WHITE PAPER

Environmental Health Risk Atlas and Action Framework for the Vidarbha Region, India:

Integrating Air, Water, Soil, Climate, and Public Health for Sustainable Development

AIR QUALITY

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CSIR- National Environmental Engineering Research Institute (NEERI), Nagpur

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Foreword

Environmental degradation and public health challenges have become major concerns of the 21st century, particularly in rapidly developing regions where industrialization, urbanization, agricultural intensification, and climate variability intersect. The Vidarbha region of Maharashtra is an environmentally sensitive landscape characterized by mining activities, coal-based thermal power generation, expanding urban centers, intensive agriculture, and ecologically important forest ecosystems. These developmental transitions have contributed significantly to increasing pressures on air, water, soil, biodiversity, and public health systems.

The present white paper, "**Environmental Health Risk Atlas and Action Framework for the Vidarbha Region, India: Integrating Air, Water, Soil, Climate, and Public Health for Sustainable Development**," is an important scientific initiative that comprehensively assesses environmental health risks across the Vidarbha region through an integrated and multidisciplinary framework. The report highlights the interconnections between environmental pollution, climate-related stressors, occupational exposures, ecosystem degradation, and human health outcomes. It also identifies pollution hotspots, vulnerable populations, emerging contaminants, and climate-sensitive risks requiring urgent policy attention and evidence-based interventions.

This white paper emphasizes the growing need to integrate environmental science, public health, geospatial technologies, epidemiology, and sustainable development planning under a One Health framework. The document highlights the importance of environmental surveillance, risk mapping, exposure assessment, ecological restoration, and climate resilience for protecting environmental quality and human well-being. It also underscores the critical role of scientific institutions in strengthening environmental governance and public health preparedness.

CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, with its expertise in environmental engineering, pollution monitoring, environmental health, remote sensing, wastewater surveillance, ecological restoration, and climate studies, can play a critical role in addressing the emerging environmental health challenges of the Vidarbha region. Through interdisciplinary research, scientific assessments, technological innovation, and stakeholder engagement, CSIR-NEERI is well positioned to support integrated environmental monitoring, pollution mitigation, health risk assessment, geospatial decision-support systems, and evidence-based policy development for sustainable environmental management and public health protection in Vidarbha.

The successful implementation of the environmental health risk management framework proposed in this white paper will require coordinated collaboration among scientific institutions, healthcare organizations, universities, administrative bodies, regulatory agencies, and policy stakeholders across the Vidarbha region. Institutions such as AIIMS Nagpur, VNIT Nagpur, RTMNU Nagpur, ICMR-associated research centres, CSIR laboratories, public health departments, Maharashtra Pollution Control Board (MPCB), Central Pollution Control Board (CPCB), urban local bodies, district administrations, forest departments, groundwater and irrigation agencies, and disaster management authorities possess complementary expertise essential for integrated environmental governance and sustainable regional development.

I appreciate the efforts of all scientists, researchers, reviewers and other contributors involved in the preparation of this white paper. I sincerely hope that this document will serve as a valuable scientific resource for policymakers, regulatory agencies, academic institutions, healthcare professionals, urban planners, environmental managers, and researchers working towards sustainable environmental management and public health protection in the Vidarbha region and beyond.

I am confident that the findings and recommendations presented in this report will support informed decision-making, strengthen environmental resilience, and contribute meaningfully towards achieving sustainable and healthy ecosystems for future generations.

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ABBREVIATIONS

Abbreviations		Full Form
AIIMS	–	All India Institute of Medical Sciences
AMR	–	Antimicrobial Resistance
AQI	–	Air Quality Index
BIS	–	Bureau of Indian Standards
BOD	–	Biochemical Oxygen Demand
CGWB	–	Central Ground Water Board
CO	–	Carbon Monoxide
COD	–	Chemical Oxygen Demand
COPD	–	Chronic Obstructive Pulmonary Disease
COVID-19	–	Coronavirus Disease 2019
CPCB	–	Central Pollution Control Board
CSIR	–	Council of Scientific and Industrial Research
NEERI	–	National Environmental Engineering Research Institute
DALY	–	Disability Adjusted Life Year
DO	–	Dissolved Oxygen
EDCs	–	Endocrine Disrupting Compounds
EIA	–	Environmental Impact Assessment
FAO	–	Food and Agriculture Organization
FSI	–	Forest Survey of India
GDP	–	Gross Domestic Product
GIS	–	Geographic Information System
GPS	–	Global Positioning System
ICMR	–	Indian Council of Medical Research
ICP-MS	–	Inductively Coupled Plasma Mass Spectrometry
IIIT	–	Indian Institute of Information Technology
IIT	–	Indian Institute of Technology
ILO	–	International Labour Organization
IPCC	–	Intergovernmental Panel on Climate Change
ISRO	–	Indian Space Research Organisation
LULC	–	Land Use Land Cover
MIDC	–	Maharashtra Industrial Development Corporation
MoEFCC	–	Ministry of Environment, Forest and Climate Change
MPCB	–	Maharashtra Pollution Control Board

Abbreviations		Full Form
NGO	–	Non-Governmental Organization
NIT	–	National Institute of Technology
NO_x	–	Nitrogen Oxides
PAHs	–	Polycyclic Aromatic Hydrocarbons
PM	–	Particulate Matter
$PM_{2.5}$	–	Particulate Matter less than 2.5 micrometers
PM_{10}	–	Particulate Matter less than 10 micrometers
POPs	–	Persistent Organic Pollutants
PPE	–	Personal Protective Equipment
RS	–	Remote Sensing
RS/GIS	–	Remote Sensing and Geographic Information System
RTMNU	–	Rashtrasant Tukadoji Maharaj Nagpur University
SARS-CoV-2	–	Severe Acute Respiratory Syndrome Coronavirus 2
SDGs	–	Sustainable Development Goals
SO_2	–	Sulfur Dioxide
TDS	–	Total Dissolved Solids
TSS	–	Total Suspended Solids
UHI	–	Urban Heat Island
UN	–	United Nations
UNEP	–	United Nations Environment Programme
VNIT	–	Visvesvaraya National Institute of Technology
VOCs	–	Volatile Organic Compounds
WCL	–	Western Coalfields Limited
WHO	–	World Health Organization

1. Executive Summary

Environmental health challenges across the Vidarbha region of Maharashtra have intensified markedly over recent decades as a consequence of rapid industrialization, expanding mining operations, coal-based thermal power generation, agricultural intensification, urban growth, and increasing climate variability (Smith et al., 2019; Kumar & Reddy, 2020). Vidarbha constitutes one of central India's most resource-intensive regions, hosting extensive coalfields, manganese mining belts, mineral-processing industries, and large thermal power complexes that contribute substantially to regional economic development and national energy security (Patel, 2021). However, these developmental activities have also resulted in deterioration of air, water, soil, and ecosystem quality, posing substantial risks to human health, ecological sustainability, and climate resilience (Landrigan et al., 2018; WHO, 2018).

The environmental health profile of the region is shaped by multiple interacting stressors operating across industrial, agricultural, and urban landscapes. Major concerns include atmospheric pollution arising from coal combustion, fly ash emissions, industrial processes, and rapidly increasing vehicular traffic (WHO, 2021). Other concerns include, heavy metal contamination linked to mining, smelting, and industrial discharge (Sharma et al., 2018), deterioration of surface and groundwater quality due to untreated sewage and industrial effluents (CPCB, 2022), and soil contamination resulting from excessive agrochemical application and pesticide-intensive farming systems (FAO, 2021). Urban centres additionally face escalating challenges associated with solid waste accumulation, plastic pollution, and inadequate waste management infrastructure (MoEFCC, 2016). Beyond these pollutants, emerging contaminants, including microplastics, pharmaceutical residues, endocrine-disrupting compounds, and antibiotic-resistant microorganisms, are increasingly being detected in environmental matrices, raising concerns regarding chronic ecological and human exposure pathways (UNEP, 2021; WHO, 2020). Simultaneously, climate-induced heat waves, droughts, and hydrological variability are amplifying environmental vulnerability and placing additional stress on water security and public health systems (IPCC, 2022). Occupational exposure among miners, thermal power plant workers, industrial labourers, and agricultural communities further compounds regional health risks, particularly among socioeconomically vulnerable populations (ILO, 2019).

Evidence generated through environmental monitoring, epidemiological investigations, and occupational health assessments indicates that chronic exposure to particulate matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide, nitrogen oxides, manganese, arsenic, mercury, pesticides, and other toxic contaminants contributes substantially to respiratory illnesses, neurological impairment, cardiovascular disorders, endocrine disruption, reproductive toxicity, and occupational diseases among exposed populations (Gupta et al., 2020; Desai, 2017). The cumulative and synergistic effects of multi-pollutant exposure are further intensified by socioeconomic disparities, inadequate healthcare access, poor environmental governance, and climate-related stressors (WHO, 2018; IPCC, 2022).

Vidarbha currently stands at a critical environmental and public health crossroads. Integrated **air–water–soil–climate–health interactions** reveal that environmental pollution cannot be addressed through isolated sectoral approaches. For Example, Emissions from the thermal power plant degrade ambient air quality and contribute to fly ash deposition and contamination of soil and aquatic ecosystems, thereby extending exposure across multiple environmental compartments (Nieuwenhuijsen, 2015). Climate-induced heat stress simultaneously exacerbates the physiological impacts of poor air quality and increases vulnerability among sensitive populations such as children, elderly individuals, outdoor workers, and economically marginalized communities (WHO, 2018). District-level vulnerability assessments indicate pronounced spatial heterogeneity in environmental risk. Chandrapur and Nagpur exhibit severe industrial and urban pollution burdens associated with thermal power generation, mining, transportation emissions, and waste disposal practices. Yavatmal and Akola continue to experience significant pesticide-related health concerns linked to intensive cotton cultivation and agrochemical dependency, while Gadchiroli faces the dual pressures of expanding mining activities and progressive ecosystem degradation. These interconnected challenges underscore the necessity of adopting a **One Health framework** (Saxena et al., 2021; Saxena et al., 2023) that recognizes the intrinsic interdependence of human, animal, and environmental health systems, particularly in the context of emerging contaminants, ecosystem disruption, and zoonotic disease risks.

In response to these multidimensional risks, this white paper advances beyond conventional Air Quality Index (AQI)-based assessments, which often fail to capture cumulative and multi-pathway environmental exposures, to propose an **integrated environmental health governance framework** for the Vidarbha region. Central recommendations include the development of a **comprehensive Spatial Risk Atlas and a**

real-time Environmental Health Monitoring Dashboard capable of integrating pollution exposure, disease prevalence, climate indicators, and geospatial vulnerability data into a unified decision-support platform. The report further proposes a policy prioritization and implementation framework that transforms existing environmental regulations from passive compliance mechanisms into proactive public health protection systems with measurable intervention thresholds. A central component of this strategy involves **strengthening the role of scientific and technical institutions in Vidarbha, particularly CSIR-National Environmental Engineering Research Institute**, as a regional centre for advanced environmental monitoring, toxicological assessment, genomic surveillance, climate adaptation research, and technological innovation.

This white paper therefore presents a comprehensive and interdisciplinary assessment of environmental health challenges in Vidarbha by integrating environmental quality data, epidemiological evidence, geospatial analysis, occupational exposure studies, and policy frameworks. The report identifies major pollution hotspots, exposure pathways, vulnerable demographic groups, and institutional governance gaps while proposing science-based strategies for mitigation, adaptation, and sustainable environmental health management. It is intended to support policymakers, researchers, environmental regulators, healthcare professionals, and regional planning authorities in designing and implementing coordinated and evidence-driven interventions to safeguard both human health and ecological integrity across the Vidarbha region. By integrating environmental risk assessment, climate resilience, adaptive governance, and public health planning, this white paper provides a long-term strategic roadmap. The proposed roadmap is aligned with the national Vision Viksit Bharat 2047 framework and is structured into phased implementation targets involving short-term environmental surveillance and monitoring strengthening (2026–2030), medium-term integrated environmental-health governance and One Health expansion (2030–2040), and long-term climate-resilient environmental health security and sustainable development goals extending up to 2047.

2. Introduction

2.1. Environmental Health Concept

Environmental health is a multidisciplinary field that examines the interactions between environmental conditions and human health outcomes, encompassing the physical, chemical, biological, occupational, and social factors that influence the well-being of individuals and communities (Figure 1). It focuses on understanding how environmental contamination and ecosystem degradation arising from both natural processes and anthropogenic activities affect public health, ecological balance, and quality of life (WHO, 2018; Prüss-Ustün et al., 2016). Major determinants of environmental health include pollution sources, environmental contamination, exposure pathways, vulnerable populations, climate variability, occupational hazards, waste management practices, and ecosystem integrity, all of which influence human exposure to harmful environmental stressors and disease risks (Landrigan et al., 2018).

