence in the eastern parts of Kochi, with values ranging from 0.0566324 to 0.5711538, and the slope map highlighted a rapid increase in HCHO concentrations in the eastern and northeastern regions, while the western and southern parts showed fewer steep trends. In 2021, the central region displayed higher p-values, indicating stable HCHO concentrations, while the northern and southern parts exhibited lower p-values, suggesting significant variation. The slope map showed a more rapid increase in HCHO levels in the central region compared to slower changes in the northern and southern parts. In 2022, p-value and slope maps indicated significant trends in HCHO concentrations, with areas of increasing levels identified in the western and northern regions, while other parts showed negative slopes, reflecting potential decreases. In 2023, the southern and eastern parts of Kochi showed the highest p-values and positive slopes, indicating increasing HCHO levels, whereas the northern and western parts exhibited lower p-values and negative slopes, suggesting declining concentrations. The observed trends across years highlight significant spatial variability in HCHO levels in Kochi, influenced by factors such as industrial emissions, traffic density, and meteorological conditions.

3.3.11 Analysis of SO_2 Trends in Kochi (2019-2023)



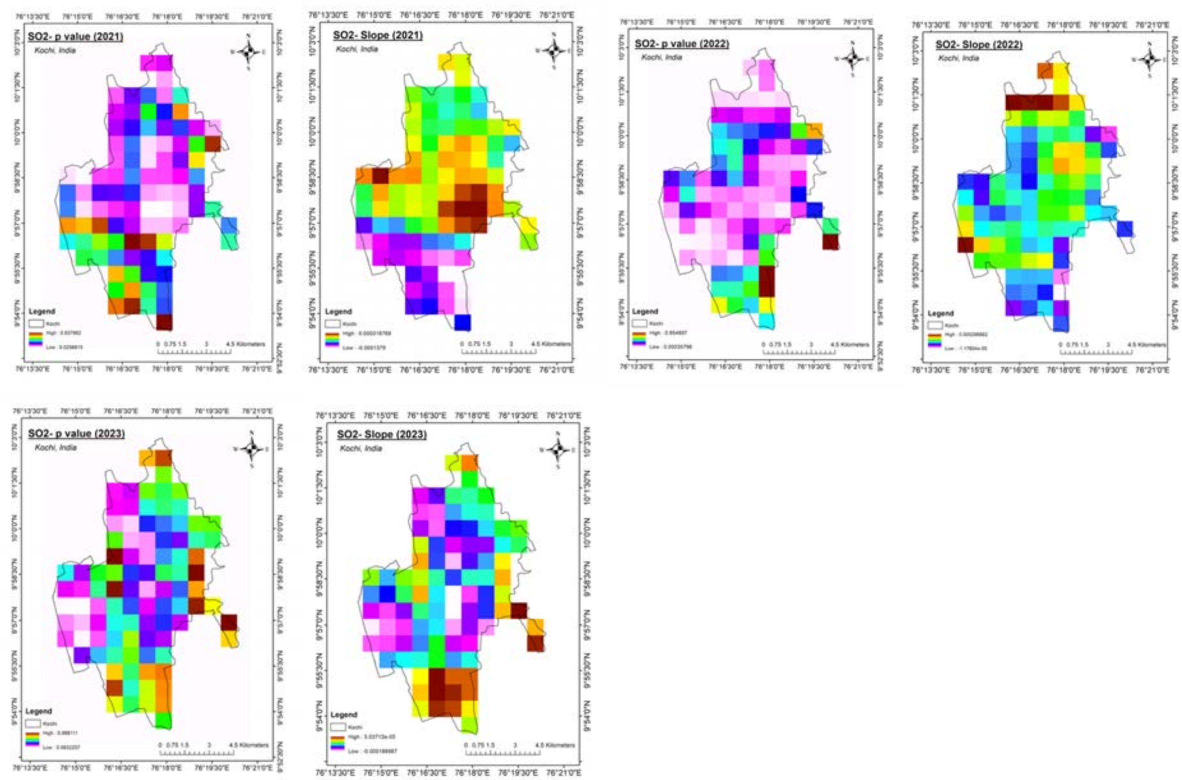


Fig. 3.3.11: Annual SO_2 Analysis of Kochi (2019- 2023)

In 2019, the spatial distribution of p-values indicated a stronger relationship between SO_2 levels and influencing factors in the northern and eastern parts of Kochi, while the western and southern parts showed weaker correlations. The slope map revealed mixed trends, with positive slopes in the northern and eastern parts suggesting increasing SO_2 levels, potentially due to industrial or traffic emissions, and negative slopes in the central and southern parts indicating decreasing SO_2 levels, likely reflecting improvements in air quality. In 2020, the combined p-value and slope analysis revealed non-uniform spatial patterns of SO_2 trends. The central and northern parts exhibited pronounced increasing trends, whereas the southern and western parts showed significant decreasing trends. In 2021, significant spatial variation in SO_2 trends was observed, with the southern and central regions showing more pronounced trends and steeper increases in SO_2 levels, indicating heightened pollution impact in these areas. In 2022, spatial variations persisted, with the western and northern areas showing more significant increases in SO_2 concentrations compared to the central and eastern parts, likely due to industrial activities, traffic density, and meteorological factors. In 2023, the spatial variability of SO_2 trends across Kochi was evident, with the eastern region emerging as a potential hotspot for increasing SO_2 levels. The observed trends highlight the need to consider factors such as industrial activity, traffic patterns, and meteorological conditions to understand the dynamics of SO_2 pollution in the region.

3.3.12 Analysis of Aerosol Optical Depth (AOD) Trends in Kochi (2019-2023)

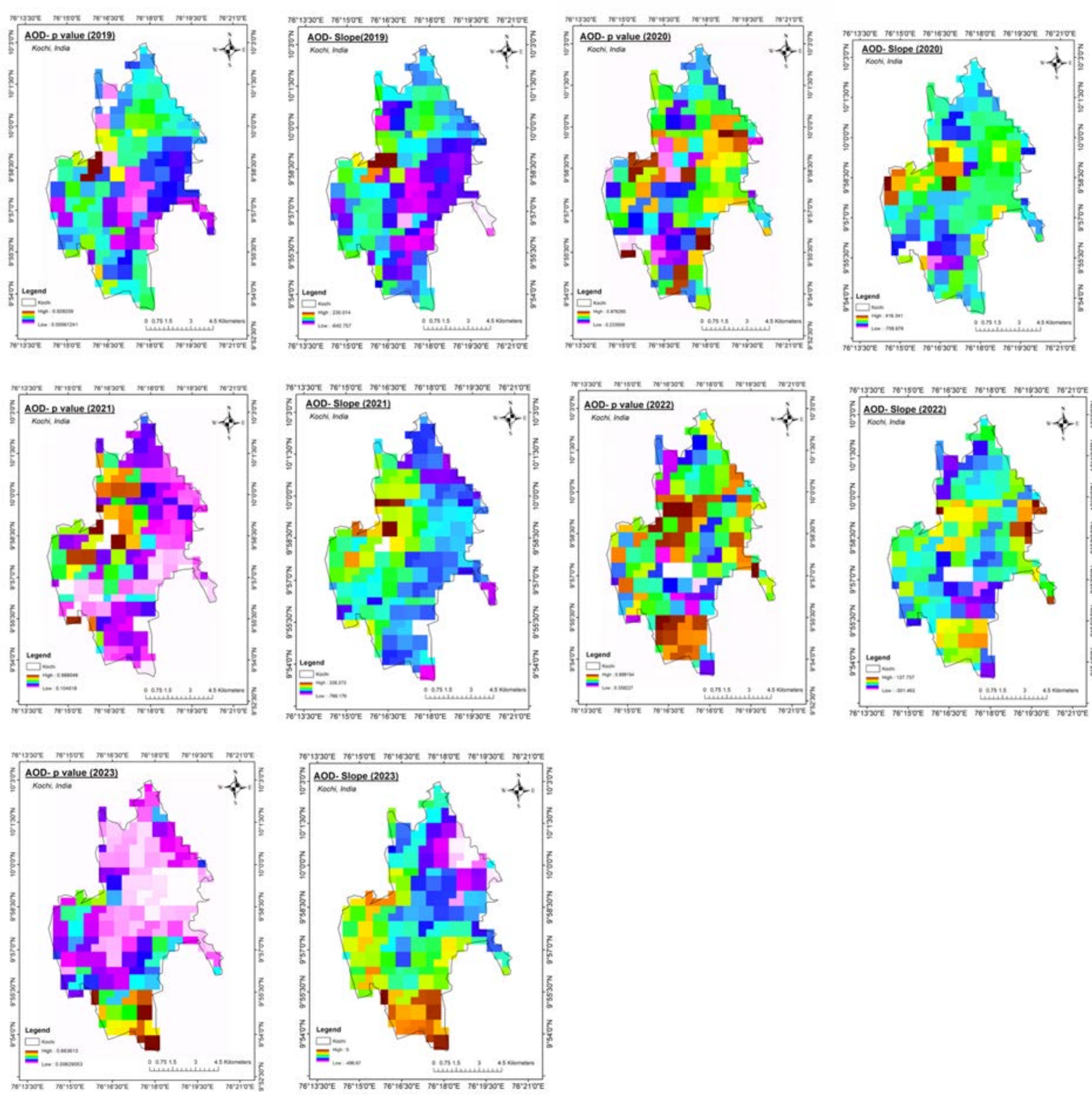


Fig. 3.3.12: Annual Aerosol Optical Depth (AOD) Analysis of Kochi (2019- 2023)