Environmental pollution originates from multiple interconnected sources, including industrial and thermal power emissions, mining and quarrying activities, agricultural practices, urban activities, household sources, emerging contaminants, and waste and wastewater pollution (Figure 1). Industrial emissions, fossil fuel combustion, vehicular exhaust, biomass burning, and mining activities release particulate matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide, nitrogen oxides, heavy metals, silica dust, and other toxic pollutants into the environment. Agricultural activities contribute pesticides, fertilizers, and agrochemical residues, while urban and household activities generate sewage discharge, domestic smoke, waste burning emissions, and chemical contaminants. In addition, emerging contaminants such as microplastics, endocrine-disrupting compounds (EDCs), pharmaceuticals, and antimicrobial resistance (AMR)-related pollutants have become important environmental health concerns. Climate change and ecosystem degradation, including heat waves, floods, droughts, wildfires, biodiversity loss, and deforestation, further intensify environmental stress and human vulnerability (IPCC, 2022).

These pollution sources contribute to environmental contamination through deterioration of air, water, soil, and food systems. Air pollution containing gases, particulate matter, and toxic aerosols is a major contributor to respiratory and cardiovascular diseases (Cohen et al., 2017). Water contamination arising from industrial effluents, sewage discharge, agricultural runoff, pathogens, heavy metals, and microplastics threatens drinking water safety and aquatic ecosystem health. Soil contamination caused by pesticides, heavy metals, industrial waste, plastics, landfill leachate, and electronic waste facilitates pollutant transfer into terrestrial ecosystems and food chains (Tóth et al., 2016). Bioaccumulation and biomagnification of contaminants in aquatic organisms and agricultural products further increase long-term human exposure risks. Inadequate management of municipal, hazardous, biomedical, and industrial waste accelerates environmental degradation and disease transmission (Hoornweg & Bhada-Tata, 2012).

Human exposure to environmental contaminants occurs through multiple pathways, including inhalation, ingestion, dermal contact, occupational exposure, food-chain transfer, maternal exposure, and ecosystem-mediated exposure (Nieuwenhuijsen, 2015). Inhalation of polluted air, smoke, aerosols, and industrial gases represents a major respiratory exposure route, whereas ingestion of contaminated water, food, fish, and crops introduces pollutants into the digestive system. Dermal exposure occurs through direct contact with contaminated soil, wastewater, chemicals, and dust particles. Occupational exposure is common among workers in mining, agriculture, industries, healthcare, and waste management sectors due to contact with hazardous chemicals, dust, solvents, toxic metals, radiation, and heat stress (ILO, 2019). Maternal and childhood exposure during prenatal and early-life stages can significantly influence developmental health outcomes. Furthermore, environmental degradation indirectly affects health through ecosystem-mediated pathways such as food insecurity, reduced water availability, and altered disease transmission patterns.

Environmental exposures disproportionately affect vulnerable populations, including children, pregnant women, elderly individuals, farmers, pesticide applicators, miners, industrial workers, informal waste workers, tribal populations, and socioeconomically disadvantaged communities. Social and behavioural determinants such as poverty, inadequate healthcare access, poor housing conditions, smoking, alcohol consumption, malnutrition, and unhealthy lifestyle practices may further increase susceptibility to environmental diseases and amplify health inequalities. Prolonged or repeated exposure to environmental contaminants can result in a wide range of adverse health effects involving multiple organ systems. Environmental exposures are strongly associated with respiratory diseases such as asthma, chronic obstructive pulmonary disease (COPD), bronchitis, pneumonia, and impaired lung function. Cardiovascular disorders including hypertension, ischemic heart disease, stroke, arrhythmias, and heart failure are also linked to environmental pollution (Landrigan et al., 2018). Exposure to heavy metals, pesticides, solvents, and industrial chemicals have shown to cause neurological toxicity, neurodevelopmental disorders, endocrine disruption, kidney and liver dysfunction, immune dysregulation, reproductive toxicity, developmental abnormalities, infertility, and increased cancer risks (Landrigan et al., 2018; Aschner et al., 2009; Bowler et al., 2006; Singh et al., 2011). Climate-related environmental stressors contribute to heat stress, occupational illnesses, mental health disorders, and climate-sensitive diseases. Long-term environmental exposures may produce acute, chronic, cumulative, and transgenerational health effects, particularly among highly vulnerable populations (WHO, 2016; Shrestha et al., 2019).

Effective environmental health management requires integrated monitoring, risk assessment, and sustainable mitigation strategies. Environmental monitoring approaches involving biomonitoring, biomarkers, GIS-based risk mapping, environmental surveillance, and risk assessment analytics are essential for identifying exposure hotspots and evaluating health risks. Public health surveillance and One Health approaches further support integrated management of environmental, human, and ecosystem health. Mitigation and sustainable solutions should include clean energy transition, emission reduction strategies, wastewater treatment, safe drinking water supply, occupational safety measures, sustainable and climate-resilient agricultural practices, integrated waste management, circular economy approaches, climate adaptation plans, and strengthened environmental regulations. Urban planning strategies such as green infrastructure, biodiversity conservation, improved sanitation, healthy housing, and sustainable transportation systems can further enhance environmental quality and community resilience. Public health education, scientific research, environmental awareness, and strong policy implementation are equally important for reducing exposure, preventing disease, and promoting environmental sustainability.

2.2. One Health Perspective

A modern understanding of environmental health increasingly incorporates the One Health perspective, which recognizes the interconnectedness of human, animal, and environmental health in addressing complex challenges such as zoonotic diseases, antimicrobial resistance, ecosystem degradation, and climate change. In India, the One Health framework has gained importance as an integrated approach for strengthening disease surveillance, environmental monitoring, and intersectoral collaboration across public health, veterinary, and ecological domains. The reviews by Saxena et al. and Raut et al., emphasizes that the One Health approach is critical for managing emerging infectious diseases, food safety concerns, environmental contamination, and climate-linked health risks through coordinated institutional and policy mechanisms (Saxena et al., 2021; Saxena et al., 2023). Understanding these complex interactions is essential for developing effective environmental monitoring, risk assessment, mitigation, and public health management strategies aimed at protecting ecosystems, reducing exposure, preventing disease, and achieving sustainable development (WHO, 2018; Prüss-Ustün et al., 2016).

2.3. Need for the White Paper

The Vidarbha region, despite its economic significance, has witnessed a steady decline in environmental quality over recent decades. The convergence of intensive mining, thermal power generation, industrial expansion, and chemical-dependent agriculture has created a complex pollution burden that disproportionately affects vulnerable populations. Previous studies have documented elevated levels of heavy metals, particulate matter, and pesticide residues in environmental samples, yet a comprehensive, multi-sectoral assessment linking environmental exposures to public health outcomes remains lacking. Furthermore, fragmented governance and limited coordination among regulatory agencies have hindered effective intervention. Therefore, there is an urgent need for an integrated white paper that consolidates existing evidence, identifies knowledge gaps, and provides actionable recommendations for policymakers, health professionals, and environmental regulators.

Figure 1: Conceptual framework of environmental health [*Source: Conceptualize using AI (OpenAI), 2026*)

2.4. Objectives of the White Paper

The primary objectives of this white paper are:

- To synthesize current scientific evidence on environmental health risks in the Vidarbha region, including pollution sources, exposure pathways, and documented health outcomes.
- To establish **integrated air – water – soil – climate – health linkages** and conduct district-wise vulnerability and exposure assessments.
- To identify pollution hotspots, vulnerable populations, and governance gaps that exacerbate environmental health burdens, including **policy prioritization** and a **spatial risk atlas** concept.
- To propose science-based strategies for mitigation, adaptation, and sustainable environmental health management tailored to the regional context.
- To support coordinated interventions among policymakers, researchers, health professionals, and environmental regulators to protect human health and ecological systems across Vidarbha, **highlighting the strengthened role of scientific institutions like** Council of Scientific and Industrial Research (CSIR)-National Environmental Engineering Research Institute (NEERI) and other prestigious institutions in Vidarbha**.**

3. Regional Context of Vidarbha

3.1. Geography

The Vidarbha region occupies the eastern part of Maharashtra State and consists of eleven districts: Nagpur, Chandrapur, Bhandara, Gondia, Wardha, Amravati, Akola, Washim, Yavatmal, Gadchiroli, and Buldhana (Census of India, 2011) (**Table 1, Figure 2**). Vidarbha covers a vast geographical area characterized by diverse ecological landscapes, including forests, river systems, agricultural plains, and mineral-rich geological formations (Deshpande, 2015). The region is geologically influenced by the Satpura and Gondwana formations, which are known for significant coal deposits that support extensive mining and energy production activities (GSI, 2018). Major river systems such as the Wainganga, Wardha, Penganga, and Kanhan traverse the region, providing important water resources for agriculture, industry, and domestic use (Kale & Gupta, 2018). Large tracts of forest cover are concentrated in districts such as Gadchiroli, Chandrapur, and Bhandara, contributing to biodiversity conservation and ecological stability (FSI, 2021). Within this region, Nagpur functions as the administrative, commercial, and scientific hub, hosting major educational and research institutions including CSIR-NEERI and the Visvesvaraya National Institute of Technology (VNIT), which play a significant role in advancing environmental research and technological development.

Table 1. Geographic and Environmental Characteristics of Vidarbha Region

Component	**Description**
Total districts	11 (Nagpur, Chandrapur, Bhandara, Gondia, Wardha, Amravati, Akola, Washim, Yavatmal, Gadchiroli, Buldhana)
Major geological formations	Satpura and Gondwana formations
Key mineral resources	Coal, manganese, and other mineral deposits
Major river systems	Wainganga, Wardha, Penganga, Kanhan
Forest-dominated districts	Gadchiroli, Chandrapur, Bhandara
Dominant climate	Semi-arid to tropical
Peak summer temperature	Often exceeds 45 °C
Regional hub	Nagpur (administrative, industrial, and research center)