AOD levels in Kochi showed an increasing trend in 2019, particularly in the central and western parts of the city, with spatial heterogeneity highlighted by variations in p-values and slopes. In 2020, the central and eastern parts of Kochi exhibited a strong positive correlation between AOD and influencing factors, as indicated by higher p-values and slopes, whereas the western and northern parts showed weaker correlations with lower p-values and slopes. In 2021, the central region displayed a statistically significant increase in AOD levels, while the eastern region demonstrated a rapid rise in AOD values. By 2022, regions with high p-values and slopes, mainly in central Kochi, indicated strong relationships between AOD and influencing factors, while areas on the outskirts with low p-values and slopes suggested weak or complex interactions. In 2023, AOD levels increased more significantly in the northern and eastern parts of Kochi compared to the southwestern areas, likely influenced by industrial activities, high traffic density, and meteorological conditions.

3.4 Divergent Air Quality Trends in Delhi and Kochi (2019–2023)

Aerosol concentrations have shown differing trends in Delhi and Kochi over these years (2019-2023). In Delhi, significant reductions were observed, particularly in the central and southern regions. Seasonal peaks occurred during winter and May, with reductions during the monsoon months. Conversely, Kochi displayed mixed trends, with decreases in the central and northwestern areas and increases in the eastern and southeastern regions. Peaks in Kochi's aerosol levels during winter indicate the influence of seasonal factors. The observed decrease in air pollution during the COVID period (2020-2023) is a well-established fact. However, additionally stringent pollution control measures and mitigation efforts, such as the odd-even rule, were also in effect during the study period. It is appropriate to mention both as contributing factors.

Aerosol Optical Depth (AOD) trends also varied between the two cities. Delhi experienced a general decline in AOD, with some higher concentrations in the northern and western regions. Seasonal peaks were observed in July during the monsoon and in winter months. Kochi exhibited a mixed trend, with increases in central and northwestern regions and decreases in eastern and southeastern areas. AOD levels in Kochi peaked in July, reflecting monsoon-associated variations.

Carbon monoxide (CO) concentrations generally declined in both cities, though with distinct spatial and temporal variations. In Delhi, reductions were significant in most areas, although central and eastern regions exhibited persistent increases. Seasonal peaks were most notable in winter, particularly in November. In Kochi, CO levels showed a consistent year-on-year decline, with marked reductions in the central and northeastern parts. January emerged as the peak month for CO in Kochi, reflecting similar seasonal influences.

Formaldehyde (HCHO) trends highlight contrasting scenarios. In Delhi, HCHO concentrations rose significantly, especially in central and eastern areas, driven by vehicular and industrial emissions. Winter months showed higher concentrations, with November as a peak period. Kochi, on the other hand, displayed notable reductions in HCHO levels across central and northern regions, though slight increases were observed in southern areas. February was the peak month for HCHO in Kochi, indicating similar seasonal patterns despite differing overall trends.

Nitrogen dioxide (NO_2) levels showed a declining trend in Delhi and an increasing trend in Kochi. In Delhi, NO_2 reductions were prominent across most areas, particularly in the central and southern parts, with seasonal peaks occurring in November and December. In contrast, Kochi witnessed a steady increase in NO_2 levels, with the central region experiencing pronounced rises. Seasonal peaks in Kochi aligned with January, driven by urban and industrial emissions.

Sulfur dioxide (SO_2) concentrations revealed notable differences. Delhi achieved significant reductions, especially in southern and western regions, with occasional peaks in December. In Kochi, SO_2 levels exhibited a mixed trend, with increases in central areas and reductions in northwestern and southeastern regions. Seasonal spikes in Kochi were noted in February and November, likely due to industrial and meteorological factors.

Seasonal patterns across both cities reflected the influence of climatic factors. Delhi consistently recorded higher pollutant levels during the winter months, with significant reductions during the monsoon season from June to September. Kochi exhibited similar seasonal variations, with winter peaks and monsoon-associated reductions, particularly in AOD and aerosols.

Regional differences highlight the role of localized factors in air quality trends. In Delhi, central and southern regions showed strong improvements due to enhanced traffic management and emission controls. However, some areas still experienced localized pollutant increases. In Kochi, urbanized central areas exhibited rising pollutant levels, while peripheral regions showed improvements, reflecting the effects of urbanization and industrial activities.

Overall, Delhi demonstrated more substantial improvements in air quality for most pollutants compared to Kochi, likely due to stricter pollution control measures. However, rising levels of NO_2 and HCHO in Kochi underscore the need for targeted interventions. Seasonal and regional variability in both cities highlights the interplay of climatic and anthropogenic factors in shaping air quality trends.

4. Conclusion

The comparative analysis of air pollutants in Delhi and Kochi from 2019 to 2023 underscores the complex interplay between urbanization, industrial activities, and climatic factors in shaping air quality trends. Delhi has demonstrated notable improvements in reducing concentrations of most pollutants, including aerosols, AOD, CO, NO_2, and SO_2, reflecting the effectiveness of targeted pollution control measures and improved traffic management. However, the rising levels of formaldehyde (HCHO) in Delhi highlight the persistent challenge posed by industrial and vehicular emissions in central and eastern regions.

In contrast, Kochi presents a more varied picture, with improvements in CO, SO_2, and HCHO levels in specific regions, but concerning increases in NO_2 and aerosols, particularly in urbanized central areas. The city's seasonal pollutant patterns, such as winter peaks and monsoon-associated reductions, parallel those of Delhi but are influenced by its unique coastal and meteorological conditions.

Both cities reveal the importance of localized interventions tailored to regional characteristics. While Delhi benefits from stricter emission controls, Kochi requires targeted strategies to address its rising NO_2 and aerosol levels, which could impede further improvements in air quality. The study also highlights the need for sustained efforts in pollution mitigation and continuous monitoring to achieve long-term air quality goals.

Overall, the findings underscore the critical need for region-specific air quality management strategies, incorporating urban planning, industrial regulation, and public awareness campaigns to ensure sustainable and healthier urban environments.

8.3 Group 3: *Analyzing Kochi's SMART city initiatives - its challenges and solutions*

Authors*: Abhinand S., Anand M., Anusha Roy, Hafin P. K., Lalitha Shanmugasundaram, Sobah A. Petersen, Bintang Noor and Alenka Temeljotov-Salaj.* See Annex 2 for affiliations.

I. Introduction
   A. What is a smart city?
   B. Case study selection/Justification
      Our group focuses on identifying barriers to smart city development. Given the limited time available, tackling the entire city of Kochi would be challenging, so we decided to focus on a specific area with high potential. This led us to explore the historical context of the city. Literature revealed that Kochi's initial development concentrated on the western side of Ernakulam district, particularly in Mattancherry. As a prominent port and a spice trade center, Mattancherry attracted traders worldwide, utilizing its extensive canal and sea routes for transport. By focusing on this historically significant part of Kochi, we aim to uncover unique challenges to implementing smart city solutions in an old, culturally rich area.

We are a group of four professionals, each bringing unique expertise to the table: social sciences, political analysis, energy systems, and urban infrastructure. Together, we merged our perspectives to craft an engaging platform for discussing and ideating sustainable city solutions.

Our collaborative approach allowed us to examine challenges and opportunities from diverse angles—addressing community needs, policy frameworks, energy efficiency, and resilient infrastructure design. Through this synergy, we facilitated meaningful conversations and innovative strategies that are both practical and forward-thinking, driving the vision of sustainable urban development.

   C. Thesis: This presentation will analyze Kochi's SMART city initiatives using Silva et al.'s characteristics of the smart city.

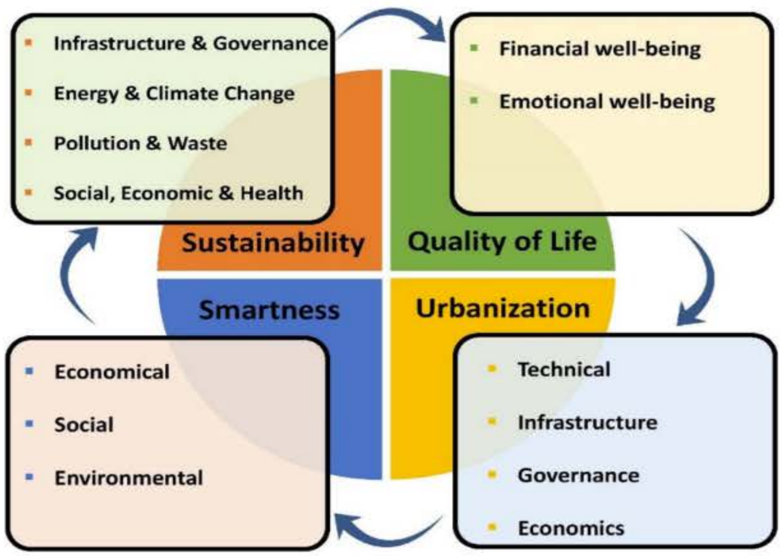


Fig. 2. Characteristics of a Smart City.