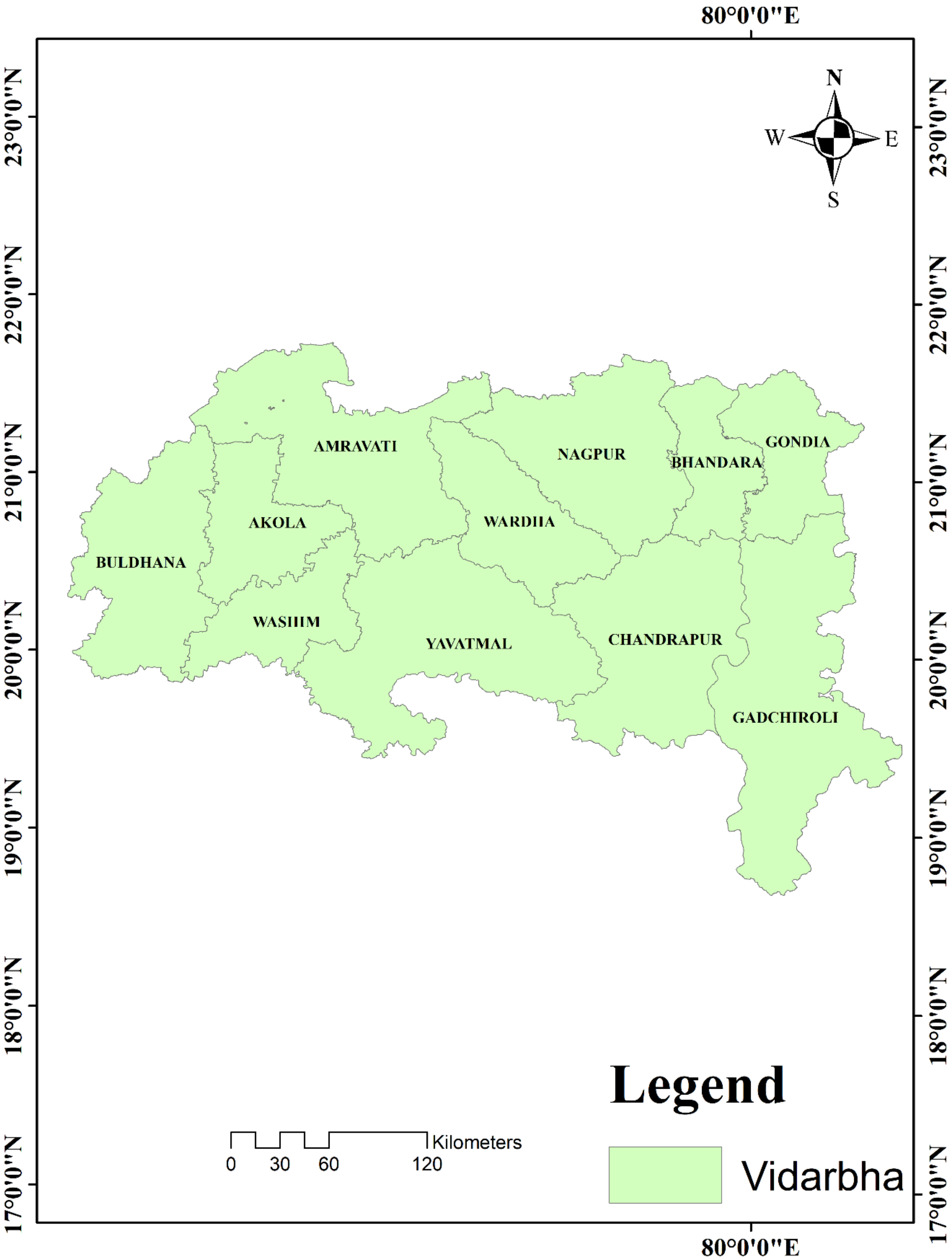

Figure 2: Location Map of Vidarbha Region, Maharashtra, India

3.2. Economy

The regional economy of Vidarbha is supported by several key sectors, with agriculture being the dominant activity, particularly cotton cultivation (Patil & Shete, 2018). Major crops grown in the region include cotton, soybean, turmeric, pulses, and rice (Government of Maharashtra, 2020). However, agricultural intensification has resulted in extensive use of pesticides and fertilizers, raising concerns about environmental contamination and potential health risks for farmers (Narayanamoorthy, 2019). In addition to agriculture, the region benefits from mineral extraction, energy generation, and manufacturing, as detailed below.

3.3. Mining

Vidarbha possesses significant mineral resources, including coal deposits in Chandrapur, Nagpur, and Yavatmal; manganese deposits in Bhandara and Nagpur; and iron ore reserves in Gadchiroli (IBM, 2020). Mining activities are primarily carried out by Western Coalfields Limited (WCL) along with private mining operators (WCL, 2019). These mining operations contribute to land degradation, dust emissions, and water contamination, with associated health impacts on nearby communities.

3.4. Industrial Profile

The region is an important center for thermal power generation, with major coal-based power plants such as the Koradi Thermal Power Station and Khaparkheda Thermal Power Station in Nagpur and the Chandrapur Super Thermal Power Station. These collectively supply electricity to large parts of Maharashtra but also contribute significantly to regional air pollution (Maharashtra Electricity Regulatory Commission, 2021; Guttikunda & Jawahar, 2014). Furthermore, Vidarbha hosts several major industrial clusters, including the Butibori MIDC Industrial Area in Nagpur, the Hingna Industrial Estate, and the Chandrapur Industrial Zone, where industries such as steel and metal processing, cement manufacturing, chemical processing, and textile production operate. These industrial activities generate air emissions, wastewater discharges, and hazardous wastes that have important implications for environmental quality and public health in the region (**Table 2**).

Table 2. Major Economic and Industrial Activities in the Vidarbha Region

Sector	Major Activities	Key Locations	Environmental Concerns
Agriculture	Cotton, soybean, turmeric, pulses, rice cultivation	Yavatmal, Akola, Amravati, Wardha	Pesticide exposure, soil degradation, groundwater contamination
Mining	Coal, manganese, iron ore extraction	Chandrapur, Nagpur, Yavatmal, Bhandara, Gadchiroli	Land degradation, dust emissions, water contamination
Thermal Power Generation	Coal-based electricity generation	Koradi, Khaparkheda, Chandrapur	Air pollution, fly ash generation, greenhouse gas emissions
Manufacturing and Industry	Steel processing, cement, chemical, textile industries	Butibori MIDC, Hingna Industrial Estate, Chandrapur Industrial Zone	Air emissions, wastewater discharge, hazardous waste
Energy and Infrastructure	Electricity supply to Maharashtra grid	Nagpur, Chandrapur	Industrial emissions and environmental impacts

3.5. Climate Characteristics

Vidarbha experiences a tropical savanna climate characterized by extremely hot summers, with temperatures often exceeding 45°C in cities such as Nagpur, monsoon-dependent rainfall, prolonged dry seasons, and frequent drought conditions (IMD, 2020; Swain et al., 2017). The climatic conditions of the region are strongly influenced by seasonal monsoon variability, which significantly affects water availability, agriculture, and ecosystem stability. Recent climate observations have indicated a steady rise in average temperatures, an increased frequency and intensity of heat waves, and irregular rainfall patterns across the region (IPCC, 2022; Murari et al., 2015). These changing climatic trends have serious implications for environmental and public health, contributing to heat stress, water scarcity, reduced agricultural productivity, and ecosystem degradation. The increasing unpredictability of rainfall and prolonged dry periods also exacerbate the vulnerability of both rural and urban populations in Vidarbha.

3.6. Ecology and Biodiversity

The region hosts significant biodiversity due to extensive forest areas including:

- Tadoba-Andhari Tiger Reserve (Chandrapur)
- Navegaon National Park (Gondia)

- Melghat Tiger Reserve (Amravati) (Rodgers & Panwar, 1988; Forest Department Maharashtra, 2021)

Forests play an important role in maintaining ecological balance but are increasingly affected by mining expansion, industrial activities, and infrastructure development (Reddy et al., 2016).

4. Major Environmental Health Issues

The Vidarbha region faces a wide range of environmental health challenges arising from the combined effects of industrialization, mining activities, agricultural intensification, rapid urbanization, population growth, and climate variability (Kumar, 2019; Singh & Pandey, 2020). Anthropogenic pressures have significant implications for environmental quality and human health across the districts of the region. Major environmental health concerns include air pollution, water quality degradation, soil contamination, exposure to agricultural chemicals, and inadequate solid waste and biomedical waste management (CPCB, 2022; MoEFCC, 2016). In addition, mining operations, particularly coal and manganese extraction, contribute to environmental pollution and occupational health risks in several districts (Ghosh & Mukherjee, 2019). Climate-related factors such as rising temperatures, recurrent heat waves, and changing rainfall patterns further exacerbate environmental stress and increase the vulnerability of communities to heat-related illnesses and water scarcity (IPCC, 2022). Emerging issues such as microplastics contamination, groundwater depletion, indoor air pollution in rural households, vector-borne diseases influenced by environmental conditions, noise pollution, urban heat island effects, food contamination through environmental pollutants, deforestation and ecosystem degradation, and occupational exposures in informal sectors also contribute to the complex environmental health landscape of Vidarbha (UNEP, 2021; CGWB, 2022; WHO, 2020; FSI, 2021; ILO, 2019). The magnitude and nature of these issues vary across districts depending on dominant economic activities, land-use patterns, and local environmental conditions. Understanding these interconnected environmental pressures and their health implications is essential for developing effective monitoring, mitigation, and policy interventions aimed at protecting environmental quality and improving public health outcomes in the region.

4.1. Integrated Air–Water–Soil–Climate–Health Linkages

A critical advancement in this white paper is the **explicit mapping of integrated air–water–soil–climate–health linkages (Figure 3)**. For instance, air pollution from thermal power plants (Chandrapur, Nagpur) does not remain airborne. Particulate matter and heavy metals from thermal power plants deposit into soil and water bodies, creating multimedia exposure pathways. Simultaneously, climate-induced heat stress exacerbates the cardiovascular and respiratory impacts of poor air quality, creating a synergistic health burden.

1. **Air-to-Soil:** Fly ash from Koradi and Chandrapur power plants deposits heavy metals (arsenic, lead, mercury) onto agricultural soils. Likewise, airborne pollutants released from various industries adsorbed onto particulate matter and subsequently settle onto soil surfaces.
2. **Soil-to-Water:** Monsoon runoff transports these accumulated soil contaminants and agricultural pesticides into the Wainganga, Wardha and other river systems.
3. **Water-to-Health:** Elevated levels of metals (nickel, cadmium etc.) in lakes and other water systems, originating from industrial effluents and urban runoff, pose risks of neurological disorders and organ damage to dependent communities.
4. **Climate-Health:** Rising temperatures and heatwaves intensify the cardiorespiratory stress caused by poor air quality, while changing rainfall patterns alter vector-borne disease transmission (e.g., malaria, dengue).

The major environmental health issues identified in the region are summarized in **Table 3**, which outlines the affected districts, key scientific sources, environmental pathways, and potential health impacts.

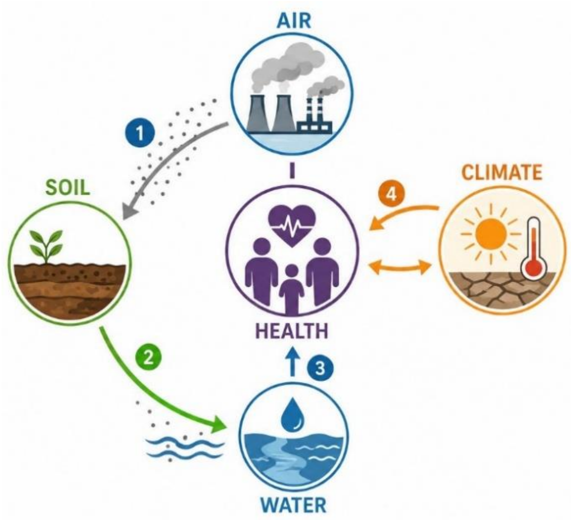

Figure 3: Integrated air–water–soil–climate–health linkages

Table 3. Major Environmental Health Issues in the Vidarbha Region

Environmental Issue	Major Districts Affected	Key Scientific Source / Driver	Environmental Pathway	Likely Human Health Impact	Key References
Air Pollution	Chandrapur, Nagpur, Wardha, Amravati	Coal-based thermal power plants, coal mining, vehicular emissions, industrial emissions, biomass burning	PM2.5, PM10, SO_2, NOx and fly ash exposure	COPD, asthma, cardiovascular diseases, lung cancer, reduced lung function	WHO (2021); CPCB (2022)
Water Quality Degradation	Nagpur, Chandrapur, Amravati, Yavatmal, Wardha	Untreated sewage, industrial effluents, mining drainage, agricultural runoff	Surface and groundwater contamination (BOD, COD, pathogens, heavy metals)	Gastrointestinal infections, cholera, typhoid, fluorosis, kidney disorders	CPCB (2022); WHO (2017)
Soil Contamination	Bhandara, Chandrapur, Nagpur, Yavatmal, Akola	Mining residues, industrial waste disposal, pesticide accumulation	Heavy metals and agrochemicals in soil and crop uptake	Neurological toxicity, kidney damage, chronic toxicological effects	FAO (2021); UNEP (2019)
Agricultural Chemical Exposure	Yavatmal, Akola, Amravati, Washim	Intensive cotton farming, high pesticide use	Occupational exposure through spraying, inhalation and residues in food	Acute pesticide poisoning, neurological disorders, endocrine disruption, cancer risk	WHO (2020); FAO (2021)
Solid Waste & Biomedical Waste	Nagpur, Amravati, Akola	Urban waste generation, landfill dumping, poor segregation, biomedical waste mismanagement	Leachate contamination, waste burning emissions, vector breeding	Respiratory illness, infections, vector-borne diseases, occupational hazards	MoEFCC (2016); WHO (2018)
Mining-related Environmental Issues	Chandrapur, Bhandara, Gadchiroli	Coal and manganese mining, mine waste	Dust emissions, heavy metal contamination, land degradation	Pneumoconiosis, neurological disorders, occupational injuries	ILO (2019); WHO (2017)
Climate Change & Heat Stress	Nagpur, Chandrapur, Yavatmal, Wardha	Rising temperatures, heat waves, declining vegetation cover	Extreme heat exposure, drought conditions	Heat stroke, dehydration, cardiovascular stress	IPCC (2022); WHO (2021)