II. Methodology
   A. Visited Mattancherry on November 12th to talk to vendors, tourists, and locals regarding the issues and challenges faced by the community regarding sustainability
   B. Visited Cochin Smart City Limited on November 13th to speak with engineers and employees regarding the data they collect, as well as any challenges they face
   C. Analyzed interviews and findings from a multidisciplinary perspective using Silva et al.'s figure on the characteristics of a SMART city
   D. Utilized literature to brainstorm collaboratively for the development of solutions to each of these challenges

III. Smartness Challenges
   A. Data governance
   B. Lack of fund (capital & maintenance)
   C. None cooperation among government departments
   D. Solution:
      1. Open access data resources
      2. Refining authenticity of the data
      3. Collecting data after and ensuring the data is up to date
      4. Collaboration with local level NGOs, civil society institutions and universities for the collection, analysis and updation of data

      If all the government departments/agencies, NGOs, universities, research organizations, civil society institutions can come under a common platform mediated by the State government or concerned municipal corporations, the collection, analysis and updation of data will become easy and transparent. And that requires sheer political will and persuasion. Attempts in that direction (building collaboration platforms/structures) are already happening with the initiatives by KILA, KDISC and LSGIs of Kerala.

The existing data the CSML possesses is only shared with three departments- KWA, KSEB and Kerala police. Regarding specific projects that require to be confidential, data should not be shared. Other than that, if the data (for example: data of flood susceptibility, waterlogged areas, land utilization etc.) is shared with research institutions and other stakeholders (of particular place or community or issues), larger awareness, participation and planning can be done.

IV. Sustainability Challenges

A. Pollution and Waste

- Effective waste management is essential for the sustainability of smart cities, as improper waste disposal poses significant risks to both human health and the environment. (Rathi, 2006; Sharholy et al., 2008)
- The number of waste bins available is inadequate to meet the needs of the area, particularly in high-traffic zones where people gather.
- The existing bins are frequently filled to capacity, leading to overflow and contributing to litter and sanitation issues.
- The problem of fishing nets getting broken by being trapped in the wastes (iron, steel etc) of the ocean.

B. Flood (heavy rain & High tide), Erosion: Severe erosion is observed to the south of Cochin Inlet (Chellanam-Kochi area) due to dredging of sediments from the ship channel. Human activities like construction of hard structures (breakwater, seawall, groynes etc.) also have a negative impact on the coast (Sheela Nair, 2018). Heavy rain, high tide, (resulting in floods) storm surges etc. also causes the loss of land.

C. Energy consumption: In Mattanchery's Jew Town, a popular tourist area, vendors face significant financial burdens. Many shop owners are required to pay high monthly rents, which places considerable pressure on their profit margins. Additionally, electricity bills become a substantial expense, particularly during the summer months when energy consumption peaks due to increased cooling needs. These high operational costs present ongoing challenges for sellers in this bustling tourist hub.

D. Solution:

1. Visualization of Environmental issues (education/awareness to invoke emotions) (Audio/smell simulation of different places of Kochi city including the Calvathy canal, bazar road, coastal land stretch affected by sea incursions, beaches etc.)
2. Sensors for water streams to monitor the water levels/pollution
3. Cleaning the water and ensuring the canals are clean and flowing (preventing vector borne illnesses)
4. Restoration of coastal ecosystem, managed by local community

5. Consistent database of coastal morphology maintained by the coastal inhabitants who have the experiential knowledge and expertise in the area
6. Integrated water management: Unless we have an integrated water management system by taking into account all the water bodies/resources including sea, lake, rivers, canals and wetlands, the area wise sustainability projects can't move forward.
7. -Install additional waste bins near common gathering areas to ensure easy access and encourage proper waste disposal.
   -Equip waste bins with sensors that monitor fill levels. When a bin reaches full capacity, the sensor will notify the municipal corporation, enabling timely waste collection and reducing overflow. Develop a responsive waste collection schedule based on sensor data to ensure bins are consistently emptied, maintaining a clean environment. (Vishnu et al., 2021)
8. -Solar Panel Subsidies: Offer subsidies or low-interest loans to make solar installations affordable, reducing long-term energy expenses.
   -Tax Incentives: Provide tax benefits for businesses that adopt renewable energy, easing the financial burden of initial investment.
   -Bulk Purchasing: Encourage local business associations to facilitate bulk purchasing agreements with solar providers. This could lower installation costs for individual vendors and create a support network for maintenance and service.
   -Green Certification: Establish a "green-certified" business program to attract eco-conscious tourists.

V. Quality of Life Challenges

A. SMART city initiatives prioritize tourism industry vs local needs and uses a top down approach to it's initiatives

1. In the context of smart city development in Kochi, it becomes clear that while data-driven initiatives have provided certain benefits, they often miss the mark on addressing essential local needs. For example, one vendor in Mantacherry benefited from a kiosk provided by the city's smart initiatives, giving him a permanent place to sell goods. However, the absence of basic facilities like public restrooms for vendors demonstrates a misalignment with the everyday needs of the community, as the area was primarily designed to accommodate tourists rather than local residents. A field survey conducted for the City sanitation plan (2011) by the Corporation of Cochin revealed that in Mattancherry, residents of the slums reported the presence of worms and maggots in the water. This highlights a central critique of many smart city developments: the over-reliance on technology and data to address urban challenges without understanding or addressing the foundational social needs of residents (Shelton, Zook, & Wiig, 2015; Morozov, 2014).
   a) Instead of examining innovative ways to reinvigorate the urban settlement or help the spice trade metamorphose into a 21st

century activity, local officials continue to turn obsessively to tourism. As a result, historical buildings are visualised as museums or tourist destinations, while residents remain unaware of their uniqueness, or potential for reuse. Meanwhile, many areas still have no water service or sewer, and open drains carry a foul mixture of refuse' (P Fels, 2006).

2. Kochi Smart City Limited collects a wealth of data on various indicators, yet the approach remains top-down, with decisions on infrastructure—like streetlamps or kiosks—largely determined by the corporation. Without direct community consultation, many smart city projects run the risk of overlooking residents' needs and perpetuating inequalities. This top-down, corporate-led approach has been seen across other smart city projects globally, where smart initiatives focus on tourists and commercial opportunities rather than inclusive city-building (Datta, 2015). A people-centric model, as advocated by scholars like Townsend (2013) and Greenfield (2013), would center on community-led identification of needs, emphasizing that technology should be a tool to serve residents rather than a standalone solution.

B. <u>Solution</u>:

1. People Centric Model
    a) A people-centric model in smart cities emphasizes prioritizing the needs, well-being, and everyday experiences of residents rather than focusing solely on technology or data collection. Unlike tech-centered models, which primarily deploy infrastructure to gather data or optimize city functions, people-centric approaches ensure that technological solutions are developed with input from local communities and address real, human-centered problems (Townsend, 2013).
    b) The core idea is that technology should be a tool for enhancing quality of life, fostering inclusivity, and meeting diverse social needs. Scholars argue that people-centric models lead to smarter, more sustainable cities by placing residents at the heart of planning processes and prioritizing basic urban needs, such as accessible transportation, safe public spaces, and affordable housing (Green, 2019; Hollands, 2008). These models also challenge the "one-size-fits-all" approach by adapting solutions to the unique cultural and social contexts of each city, thus making smart city initiatives more effective and equitable (Datta, 2015).
2. Participatory Governance Model/Bottom Up Approaches
    a) The solution to this disconnect lies in shifting from technology-first approaches to ones that genuinely engage communities through participatory governance. By including residents in the planning process, city planners can ensure that initiatives align with what locals find most urgent, such as access to sanitation, affordable

housing, or safer pedestrian infrastructure. Research shows that participatory models are effective in achieving this alignment and building community trust in smart city projects (Caragliu, Del Bo, & Nijkamp, 2011).

b) A participatory governance model emphasizes active involvement of local communities in decision-making processes, allowing citizens to contribute directly to policies and projects that affect their lives. This approach contrasts with traditional top-down governance models, which often exclude public input and rely on centralized authorities to determine urban planning and development priorities. Participatory governance in smart cities aims to empower residents, especially marginalized groups, by fostering transparency, accountability, and inclusivity in urban management (Caragliu, Del Bo, & Nijkamp, 2011).

c) In the context of smart city planning, participatory governance often involves creating platforms for citizens to provide feedback on initiatives, voice concerns, and co-create solutions. Scholars argue that involving local populations in these processes leads to smarter, more sustainable cities that reflect the true needs of their residents. For instance, Bifulco et al. (2016) highlight that participatory approaches not only improve satisfaction with city policies but also strengthen the social fabric and trust between citizens and municipal authorities. In practical terms, participatory governance might include community workshops, collaborative design of public spaces, and digital platforms that facilitate citizen engagement (Arnstein, 1969; Fung, 2006).

d) Moving towards a "smart enough" city, as Ben Green (2019) argues, means putting technology in service of inclusivity and social needs, creating an environment where both technology and people can thrive.

e) Example of this: Government initiatives to promote civil society engagement and use insights from public with a sense of accountability with trackable management of policies (digital platform)

3. Summary

a) In sum, while the smart city vision for Kochi holds promise, it requires a recalibration from a tourism-driven, data-centric model to one that centers local voices and needs. By adopting a bottom-up approach and prioritizing community consultation, smart city initiatives in Kochi could achieve sustainable development that is not only technologically advanced but also socially inclusive.

VI. Urbanization Challenges

Mattancherry is experiencing a shift in cultural identity as new urban developments overshadow its historical significance. Once a thriving spice trade centre, it’s now a hub for artefacts from across India, signalling a change in its cultural core. Rapid urbanization has also impacted the quality of life for local traders and marginalized workers, with informal settlements lacking essential services, sanitation, and safety. Addressing these gaps through smart city initiatives could help improve living conditions for all residents.