Environmental Issue	Major Districts Affected	Key Scientific Source / Driver	Environmental Pathway	Likely Human Health Impact	Key References
Emerging Contaminants & Microplastics	Nagpur urban lakes, urban water bodies	Plastic waste fragmentation, wastewater discharge	Microplastics in water, aquatic organisms, food chain transfer	Oxidative stress, endocrine disruption, unknown long-term impacts	UNEP (2021)
Groundwater Depletion & Contamination	Yavatmal, Wardha, Akola, Washim, Buldhana	Over-extraction for irrigation, agrochemical runoff, geogenic contamination	Declining groundwater levels and nitrate/fluoride contamination	Fluorosis, methemoglobinemia, kidney disease	CGWB (2022); WHO (2017)
Indoor Air Pollution	Gadchiroli, Gondia, Bhandara, Yavatmal	Biomass fuel combustion in households	PM2.5, CO, PAHs exposure in indoor environment	Chronic respiratory disease, lung infections, adverse pregnancy outcomes	WHO (2021)
Vector-borne Diseases	Nagpur, Amravati, Gadchiroli, Gondia	Stagnant water, poor drainage, climatic variability	Mosquito breeding and disease transmission	Dengue, malaria, chikungunya outbreaks	WHO (2020)
Noise Pollution	Nagpur, Amravati	Traffic congestion, industrial activity, construction	Continuous exposure to high decibel levels	Hearing loss, stress, hypertension, sleep disorders	WHO (2018)
Urban Heat Island Effect	Nagpur, Amravati	Urbanization, reduced vegetation, built infrastructure	Increased urban surface temperature	Heat stress, cardiovascular strain	IPCC (2022)
Food Safety Contamination	Industrial and agricultural districts	Heavy metals, pesticides, contaminated irrigation water	Food chain transfer through crops and fish	Neurological disorders, endocrine disruption, cancer risks	FAO (2021)
Deforestation & Ecosystem Degradation	Gadchiroli, Chandrapur, Gondia	Mining expansion, timber extraction, land-use change	Loss of ecosystem services and biodiversity	Reduced food and water security, livelihood impacts	UNEP (2019)
Occupational Health Risks	Region-wide	Informal labor sectors, construction, waste picking	Dust, chemical exposure, unsafe working conditions	Respiratory disease, injuries, chemical poisoning	ILO (2019)

The environmental health challenges outlined in **Table 3** highlight the complex interactions between environmental degradation, economic activities, and human health in the Vidarbha region. Industrialization, mining, agricultural intensification, and rapid urbanization contribute significantly to environmental pollution and ecological stress (Kumar, 2019; Singh & Pandey, 2020). Addressing these issues requires integrated environmental monitoring, improved regulatory enforcement, sustainable resource management, and targeted public health interventions (WHO, 2018; Prüss-Ustün et al., 2016).

4.2. Economic Implications of Environmental Degradation and Health Burden

Environmental degradation in the Vidarbha region imposes substantial economic costs through increased healthcare expenditure, reduced labor productivity, agricultural losses, ecosystem degradation, and infrastructure stress. These impacts extend beyond environmental damage and directly influence regional economic sustainability and public welfare.

Air pollution, contaminated water resources, soil degradation, climate-related heat stress, and occupational exposure collectively contribute to both direct and indirect economic losses.

Major economic consequences include:

- Increased healthcare expenditure associated with respiratory, cardiovascular, neurological, and waterborne diseases (Landrigan et al., 2018; Cohen et al., 2017).
- Reduced labour productivity due to heat stress and occupational illness (ILO, 2019; IPCC, 2022).
- Agricultural losses resulting from declining soil quality and groundwater depletion.
- Economic burden associated with environmental remediation and pollution control infrastructure.
- Ecosystem service losses arising from deforestation, biodiversity decline, and water contamination.
- Environmental degradation in the Vidarbha region has substantial economic implications that extend beyond ecological deterioration and directly affect public health, agricultural productivity, industrial sustainability, ecosystem services, and regional socioeconomic development. Increasing levels of environmental pollution, climate stress, natural resource depletion, and ecosystem degradation contribute to both direct and indirect economic losses through rising healthcare expenditure, reduced labour productivity, declining agricultural output, infrastructure stress, and long-term

environmental remediation costs. These cumulative impacts impose a significant burden on regional development and disproportionately affect economically vulnerable populations dependent on agriculture, mining, and natural resource-based livelihoods.

- Air pollution associated with thermal power plants, mining operations, industrial emissions, vehicular traffic, and biomass burning in districts such as Chandrapur, Nagpur, and Amravati contributes significantly to increased healthcare expenditure resulting from respiratory diseases, cardiovascular disorders, asthma, chronic obstructive pulmonary disease (COPD), and occupational illnesses. Long-term exposure to particulate matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide, nitrogen oxides, and heavy metals increase hospital admissions, pharmaceutical dependency, and premature mortality (Cohen et al., 2017; WHO, 2021), thereby imposing substantial economic costs on both households and public healthcare systems. Reduced workforce productivity due to illness-related absenteeism and decreased labour efficiency further contributes to economic losses in industrial and urban sectors.
- Agricultural environmental degradation, particularly in Yavatmal, Akola, Washim, Wardha, and Buldhana districts, has serious economic consequences through declining soil fertility, groundwater depletion, pesticide dependency, and climate-induced agricultural instability. Excessive agrochemical uses and soil degradation increase input costs for farmers while simultaneously reducing long-term agricultural productivity and crop resilience. Groundwater contamination and water scarcity further elevate irrigation and water treatment expenses (CGWB, 2022; WHO, 2017), placing additional economic pressure on rural communities already vulnerable to climatic variability and agrarian distress. In addition, pesticide exposure among agricultural workers contributes to chronic health impacts, occupational toxicity, and loss of productive labour capacity.
- Water pollution resulting from untreated sewage discharge, industrial effluents, agricultural runoff, and solid waste mismanagement in urban and peri-urban regions such as Nagpur, Amravati, and Chandrapur significantly increases the economic burden associated with water treatment, sanitation infrastructure, and public health management. Contamination of rivers, lakes, and groundwater resources adversely affects drinking water security, fisheries, aquatic biodiversity, and ecosystem services. Increased prevalence of waterborne diseases such as gastrointestinal infections,

typhoid, and cholera further escalates healthcare expenditure and productivity losses among affected populations.

- Mining-related environmental degradation in districts such as Chandrapur, Bhandara, and Gadchiroli contributes to land degradation, deforestation, biodiversity loss, and heavy metal contamination of soil and water resources. These impacts reduce agricultural land productivity, increase ecological restoration costs, and adversely affect ecosystem-dependent livelihoods. Rehabilitation of abandoned mines, treatment of contaminated sites, and restoration of degraded landscapes require substantial long-term financial investment from both government agencies and industries. Occupational health impacts among mining workers, including respiratory diseases and heavy metal toxicity, further increase healthcare and compensation-related economic burdens.
- Climate change and associated environmental stressors are expected to amplify economic vulnerability across the Vidarbha region. Increasing heatwave frequency, erratic rainfall patterns, drought conditions, and groundwater stress contribute to reduced agricultural productivity, increased irrigation demand, and declining labour efficiency, particularly among outdoor workers and economically vulnerable populations. Urban heat island effects in rapidly urbanizing districts such as Nagpur increase electricity demand for cooling, elevate public health risks, and place additional stress on urban infrastructure systems. Climate-induced environmental stress therefore represents both a public health challenge and a significant economic risk for long-term regional development (IPCC, 2022; WHO, 2018).
- Improper solid waste management, biomedical waste disposal, and plastic pollution also contribute to increasing municipal expenditure associated with waste collection, landfill management, environmental remediation, and disease control measures. Urban local bodies face growing financial pressure in managing expanding waste streams generated by urbanization and industrial growth. Emerging contaminants such as microplastics, pharmaceutical residues, and persistent organic pollutants may additionally impose future economic burdens due to long-term ecological impacts and increasing environmental monitoring requirements (UNEP, 2021).
- The economic valuation of environmental degradation in Vidarbha should therefore incorporate direct healthcare costs, productivity losses, ecosystem service valuation, agricultural output decline, infrastructure stress, and climate adaptation expenditure.

Adoption of environmental economic assessment frameworks such as cost-of-illness analysis, ecosystem service valuation, Disability Adjusted Life Year (DALY)-based burden estimation, and climate vulnerability assessment can significantly strengthen environmental policy planning and investment prioritization.

Overall, the economic implications of environmental degradation in Vidarbha demonstrate that environmental protection and public health management should not be viewed solely as ecological concerns, but as critical components of sustainable economic development, climate resilience, and long-term regional stability. Strengthening pollution control measures, ecosystem restoration initiatives, sustainable agricultural practices, and climate adaptation strategies will therefore generate substantial economic co-benefits through improved public health, enhanced productivity, reduced environmental remediation costs, and increased ecological sustainability across the region (WHO, 2018; UNEP, 2019).

4.3. Risk Prioritization Matrix for Environmental Health Management

Environmental health risks in the Vidarbha region vary significantly in terms of exposure intensity, affected population, ecological sensitivity, public health burden, and governance urgency. While all identified environmental issues require attention, effective environmental management necessitates prioritization of interventions based on risk severity and regional vulnerability. A structured risk prioritization framework enables policymakers, regulatory agencies, and public health institutions to identify critical intervention areas, optimize resource allocation, and strengthen environmental governance. The prioritization integrates environmental exposure, disease burden, socioeconomic implications, reversibility, and implementation urgency.

Based on exposure severity, population vulnerability, disease burden, environmental persistence, and governance urgency, the identified environmental health concerns may be categorized into very high, high, moderate, and emerging priority levels for policy intervention and environmental management.

The district of Chandrapur falls within the very high priority and high vulnerability category due to the intense combined impacts of coal-based thermal power generation, mining activities, industrial emissions, and associated environmental contamination. Continuous exposure to particulate matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide, nitrogen oxides, fly ash, and heavy metals pose significant risks to public health and the environment. Fly ash from nearby thermal power plants contributes to the accumulation of toxic metals such as arsenic, lead, and mercury in surrounding agricultural soils, while industrial air pollutants adsorbed onto particulate matter further deteriorate soil and air quality. These conditions substantially increase the incidence of respiratory diseases, cardiovascular disorders, occupational illnesses, and ecological degradation.

Nagpur falls within the moderate to high vulnerability category. Although the district experiences environmental stress from vehicular emissions, industrial activities, and urbanization, the impacts of thermal power plants and mining activities are comparatively lower because major coal mines and large thermal power facilities are located farther from the urban core. Nevertheless, increasing urban expansion, traffic-related air pollution, particulate matter exposure, and urban heat stress continue to contribute to environmental degradation and associated public health concerns.

The agricultural districts of Yavatmal, Akola, and Washim represent High Priority environmental health zones because of intensive pesticide application, fertilizer overuse, groundwater contamination, and occupational exposure among farming communities. Vulnerability in these districts is elevated due to socioeconomic dependence on agriculture, inadequate awareness regarding safe agrochemical handling, and limited healthcare accessibility in rural areas. Long-term exposure to pesticides and contaminated groundwater may contribute to neurological disorders, endocrine disruption, kidney diseases, and chronic toxicological impacts.

Mining-dominated districts such as Bhandara, Chandrapur, and Gadchiroli also fall within the High Vulnerability and High Priority category owing to coal, manganese, and iron ore extraction activities. Environmental pathways associated with mining include dust emissions, heavy metal contamination of soil and water resources, land degradation, and ecosystem disturbance. Workers and nearby communities are particularly vulnerable to respiratory illnesses, neurological toxicity, and occupational hazards arising from prolonged exposure to mining pollutants.

Urban wastewater pollution, inadequate sewage treatment, and solid waste mismanagement in Nagpur, Amravati, and Akola constitute Moderate to High Priority environmental concerns due to their implications for water quality deterioration, vector-borne diseases, and urban environmental degradation. In addition, rapidly increasing temperatures, declining vegetation cover, and urban heat island effects in Nagpur and Chandrapur have emerged as High Priority climate-related environmental health risks, particularly affecting elderly populations, outdoor workers, and socioeconomically vulnerable communities.

Emerging contaminants such as microplastics, pharmaceutical residues, biomedical waste pollutants, and persistent organic contaminants currently fall within the Emerging Risk and Moderate Vulnerability category due to limited monitoring data and incomplete understanding of long-term ecological and human health impacts. However, their increasing prevalence in urban water bodies and waste streams indicates the need for precautionary monitoring and future risk assessment frameworks.

Overall, the prioritization of environmental health risks in Vidarbha demonstrates that industrial air pollution, agricultural chemical exposure, groundwater contamination, mining-related pollution, and climate-induced heat stress represent the most critical environmental health challenges requiring immediate regulatory intervention, enhanced environmental monitoring, and integrated public health response mechanisms. Adoption of a vulnerability-based and priority-driven governance framework will therefore be essential for strengthening environmental resilience, guiding district-level interventions, improving healthcare preparedness, and ensuring sustainable environmental management across the Vidarbha region.