A. **Infrastructural Barriers**:

- **Space Constraints and Accessibility**: High-density areas limit space for new infrastructure, and historical buildings in disrepair—such as the old spice trade center—could be revitalized but pose significant renovation challenges. Additionally, limited open spaces and deteriorating canals affect the city's usability and appeal, while lack of pedestrian-only zones and amenities (e.g., dustbins, water stations) reduce the quality of the public experience. The site lacks disable friendly spaces.
- **Technological Solutions**: CSML has already mapped and drafted the 3D model for the entire area in GIS. It can be utilised to demarcate various buffer zones within the area and identify the potential zone for retrofitting. Suggestions include creating scalable digital infrastructure, multilingual information screens, emergency alert systems, and renewable energy kiosks. These solutions aim to support tourism, improve environmental conditions, and enhance accessibility.
- **Emergency and Utility Needs**: The absence of refuge areas for heat or fire emergencies is a critical shortfall, especially in densely populated zones. The implementation of waste-to-energy plants and sustainable resources can support better waste management and utility infrastructure.

B. **Governance Barriers**:

- **Public Resistance to Change**: Community pushback against government initiatives reflects a need for transparency and public involvement. Suggested solutions include interactive digital platforms where residents can visualize proposed changes, potentially increasing acceptance and engagement in smart city initiatives.
- **Community Engagement**: Hosting local events and setting up wellness centres are proposed as ways to strengthen local engagement. Providing digital platforms for feedback can enhance collaboration between residents and city planners, fostering a participatory approach to city improvement. Offering platforms for grievances and community-driven suggestions, along with automated fine systems for regulatory violations, could improve public services and ensure better adherence to city ordinances.

C. **Economic Barriers**:

- **Seasonal Income Variability**: Kochi's reliance on tourism, which has seasonal peaks, creates income fluctuations. Expanding digital marketing and remote work opportunities could stabilize economic inflows by reaching broader markets year-round.
- **Digital Events and Markets**: Hosting virtual and augmented reality-supported local events, cultural festivals, and markets can attract regional visitors and tourists by highlighting Mattancherry's heritage. This approach allows wider outreach and engages both in-person and online audiences, benefiting local artisans and vendors.

- **Virtual Wellness Centers**: ICT-enabled wellness centers can provide residents with easy access to health resources, fitness programs, and mental health support via apps or online platforms. These digital solutions promote community well-being and serve as hubs for social engagement.
- **Smart Transportation Network**: An ICT-driven transportation network with real-time data and route optimization can make commuting more efficient. User-friendly apps offering live updates on routes and eco-friendly options encourage more visitors and workers to travel to the area, supporting the local economy.

VII. Conclusions/Recommendations

A. General Solutions:

1. Focus on local communities and concerns
2. Using technology to promote the idea of ‘urban citizenship’ through art, culture, etc
    a) Can serve as awareness and the development of a place based identity

9 Conclusion and Next Steps

The URSA MAJOR Hackathon successfully provided a collaborative platform for addressing real-world urban sustainability challenges in the Global South. The generated insights and solutions can inform policy-making and smart city planning.

Future steps include follow-up research, scientific publications, and collaborations with local authorities for real-world implementation. Ongoing engagement with stakeholders is crucial for ensuring sustainable urban development.

Acknowledgments

The organizers thank all mentors, experts and practitioners, researchers, and students for their active participation. Special thanks to the Research Council of Norway for supporting the project *URban Sustainability in Action: Multi-disciplinary Approach through Jointly Organized Research schools* through their INTPART program Grant # 322317. This support was essential for the implementation of the Hackathon.

Annexure 1: Program Schedule

Day 1: Monday, November 11, 2024

Opening Ceremony & Welcome (9:30 AM – 10:15 AM)

- Dr. Ajith Joseph K., Executive Director, NERCI – Welcome Address
- Er. Sreekala, Chairperson, KSPCB, Trivandrum – Inaugural Address
- Lasse H. Pettersson, Senior Researcher, NERSC, Norway – Introduction to URSA MAJOR
- Dr. Bindu G., Principal Scientist, NERCI – Introduction to URSA MAJOR HACKATHON 2024

Keynote Address (10:15 AM – 11:00 AM)

Topic: 'Toward Environmentally and Climate-Smart, Resilient & Sustainable Cities'

Dr. Alexander Baklanov, Professor, Niels Bohr Institute, University of Copenhagen, Denmark

Tea Break: 11:00 AM – 11:30 AM

Technical Session 1: **Air Quality Monitoring & Modelling** (11:30 AM – 3:30 PM, with Lunch Break 1:00 PM – 2:00 PM)