4.4. Environmental Health Risk Mapping and Hotspot Identification

The district wise pollution hotspots summarized in **Table 4** indicate that industrial development, mining activities, thermal power generation, and intensive agriculture are the primary drivers of environmental pollution in the Vidarbha region**.** Districts such as Chandrapur and Nagpur represent major industrial and energy production centers**,** while Yavatmal, Akola, and Amravati are associated with agricultural chemical pressures**.** In addition, river systems including Wainganga, Wardha, Penganga, and Kanhan serve as important environmental receptors**,** accumulating contaminants from multiple anthropogenic sources. Identifying these hotspots is essential for prioritizing environmental monitoring, pollution mitigation, and public health interventions across the region.

Table 4. District wise Environmental Pollution Hotspots in the Vidarbha Region

District / Area	Major Pollution Source	Key Activities / Facilities
Chandrapur	Coal mining and thermal power generation	Chandrapur Super Thermal Power Station, WCL coal mines
Nagpur (Koradi–Khaparkheda belt)	Coal-based power plants	Koradi Thermal Power Station, Khaparkheda Thermal Power Station
Nagpur Industrial Area	Industrial emissions and wastewater	Butibori MIDC Industrial Area, Hingna Industrial Estate
Bhandara	Manganese mining	Tumsar and surrounding manganese mining belts
Gadchiroli	Iron ore and mineral extraction	Mining operations and forest resource exploitation
Yavatmal	Intensive agriculture	Cotton cultivation with high pesticide use
Akola	Agricultural intensification	Cotton and soybean cultivation
Amravati	Agricultural chemical use	Cotton, pulses, and cereal cultivation
Urban Nagpur	Urban pollution	Vehicular emissions, municipal waste, construction activities
Wainganga River Basin	Industrial discharge and agricultural runoff	Industrial areas and agricultural fields along river
Wardha River Basin	Industrial and mining runoff	Mining belts and agricultural landscapes
Penganga River Basin	Agricultural runoff	Agricultural activities along river basin
Kanhan River Basin	Industrial and urban wastewater	Industrial discharge near Nagpur region

Moving beyond district-level analysis, this paper advocates for high-resolution environmental health risk mapping. By integrating geospatial data on pollution sources (industry, mining, agriculture), environmental monitoring data (air, water, soil), and public health surveillance data (disease prevalence), specific pollution hotspots can be identified and correlated with health outcome hotspots.

Current evidence indicates primary hotspots in:

a) Chandrapur – Coal Power and Industrial Pollution Hotspot

Chandrapur is recognized as one of the most critically polluted districts in Maharashtra due to the concentration of coal-based thermal power plants, cement industries, coal mining operations, and associated industrial activities. Elevated levels of $PM_{2.5}$, PM_{10}, SO_2, NO_x, and fly ash have been reported from the Chandrapur industrial region, contributing to severe air quality deterioration and associated respiratory and cardiovascular health risks (Cummiskey et al., 2019; Guttikunda & Jawahar, 2014). Fly ash deposition from thermal power plants has also been linked to heavy metal accumulation in nearby agricultural soils, particularly arsenic, lead, mercury, iron, and manganese (Raut et al., 2012). The district's environmental vulnerability is further intensified by open-cast coal mining, transportation dust, and ash pond contamination affecting surrounding ecosystems and rural settlements.

b) Nagpur – Urban Air Pollution and Contaminated Urban Lakes

Nagpur is a major urban environmental hotspot in Vidarbha due to rapid urbanization, vehicular emissions, industrial growth, sewage discharge, and degradation of urban water bodies. Studies on Ambazari, Futala, and Gandhisagar lakes documented elevated concentrations of heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), iron (Fe), and manganese (Mn) in water, sediments, and fish tissues, often exceeding permissible BIS and WHO limits (Giripunje et al., 2014). Biomonitoring studies also identified significant organic pollution, eutrophication, and ecological stress in Nagpur urban lakes (Paydalwar & Dhadse, 2022). Increasing microplastic contamination in surface and groundwater systems of Nagpur has emerged as an additional environmental concern (Lade & Gogle, 2025). Vehicular emissions and urban heat island effects further contribute to chronic exposure to particulate pollution and associated respiratory illnesses.

c) Yavatmal – Akola Cotton Belt Agrochemical Hotspot

The cotton-growing districts of Yavatmal and Akola represent one of the most pesticide-intensive agricultural zones in India. Extensive use of organophosphate and synthetic pyrethroid pesticides has resulted in contamination of agricultural soils and irrigation water, along with repeated pesticide poisoning incidents among farmers and agricultural workers (Kishi et al., 2017; PAN India, 2024). Occupational exposure during pesticide spraying has been associated with neurological disorders, endocrine disruption, reproductive toxicity, dermatological problems, and respiratory illnesses (Singh et al., 2011). Unsafe pesticide handling practices, lack of personal protective equipment, and improper disposal of agrochemical waste remain major contributors to environmental and public health risks in the Vidarbha cotton belt (ILO, 2019; WHO, 2020).

d) Bhandara and Gadchiroli – Mining and Metal Dust Exposure Hotspot

Bhandara and Gadchiroli districts are environmentally sensitive mining belts characterized by manganese and iron ore extraction activities. Mining, crushing, ore transportation, and associated dust emissions generate high levels of metal-rich suspended particulate matter. Chronic exposure to manganese-bearing dust has been associated with pulmonary inflammation, chronic bronchitis, neurological impairment, and occupational respiratory diseases (Aschner et al., 2009; Bowler et al., 2006). Open-cast mining activities in Gadchiroli also contribute to deforestation, soil erosion, groundwater contamination, and ecological fragmentation in forest-dominated landscapes.

e) Amravati and Wardha – Biomass Burning and Groundwater Stress

Amravati and Wardha districts face increasing environmental stress associated with crop residue burning, biomass combustion, dust pollution, and fertilizer-intensive agriculture. Seasonal agricultural burning contributes significantly to $PM_{2.5}$ loading and regional haze episodes (Jethva et al., 2019). Groundwater systems in intensively cultivated regions are increasingly vulnerable to nitrate contamination and agrochemical leaching, posing risks to rural drinking water quality and long-term ecological sustainability (CGWB, 2022; WHO, 2017).

5. Vulnerable Populations

Environmental health risks in the Vidarbha region disproportionately affect vulnerable and marginalized populations due to socioeconomic limitations, occupational exposure, inadequate infrastructure, and restricted access to healthcare facilities. These groups are often more susceptible to adverse health outcomes because of prolonged exposure to environmental pollutants, poor nutrition, unsafe living conditions, and limited adaptive capacity to environmental stressors.

5.1 Children

Children are among the most vulnerable populations affected by environmental pollution and climate-related risks (Landrigan et al., 2018; WHO, 2018). Exposure to contaminated air, unsafe drinking water, heavy metals, pesticides, and poor sanitation can adversely affect physical growth, cognitive development, respiratory health, and immune function. In rural and industrial areas of Vidarbha, children are frequently exposed to indoor and outdoor air pollution, contaminated groundwater, and agricultural chemicals. Malnutrition and inadequate healthcare further increase their vulnerability to environmentally induced diseases such as respiratory infections, diarrheal illnesses, developmental disorders, and vector-borne diseases (WHO, 2020; Prüss-Ustün et al., 2016).

5.2 Elderly Individuals

Elderly populations are highly sensitive to environmental stressors due to age-related physiological decline and pre-existing chronic diseases (WHO, 2018). Increasing temperatures, poor air quality, contaminated water sources, and extreme weather events can aggravate cardiovascular diseases, respiratory disorders, heat stress, and mobility-related challenges among older adults. In many parts of Vidarbha, elderly individuals residing in rural or economically weaker communities may face inadequate healthcare access, social isolation, and insufficient adaptive infrastructure, thereby increasing their environmental health risks.

5.3 Miners and Industrial Workers

Mining and industrial workers in the Vidarbha region are exposed to a variety of occupational and environmental hazards associated with coal mining, thermal power plants, cement industries, metal processing, and manufacturing activities (ILO, 2019). Continuous exposure to particulate matter, toxic gases, silica dust, heavy metals, excessive heat, noise pollution, and hazardous chemicals may result in respiratory illnesses, occupational lung diseases, skin disorders, hearing impairment, and cardiovascular complications. Workers employed in informal or contract-based sectors often lack adequate protective equipment, occupational safety measures, and regular health monitoring, further increasing their health vulnerability (ILO, 2019).

5.4 Farmers Exposed to Pesticides

Agricultural workers and farmers are particularly vulnerable due to extensive exposure to pesticides, fertilizers, contaminated irrigation water, and climatic uncertainties (Narayanamoorthy, 2019). Vidarbha is predominantly an agrarian region where intensive farming practices and pesticide usage have increased over time to improve crop productivity. Improper handling, storage, and application of agrochemicals can lead to acute poisoning, neurological disorders, endocrine disruption, reproductive health impacts, and chronic illnesses among farmers. In addition, recurrent droughts, crop failures, and economic distress further compound mental health concerns, including anxiety, depression, and psychological stress within farming communities.

5.5 Informal Waste Workers

Informal waste workers involved in waste collection, segregation, recycling, and disposal are routinely exposed to hazardous environmental conditions (Wilson et al., 2018). These workers frequently come into contact with biomedical waste, toxic chemicals, plastics, electronic waste, pathogens, and contaminated water without adequate protective measures. Exposure to smoke from waste burning, landfill gases, and infectious materials can result in respiratory diseases, skin infections, gastrointestinal disorders, musculoskeletal injuries, and long-term occupational health complications. Poor socioeconomic conditions and lack of social security further increase their vulnerability.

5.6 Tribal Communities in Forest Districts

Tribal populations residing in forested and remote districts of Vidarbha often depend directly on natural ecosystems for their livelihoods, food security, and traditional healthcare practices (Reddy et al., 2016). Environmental degradation, deforestation, mining expansion, biodiversity loss, and changing climatic conditions can severely impact their access to clean water, forest resources, and traditional means of subsistence. These communities frequently experience limited healthcare infrastructure, malnutrition, inadequate sanitation, and poor connectivity, making them highly susceptible to communicable diseases, vector-borne illnesses, and environmental health stressors. Socioeconomic marginalization and displacement due to developmental activities further intensify their vulnerability.

Overall, the environmental health burden in Vidarbha is unevenly distributed, with vulnerable populations facing disproportionately higher exposure to environmental hazards and reduced access to preventive and curative healthcare services. Addressing these disparities requires targeted policy interventions, improved environmental governance, occupational safety measures, healthcare accessibility, community awareness programs, and inclusive sustainable development strategies tailored to the needs of these high-risk groups.

6. Case study: LULC Analysis of Vidarbha Region for the year 2017 and 2024

LULC analysis carried out at CSIR-NEERI summarize the Land Use Land Cover (LULC) analysis of the Vidarbha region for the years 2017 and 2024, highlighting the changes observed in various land cover classes during the study period (**Table 5, Figure 4, and Figure 5**). The analysis indicates notable variations in water bodies, tree cover, crop area, built-up land, barren land, flooded vegetation, and rangeland due to natural as well as anthropogenic factors.

The area under water bodies increased from 1371.20 sq. km (1.46%) in 2017 to 1754.91 sq. km (1.87%) in 2024, showing a net increase of 383.71 sq. km (0.41%). This increase can be attributed to various water conservation and watershed management initiatives implemented by the Government of Maharashtra. Schemes such as Jalyukt Shivar Abhiyan**,** Magel Tyala Shettale Yojana**,** Atal Bhujal Yojana, construction of farm ponds, check dams, nala deepening, and desiltation activities have significantly improved water storage capacity and groundwater recharge across the region. The tree canopy area decreased from 18610.60 sq. km (19.86%) in 2017 to 15251.39 sq. km (16.27%) in 2024, indicating a reduction of 3359.21 sq. km (3.58%). The decline in tree cover may be associated with increasing industrialization, urban expansion, infrastructure development, mining activities, and conversion of vegetated land into agricultural and built-up areas. Continuous anthropogenic pressure has contributed to the reduction in natural vegetation across several parts of the Vidarbha region.

The crop area increased from 52228.94 sq. km (55.73%) in 2017 to 54100.62 sq. km (57.73%) in 2024, representing an increase of 1871.68 sq. km (2.00%). The increase in agricultural land may be attributed to rising food demand, improved irrigation facilities, enhanced water availability due to conservation measures, and expansion of cultivated land for agricultural production. The built-up area increased significantly from 2174.22 sq. km (2.32%) in 2017 **to** 2899.65 sq. km (3.09%) in 2024, with a net increase of 725.43 sq. km (0.77%). This growth reflects rapid industrialization, urbanization, population growth, and expansion of residential, commercial, and transportation infrastructure within the region.

In addition, rangeland increased by 442.68 sq. km (0.47%), while barren land decreased by 59.80 sq. km (0.06%), possibly due to conversion into agricultural or developmental land uses. Flooded vegetation showed a marginal decrease of 6.03 sq. km (0.01%) during the study period. Overall, the LULC analysis demonstrates the dynamic land cover changes occurring in the Vidarbha region as a result of developmental activities, agricultural expansion, and implementation of water resource management measures.

Table 5: Summary of LULC Analysis for the year 2017 and 2024

LULC Classes		LULC 2024		LULC 2017		Change	
		Area Sq. Km	**%**	**Area Sq. Km**	**%**	**Area Sq. Km**	**%**
1	Water	1754.91	1.87	1371.20	1.46	383.71	0.41
2	Trees	15251.39	16.27	18610.60	19.86	-3359.21	-3.58
3	Flooded vegetation	69.03	0.07	75.06	0.08	-6.03	-0.01
4	Crops	54100.62	57.73	52228.94	55.73	1871.68	2.00
5	Built-up	2899.65	3.09	2174.22	2.32	725.43	0.77
6	Barren	73.09	0.08	132.89	0.14	-59.80	-0.06
9	Rangeland	19571.23	20.88	19128.56	20.41	442.68	0.47
	Total Area	**93719.93**					

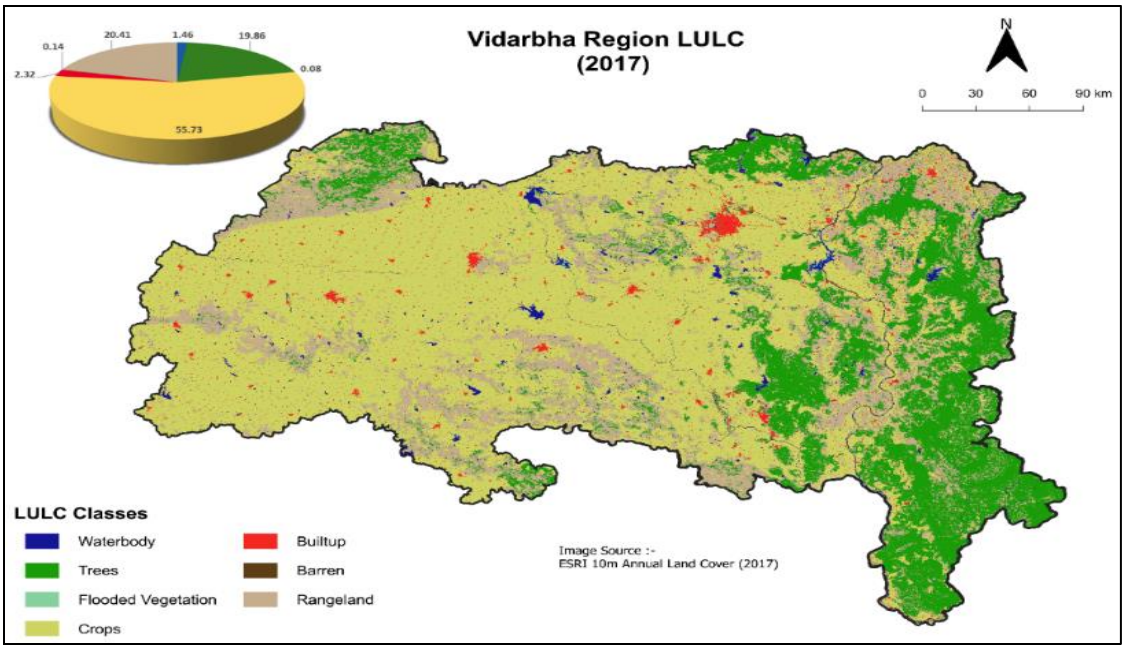

Figure 4: LULC of 2017 for Vidarbha Region

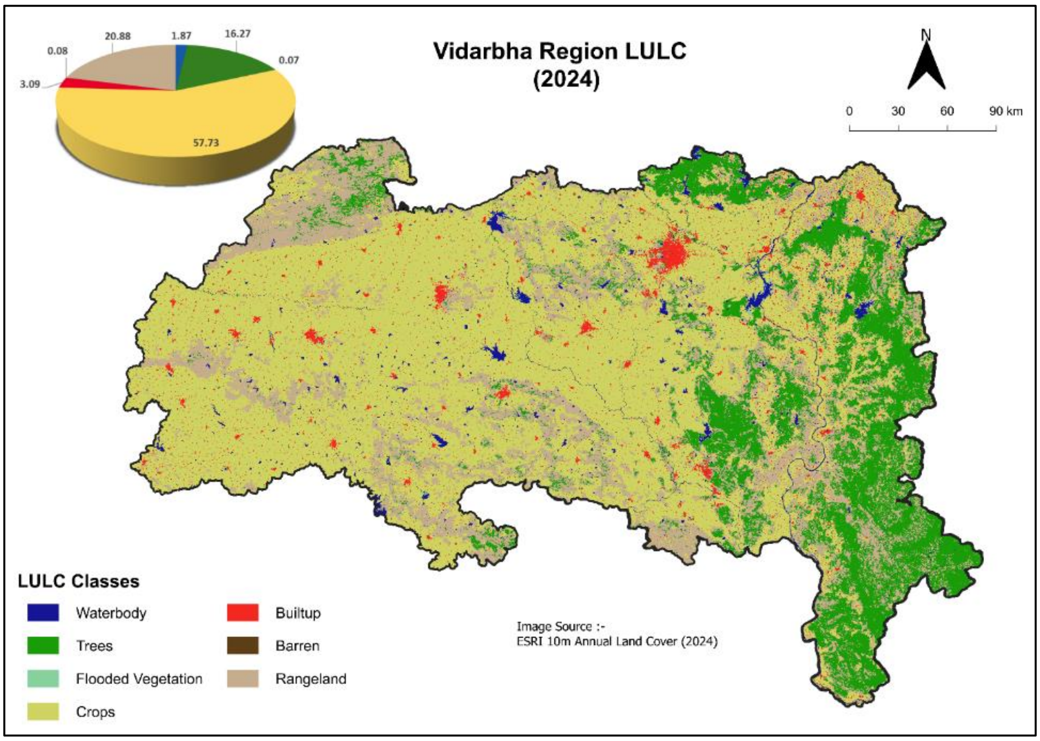

Figure 5: LULC of 2024 for Vidarbha Region

Overall, the LULC analysis of the Vidarbha region highlights substantial landscape transformations driven by rapid urbanization, industrialization, agricultural expansion, and implementation of water conservation initiatives. These changes not only influence land resource distribution and ecological balance but also have significant implications for environmental quality, biodiversity, natural resource sustainability, and human health (IPCC, 2022; UNEP, 2019). Increasing built-up areas, reduction in tree canopy, intensified agricultural activities, and changing hydrological conditions may contribute to issues such as air and water pollution, habitat degradation, soil stress, and climate-related vulnerabilities (IPCC, 2022; FSI, 2021). Therefore, understanding these dynamic land use changes is essential for developing sustainable environmental management strategies and evidence-based policy interventions (WHO, 2018; UNEP, 2019).

7. Research Approach and Methodology

Addressing environmental health challenges in the Vidarbha region requires an integrated and interdisciplinary research framework that combines environmental monitoring, epidemiological investigations, geospatial analysis, ecological assessments, technological and ecological interventions (Nieuwenhuijsen, 2015; Jerrett et al., 2011). Environmental issues such as air pollution, water contamination, soil degradation, pesticide exposure, mining impacts, and climate-related **stressors** are interconnected and require systematic scientific investigation.

7.1. Strengthening the Role of Scientific Institutions: The CSIR-NEERI Imperative

A cornerstone of this framework is the strengthening of scientific institutions as active partners in environmental governance, public health planning, and evidence-based policy implementation rather than functioning solely as research organizations. In this context, CSIR-NEERI, headquartered in Nagpur, is uniquely positioned to lead integrated environmental health surveillance and risk governance initiatives across the Vidarbha region.

Given the increasing environmental burden associated with thermal power generation, mining, industrialization, pesticide-intensive agriculture, urban expansion, climate variability, and deteriorating water quality, CSIR-NEERI’s multidisciplinary scientific infrastructure can serve as the backbone for a regional Environmental Health Risk Assessment and Spatial Decision Support System for Vidarbha. Its long-standing expertise in environmental engineering, pollution assessment, epidemiology, remote sensing, biotechnology, ecological restoration, and climate resilience makes it one of the most strategically important scientific institutions in central India. NEERI's existing and potential contributions are critical for the **Spatial Risk Atlas and monitoring dashboard concept**, providing the scientific rigor and real-time data needed for evidence-based decision-making.

CSIR-NEERI's Pivotal Role in Vidarbha:

a) Environmental Monitoring & Risk Assessment:

CSIR-NEERI has extensive expertise in comprehensive monitoring of air, water, soil, industrial emissions, hazardous waste, and environmental noise. The institute has supported multiple environmental impact assessments and pollution mitigation studies across Maharashtra, particularly in industrial and mining regions of Vidarbha. NEERI was entrusted by the Maharashtra Pollution Control Board (MPCB) to conduct environmental noise mapping in 27 cities, including Nagpur, Chandrapur, Amravati, and Akola, for identifying high-risk noise zones and designing mitigation strategies. Such geospatial environmental mapping frameworks can be expanded into integrated district-level environmental vulnerability indices.

Scientific investigations conducted by NEERI and collaborating institutions have also documented heavy metal contamination, eutrophication, and ecological degradation in urban lakes such as Ambazari, Futala, Gandhisagar, and Sakkardara lakes in Nagpur. Elevated concentrations of nickel, cadmium, lead, manganese, and iron in water, sediments, and fish tissues indicate serious anthropogenic pressure arising from sewage discharge, urban runoff, idol immersion, and industrial contamination (Giripunje et al., 2014; Paydalwar & Dhadse, 2022). These studies provide a strong scientific basis for targeted remediation and ecological restoration programs.

In Vidarbha, NEERI can further strengthen:

- Continuous ambient air quality monitoring,
- Fly ash characterization and utilization studies,
- Source apportionment of $PM_{2.5}$ and PM_{10},
- Human exposure assessment studies,
- Biomonitoring of heavy metals and persistent pollutants,
- Risk assessment for coal mining and thermal power clusters.

b) One Health, Environmental Epidemiology, Wastewater Surveillance, and Genomic Monitoring:

CSIR-NEERI has played a pioneering role in environmental health research, occupational toxicology, environmental epidemiology, wastewater surveillance, and public health risk assessment across the Vidarbha region. The institute has generated region-specific scientific evidence linking mining exposure, industrial pollution, contaminated groundwater, urban environmental degradation, and emerging infectious diseases with adverse human health outcomes, thereby providing a strong scientific foundation for environmental health governance and One Health-based planning.

In the coal mining and industrial belts of Chandrapur and Nagpur, CSIR-NEERI conducted major occupational exposure and epidemiological studies among coal miners and industrial workers exposed to coal dust, silica, fly ash, diesel exhaust, and respirable suspended particulate matter. CSIR-NEERI also examined diesel particulate exposure in mining operations, identifying diesel exhaust aerosols and ultrafine particulate matter as significant occupational hazards in underground and open-cast coal mining environments.

The institute additionally carried out toxicological and occupational health studies in manganese mining and ore-processing regions near Ramtek and eastern Vidarbha. Investigations led by CSIR-NEERI scientists demonstrated that chronic exposure to manganese-rich dust was associated with neurological impairment, pulmonary dysfunction, cognitive effects, and occupational respiratory disorders among mining workers and nearby populations. These studies contributed significantly to understanding the environmental neurotoxicity associated with metal mining activities in central India. CSIR-NEERI also conducted important epidemiological investigations in fluoride-affected villages of Nagpur district and adjoining Vidarbha regions, where elevated fluoride concentrations in groundwater were associated with dental fluorosis, skeletal fluorosis, musculoskeletal disorders, chronic pain, and impaired mobility in exposed populations. These investigations supported the development of defluoridation technologies, groundwater quality assessment frameworks, and rural drinking water mitigation strategies for vulnerable communities.

In urban ecosystems, CSIR-NEERI contributed substantially to environmental health risk assessment studies involving heavy metal contamination, eutrophication, and ecological degradation of Nagpur’s urban lakes including Ambazari, Futala, Gandhisagar, and Sakkardara. Elevated concentrations of lead, cadmium, nickel, manganese, and other contaminants in water, sediments, and fish tissues indicated serious anthropogenic pressure arising from sewage discharge, urban runoff, industrial contamination, and idol immersion activities.