- Er. Sreekala, Chairperson, KSPCB – Activities of KSPCB
- Er. Bindhu Radhakrishnan, Chief Environmental Engineer, KSPCB – Air Pollution Overview
- Dr. Jayanarayanan Kuttippurath, Associate Professor, IIT Kharagpur – Heat & Pollution in Indian Cities
- Dr. Igor Esau, Professor, UiT (Online) – High-Resolution Urban Meteorological Models
- Mr. Vishnu N.G, SRF, Mahatma Gandhi University – Portable GHG Instruments

Tea Break: 3:30 PM – 4:00 PM

Group Activity (4:00 PM – 6:00 PM)

Day 2: Tuesday, November 12, 2024

Technical Session 2: Air Quality Monitoring & Modelling (9:00 AM – 11:00 AM)

- Dr. Harish, Professor, IIT Bombay – Health Effects of Air Pollution
- Mr. Pravin Punde, Researcher, UiT, Norway – WRF Modelling: Cloud Microphysics & Atmospheric Icing
- Mr. Prince, Researcher, IIT Bombay – Overview of AERMOD
- Mr. Christofer Mount, Imuk, Germany (Online) – PALM Air Quality Modelling

Tea Break: 11:00 AM – 11:30 AM

Technical Session 3: Remote Sensing of Environmental Status (11:30 AM – 1:00 PM)

- Dr. Victoria Miles, NERSC (Online) – Remote Sensing of the Urban Environment
- Dr. R. Ranith, NERCI – Remote Sensing Data Analytics for Air Pollution Surveillance
- Dr. Shailendra K. Mandal (Online) – GIS-based Air Pollution Mapping in Patna

Lunch Break: 1:00 PM – 2:00 PM

Group Activity (2:00 PM – 6:00 PM)
Tea Break: 4:00 PM – 4:30 PM

Day 3: Wednesday, November 13, 2024
Technical Session 4: Barriers to Smart City Development (9:00 AM – 1:00 PM)

- Dr. Sobah Abbas Petersen, SINTEF Digital – Barriers & Opportunities in Smart Cities
- Mr. Clipson, GM, Cochin Smart City Mission – Digitization of Urban Governance
- Dr. Alenka Temeljotov Salaj, NTNU (Online) – Literature Review on Smart City Barriers
- Dr. Bintang Noor, NTNU – Urban Heritage Facility Management

Tea Break: 10:30 AM – 11:00 AM

Group Activity (11:30 AM – 1:00 PM)
Lunch Break: 1:00 PM – 2:00 PM

Open Activity (Weather Permitting): Boating in Backwaters (3:00 PM – 6:00 PM)

Day 4: Thursday, November 14, 2024
Group Work (9:00 AM – 6:00 PM)

Day 5: Friday, November 15, 2024
Group Work, Reporting Consolidation & Valedictory (9:00 AM – 4:00 PM)

Annexure 2: The Participants

Total Student Participants: 22 from India and abroad.

Total Supervisor Participants: 12 from India and abroad.

Group 1: Air Quality Monitoring & Modelling

Supervisors:
- Dr. Igor Esau (UiT) (Online)
- Dr. Bindu G. (NERCI)
- Dr. Jayanarayanan Kuttippurath (IIT Kharagpur)
- Dr. Alexander Baklanov (Niels Bohr Institute - University of Copenhagen)
- Mr. Prince Vijay (IIT Bombay)

Students:
- Pravin Punde (UiT)
- Sneha K. S. (Kerala Agricultural University)
- Anagha Satheesan K. (Pondicherry University)
- Madhuraj P. K. (CUSAT)
- Peediyakkathodi Sajna (CUSAT)
- Sruthy Robert (SCMS)
- Vishnu N. G. (MG University)
- Anjaly P. S. (Kerala Agricultural University)
- Rakhi K. Raj (NERCI)
- Ajaya Indrani (NIT)

Group 2: Remote Sensing

Supervisors:
- Lasse H. Pettersson (NERSC)
- Dr. Victoria Miles (NERSC) (Online)
- Dr. Ajith Joseph K. (NERCI)
- Dr. Ranith (NERCI)

Students:
- Ibrahim Bathis K. (KSCTE)
- Layana Vijayan (Bharathidasan University)
- Kiruthika N. (Bharathidasan University)
- Hemand A. (Central University of Karnataka)

- Swathy Krishna M. C. (NERCI)
- Farzana Haris (NERCI)
- Sarath Kumar D. (Bharathidasan University)

Group 3: Barriers for Smart City Development (Social Science)

Supervisors:
- Dr. Sobah A. Petersen (SINTEF Digital)
- Dr. Bintang Noor (NTNU)
- Dr. Alenka Temeljotov-Salaj (NTNU) (Online)

Students:
- Lalitha Shanmugasundaram (George Washington University, USA)
- Anusha Roy (IIT, Bombay)
- Hafin P. K. (KUFOS)
- Abhinand S. (MG University)
- Anand M. (NERCI)