During the COVID-19 pandemic, CSIR-NEERI emerged as a national leader in wastewater-based epidemiology and environmental genomic surveillance. The institute pioneered surveillance of SARS-CoV-2 genetic material in sewage and wastewater systems as an early warning tool for monitoring community transmission dynamics and outbreak prediction in urban populations. These studies demonstrated the effectiveness of wastewater surveillance for population-scale infectious disease monitoring and public health preparedness. CSIR-NEERI was subsequently recognized by the World Health Organization (WHO) as a collaborating reference laboratory for wastewater and environmental surveillance of emerging viral variants.

The institute's ongoing work on wastewater microbiology, antimicrobial resistance (AMR), pathogen genomics, and environmental surveillance further strengthens its role in advancing an integrated One Health framework linking human health, environmental quality, microbial ecology, and climate resilience. Current scientific initiatives involving wastewater surveillance, pathogen tracking, and environmental microbiome analysis provide important opportunities for establishing a regional Environmental Health and One Health Surveillance Network for Vidarbha integrating environmental monitoring, epidemiology, toxicology, genomic surveillance, GIS-based exposure mapping, and climate-health vulnerability assessment.

c) **Technological Innovation:**

CSIR-NEERI has developed several pollution control and environmental remediation technologies with direct applicability to Vidarbha's environmental challenges. These include:

- Flue gas desulfurization systems for thermal power plants,
- Industrial wastewater treatment technologies,
- Bioremediation and phytoremediation approaches,
- Constructed wetlands for sewage treatment,
- Hazardous waste stabilization methods,
- Air pollution control systems,
- Biofilters and decentralized sanitation systems,
- Lake restoration and sediment remediation technologies.

These technologies can play a critical role in:

- Restoration of polluted urban lakes in Nagpur,
- Mitigation of fly ash contamination in Chandrapur,
- Treatment of mining-affected wastewater in Gadchiroli and Bhandara,
- Sustainable wastewater reuse in water-stressed districts,
- Reduction of industrial emissions across the Nagpur–Chandrapur industrial corridor.

d) ***Climate* Change, Urban Heat Islands, and Spatial Analytics:**

Vidarbha is increasingly vulnerable to climate-linked stressors including heat waves, droughts, groundwater depletion, forest fires, and urban heat island effects. NEERI's expertise in remote sensing, GIS-based spatial analysis, atmospheric sciences, and environmental modelling can support:

- Climate vulnerability assessments,

- Urban heat island mapping,
- Aerosol transport modelling,
- Land use and land cover (LULC) change analysis,
- Flood and drought risk assessments,
- Carbon emission inventories,
- Ecosystem service mapping.

Such studies are particularly relevant for rapidly urbanizing districts like Nagpur, industrial regions such as Chandrapur, and ecologically sensitive forest landscapes in Gadchiroli.

e) GIS-Based Environmental Health Monitoring Dashboard and Spatial Risk Atlas:

CSIR-NEERI can lead the development of a real-time, GIS-enabled Environmental Health Monitoring Dashboard for Vidarbha integrating multi-sectoral datasets into a unified decision support platform. This system could transform environmental governance from reactive monitoring to predictive and preventive management.

Proposed Components of the Dashboard

- Real-Time Environmental Data
- CPCB and MPCB air quality monitoring stations,
- Water quality sensors in rivers, reservoirs, and lakes,
- Industrial stack emission data,
- Noise monitoring networks,
- Meteorological observations,
- Groundwater contamination indicators.

Satellite and Remote Sensing Inputs

- Land use and land cover (LULC) dynamics,
- Aerosol optical depth and dust transport,
- Thermal mapping and heat island analysis,
- Forest degradation and mining expansion,
- Surface water quality indicators,
- Crop residue burning hotspots.

Health Surveillance Integration

- District hospital admission data,
- Respiratory and cardiovascular disease incidence,

- Water-borne and vector-borne disease records,
- Occupational health datasets,
- Cancer registry information,
- Toxic exposure and biomonitoring datasets.

Spatial Risk Atlas Layers

- Pollution source inventories,
- Exposure pathways,
- Vulnerable population distribution,
- Tribal and socio-economically sensitive communities,
- Industrial accident risk zones,
- Climate vulnerability layers,
- Environmental justice indicators.

The integration of these datasets would enable generation of dynamic district-level environmental health risk scores and predictive alerts allowing agencies like MPCB, public health agencies and district collectors to issue targeted health advisories and deploy mitigation resources efficiently. for policymakers, district administrations, and public health agencies.

7.2. Role of other Prime Institutions in Environmental Health Research and Future Collaboration in Vidarbha

Apart from CSIR-NEERI, other prime institutions in Vidarbha can significantly contribute to develop an integrated regional Environmental Health and One Health framework. For example, All India Institute of Medical Sciences (AIIMS), Nagpur has emerging capabilities in public health, environmental epidemiology, clinical toxicology, occupational health, infectious diseases, and advanced biomedical research. AIIMS Nagpur can contribute to hospital-based environmental disease surveillance, biomarker studies, exposure-health linkage assessment, and One Health initiatives. Similarly, Mahatma Gandhi Institute of Medical Sciences (MGIMS), Wardha has long-standing expertise in rural health, community medicine, public health outreach, environmental sanitation, nutrition, and epidemiological research. MGIMS can play an important role in rural environmental health assessment, pesticide exposure studies, groundwater-related health investigations, and community-based intervention programs in vulnerable agricultural districts.

Government Medical College and Hospital (GMCH), Nagpur has contributed through clinical services, disease surveillance, occupational and respiratory health management, and public health investigations. GMCH Nagpur can support environmental exposure-linked disease registries, heat stress surveillance, respiratory disease monitoring, and emergency response during pollution episodes. In addition, Visvesvaraya National Institute of Technology (VNIT), Nagpur can contribute through research in environmental engineering, remote sensing, GIS, air pollution modelling, water resource management, and sustainable urban infrastructure. VNIT can support technological innovation, environmental modelling, climate resilience studies, and smart environmental monitoring systems.

ICAR-Central Institute for Cotton Research (CICR), Nagpur can contribute to sustainable agriculture, pesticide risk reduction, soil health management, and climate-resilient farming practices, particularly in pesticide-intensive cotton-growing districts such as Yavatmal and Akola. Regional University such as Rashtrasant Tukadoji Maharaj Nagpur University (RTMNU) can strengthen interdisciplinary environmental health education, toxicology, biodiversity assessment, microbiology, environmental biotechnology, and public awareness initiatives.

Together, these institutions can establish a coordinated regional network for environmental monitoring, health surveillance, environmental epidemiology, climate-health assessment, occupational safety, wastewater surveillance, and policy support for sustainable environmental health governance in Vidarbha.

7. 3 Integrated and Interdisciplinary Research Framework

7.3.1 Environmental Monitoring, Epidemiological Investigations, Geospatial Analysis, Ecological Assessments

In addition to environmental monitoring, the framework incorporates epidemiological investigations to evaluate disease prevalence, exposure-response relationships, occupational health risks, and vulnerable population groups across urban and rural districts of Vidarbha. Geospatial analysis using GIS and remote sensing tools is integrated to map pollution hotspots, land-use change, exposure pathways, and environmental risk zones associated with mining, industrialization, urbanization, and agricultural intensification. Ecological assessments including biomonitoring, biodiversity evaluation, aquatic toxicity studies, and ecosystem health assessment are used to understand the impacts of pollutants on terrestrial and aquatic ecosystems. The methodology also emphasizes technological interventions such as continuous environmental monitoring systems, remote sensing platforms, pollution control technologies, environmental health dashboards, and decision-support systems to strengthen environmental governance, risk mitigation, and sustainable resource management in the region.

The research methodology adopted for evaluating environmental health issues in Vidarbha integrates field monitoring, laboratory analysis, spatial mapping, health surveillance, and community-based studies to identify pollution sources, exposure pathways, and vulnerable populations.

a) Monitoring, Evaluation, and Environmental Health Indicators:

Effective environmental governance requires continuous monitoring, periodic evaluation, and measurable indicators that link environmental quality with human health outcomes (**Table 6**). Monitoring and evaluation systems are essential for assessing policy effectiveness, identifying emerging risks, improving accountability, and enabling evidence-based decision-making.

An integrated Environmental Health Monitoring Framework is therefore proposed for Vidarbha, combining environmental indicators, epidemiological surveillance, governance metrics, and climate resilience indicators. Effective environmental health governance in the Vidarbha region requires a robust monitoring and evaluation framework capable of integrating environmental quality assessment, public health surveillance, climate vulnerability analysis, and regulatory compliance mechanisms. Continuous environmental monitoring combined with periodic evaluation of health and ecological indicators is essential for identifying emerging risks, assessing intervention effectiveness, strengthening institutional accountability, and supporting evidence-based policymaking.

The proposed monitoring framework should incorporate sector-specific indicators across air quality, water resources, soil health, waste management, ecosystem integrity, occupational exposure, and climate-related environmental stressors. In the air quality sector, continuous monitoring of particulate matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide (SO_2), nitrogen oxides (NOx), ozone, and Air Quality Index (AQI) should be conducted in industrial and urban districts such as Chandrapur, Nagpur, and Amravati through Continuous Ambient Air Quality Monitoring Stations (CAAQMS) operated by the Central Pollution Control Board (CPCB) and Maharashtra Pollution Control Board (MPCB). Seasonal monitoring of fly ash deposition and industrial emissions should also be integrated into regional environmental surveillance systems.

Within the water quality sector, monthly monitoring of biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen, microbial contamination, pesticide residues, fluoride, nitrates, and heavy metals should be carried out in rivers, lakes, groundwater sources, and drinking water systems across districts such as Nagpur, Wardha, Akola, Yavatmal, and Bhandara. These monitoring activities should be coordinated by the MPCB, Water Resources Department, Public Health Engineering Department, and local municipal authorities. Periodic assessment of eutrophication levels and aquatic ecosystem health should additionally be incorporated for ecologically sensitive wetlands and reservoirs.

Soil health monitoring should be conducted on a seasonal basis in agriculturally intensive districts including Yavatmal, Akola, Washim, Amravati, and Buldhana to evaluate pesticide residues, heavy metal accumulation, nutrient imbalance, soil organic carbon levels, and salinity trends. The Agriculture Department, State Soil Testing Laboratories, and agricultural universities should jointly support this monitoring framework to assess the long-term sustainability of agricultural practices and environmental contamination pathways.

Climate-related environmental indicators should include seasonal assessment of heatwave frequency, land surface temperature anomalies, drought occurrence, rainfall variability, groundwater recharge status, and vegetation cover change. These indicators should be monitored through coordination among the India Meteorological Department (IMD), State Disaster Management Authority, Forest Department, and remote sensing agencies. Urban districts such as Nagpur and Chandrapur should additionally implement heat stress vulnerability monitoring systems to support climate adaptation planning and Heat Action Plan implementation.

Public health surveillance systems should integrate environmental exposure indicators with disease burden monitoring through monthly and quarterly assessments of respiratory illnesses, chronic obstructive pulmonary disease (COPD), asthma prevalence, cardiovascular disorders, waterborne diseases, pesticide poisoning incidents, occupational diseases, and heat-related illnesses. The Health Department, medical colleges, district hospitals, Integrated Disease Surveillance Programme (IDSP), and research institutions should collectively support epidemiological surveillance and environmental health data integration.

Occupational health monitoring should receive special emphasis in mining and industrial districts such as Chandrapur, Bhandara, and Gadchiroli through periodic screening of mine workers, industrial laborers, and vulnerable populations exposed to heavy metals, coal dust, and industrial pollutants. Monitoring indicators should include respiratory function impairment, neurological disorders, heavy metal bioaccumulation, and occupational injury prevalence. These activities should be coordinated by the Labour Department, Directorate of Industrial Safety and Health, and public health institutions.

In the waste management sector, quarterly evaluation of municipal solid waste segregation efficiency, biomedical waste treatment compliance, landfill management practices, plastic waste recovery, and wastewater treatment performance should be undertaken by Urban Local Bodies, Municipal Corporations, and MPCB. Urban centres such as Nagpur, Amravati, and Akola should prioritize digital monitoring systems for waste generation and disposal tracking to strengthen urban environmental governance.

Forest and ecosystem health indicators should include annual assessment of forest cover change, biodiversity status, wetland integrity, habitat fragmentation, and ecosystem restoration progress, particularly in ecologically sensitive districts such as Gadchiroli, Gondia, and Bhandara. The Forest Department, biodiversity boards, and environmental research institutions should jointly support ecosystem monitoring using GIS and remote sensing technologies.

The proposed monitoring and evaluation framework should ultimately be integrated into a centralized GIS-based Environmental Health Information System capable of generating district-level environmental risk maps, real-time environmental alerts, public health advisories, and policy performance indicators. Such an integrated system would significantly strengthen environmental governance, improve institutional coordination, enhance climate resilience, and support adaptive environmental health management across the Vidarbha region.

Table 6. Integrated Environmental Health Research Framework and District-wise Monitoring Priorities in Vidarbha

Research Component	Key Parameters / Indicators	Priority Districts / Locations	Expected Outcomes
Air Quality Monitoring	$PM_{2.5}$, PM_{10}, SO_2, NOx, CO, O_3; meteorological parameters	**Chandrapur, Nagpur, Amravati**; monitoring near Koradi, Khaparkheda, Chandrapur thermal plants; urban corridors in Nagpur	Identification of air pollution hotspots; assessment of compliance with national ambient air quality standards; support for emission control technologies and urban air quality management plans
Water Quality Monitoring	pH, DO, BOD, COD, nutrients, heavy metals, pesticides, microbial contamination	**Nagpur (Nag River), Bhandara & Gondia (Wainganga River), Wardha (Wardha River), Yavatmal (Penganga River)**	Protection of drinking water sources; identification of polluted river stretches; improved wastewater treatment and water management strategies
Groundwater Quality Assessment	Nitrates, fluoride, heavy metals, pesticide residues	**Yavatmal, Akola, Wardha, Amravati**	Identification of contaminated aquifers; improved groundwater management and drinking water safety
Soil Quality Monitoring	Heavy metals (Mn, Fe, Pb, Cd), pesticide residues, nutrient levels, soil organic carbon	**Bhandara, Chandrapur, Yavatmal, Akola**	Assessment of soil contamination and land degradation; improved agricultural sustainability and food safety
Biomonitoring and Ecotoxicological Assessment	Heavy metals and persistent pollutants in fish tissues; biodiversity indicators; aquatic toxicity tests	**Bhandara, Gondia, Gadchiroli reservoirs and river systems**	Evaluation of bioaccumulation risks in aquatic food chains; protection of fisheries and ecosystem health

Research Component	Key Parameters / Indicators	Priority Districts / Locations	Expected Outcomes
GIS-Based Environmental Risk Mapping	Spatial distribution of pollution sources, land-use change, population exposure patterns	**Nagpur (industrial cluster), Chandrapur (mining and power plants), Bhandara (mining), Yavatmal (agriculture), Gadchiroli (deforestation)**	remote sensing platforms, Identification of environmental risk zones; prioritization of intervention areas and resource allocation
Epidemiological and Public Health Studies	Respiratory disease prevalence, waterborne diseases, pesticide poisoning cases, occupational health indicators	**Chandrapur, Nagpur (air pollution); Yavatmal (pesticide exposure); rural districts across Vidarbha**	Identification of high-risk populations, pollution control technologies, development of targeted public health advisories and intervention strategies
Community Exposure and Socio-environmental Surveys	Household exposure patterns, occupational exposure, sanitation and waste management practices	**Urban Nagpur, rural agricultural districts (Yavatmal, Akola, Amravati)**	Decision-support systems, environmental health dashboards, Improved understanding of exposure pathways and community vulnerability

7.3.2. Technological and Ecological Interventions

Addressing environmental pollution and associated public health risks in the Vidarbha region requires integrated technological, ecological, and policy interventions that go beyond monitoring and assessment (UNEP, 2019; MoEFCC, 2016). While environmental monitoring helps identify pollution hotspots and exposure pathways, effective mitigation demands the deployment of pollution control technologies, ecosystem restoration measures, sustainable resource management practices, and climate resilience strategies (IPCC, 2022; Smith et al., 2019).

Given the diverse environmental challenges across Vidarbha such as industrial emissions in Nagpur, coal mining and thermal power pollution in Chandrapur, pesticide-intensive agriculture in Yavatmal and Akola, and deforestation in Gadchiroli and Gondia, interventions must be district-specific and sector-oriented. Combining technological innovation with ecological restoration and community participation can significantly reduce pollution loads, restore degraded ecosystems, and strengthen regional environmental sustainability (MEA, 2005; Foley et al., 2011).

The following **Table 7** summarizes priority environmental issues, districts of concern, and recommended technological and ecological interventions for improving environmental quality and public health across the Vidarbha region.

Table 7. District-wise Technological and Ecological Interventions for Environmental Management in Vidarbha

Environmental Issue	Priority Districts / Locations	Key Pollution Drivers	Recommended Technological Interventions	Ecological / Policy Interventions	Expected Outcomes
Air Pollution from Thermal Power and Industries	Chandrapur, Nagpur (Koradi, Khaparkheda, Butibori MIDC)	Coal-based thermal power plants, industrial emissions, vehicular pollution	Installation of flue gas desulfurization (FGD) units, electrostatic precipitators, low-NOx burners; adoption of cleaner industrial technologies; continuous emission monitoring systems	Urban green belts, industrial buffer zones, promotion of electric mobility and public transport, stricter emission regulations	Reduction in particulate and gaseous emissions; improved urban air quality and reduced respiratory health risks
Urban Water Pollution and Wastewater Discharge	Nagpur (Nag River), Amravati, Akola	Untreated sewage, municipal wastewater, industrial effluents	Expansion and modernization of sewage treatment plants (STPs); decentralized wastewater treatment systems; zero-liquid discharge technologies for industries	River restoration programs, constructed wetlands, stricter effluent discharge standards	Improved river water quality; safer drinking water sources and healthier aquatic ecosystems
Agricultural Chemical Pollution	Yavatmal, Akola, Washim, Amravati	Intensive cotton cultivation, excessive pesticide and fertilizer use	Precision agriculture technologies, soil nutrient sensors, controlled irrigation systems	Promotion of Integrated Pest Management (IPM), organic farming, farmer training programs, pesticide regulation	Reduced pesticide exposure, improved soil health, safer agricultural products
Soil Degradation and Land Contamination	Bhandara, Chandrapur, Yavatmal	Mining activities, industrial emissions, agrochemical accumulation	Soil remediation technologies, phytoremediation, biochar application	Soil conservation programs, crop rotation, organic manure use	Restoration of soil fertility and reduction of contaminant accumulation

Environmental Issue	Priority Districts / Locations	Key Pollution Drivers	Recommended Technological Interventions	Ecological / Policy Interventions	Expected Outcomes
Mining Impacts and Land Degradation	Chandrapur, Bhandara, Gadchiroli	Coal and manganese mining, mine waste disposal	Mine drainage treatment systems, dust suppression technologies, remote sensing monitoring of mining activities	Mine reclamation programs, reforestation, wetland creation, biodiversity restoration	Reduced environmental damage from mining and improved ecosystem recovery
Aquatic Ecosystem Contamination and Fisheries Risks	Bhandara, Gondia, Gadchiroli reservoirs and rivers	Industrial discharge, mining runoff, agricultural pollutants	Advanced water filtration technologies, pollution monitoring in fisheries	Fish biomonitoring programs, aquatic habitat restoration, conservation of wetlands	Protection of fisheries resources and reduced human exposure to contaminated fish
Urban Heat Stress and Climate Vulnerability	Nagpur, Chandrapur, Amravati	Urban heat island effects, climate change, loss of vegetation	Cool roofs, reflective building materials, urban climate monitoring systems	Urban forestry, green infrastructure, heat action plans, public cooling shelters	Reduced heat stress and improved urban climate resilience
Solid Waste and Landfill Pollution	Nagpur (Bhandewadi landfill), Amravati, Akola	Poor waste segregation, landfill leachate, urban population growth	Waste-to-energy technologies, improved landfill liners and leachate treatment systems	Source segregation, recycling programs, circular economy initiatives	Reduced landfill pollution and improved municipal waste management
Forest Degradation and Biodiversity Loss	Gadchiroli, Gondia, Chandrapur	Deforestation, mining expansion, unsustainable resource use	Satellite monitoring of forest cover, early fire detection systems	Community-based forest management, afforestation programs, conservation of wildlife corridors	Improved ecosystem resilience and biodiversity conservation

7.3.3. District-Specific Environmental Health Action Plans

Environmental challenges across Vidarbha are spatially heterogeneous and strongly influenced by district-specific industrial, agricultural, mining, urbanization, and climatic conditions. Therefore, environmental management strategies must move beyond generalized interventions and adopt district-specific action plans tailored to local environmental drivers and public health vulnerabilities. A district-specific environmental health action plans (**Figure 6**) is therefore essential for developing targeted mitigation strategies, strengthening environmental governance, and improving adaptive capacity across the region.

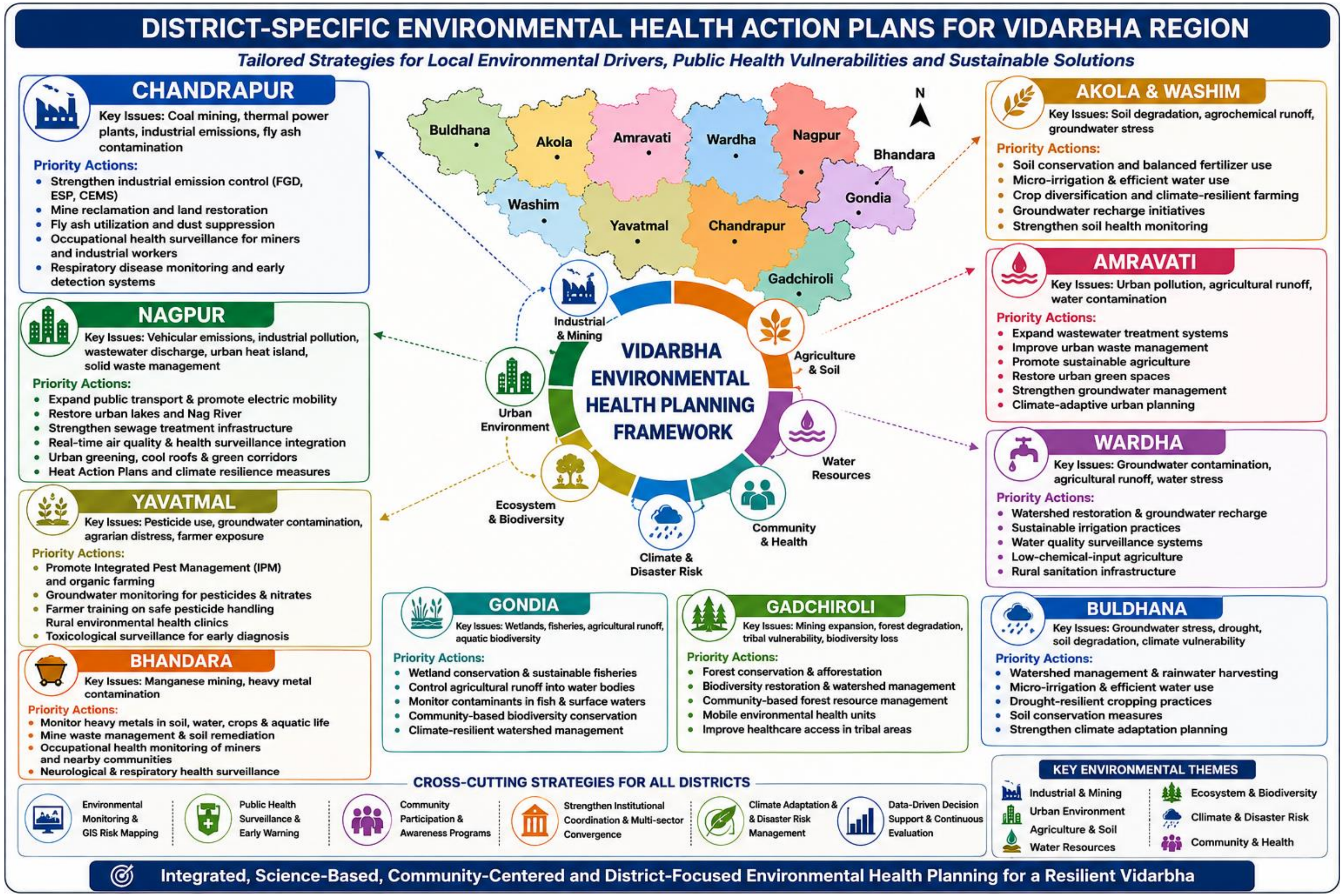

Figure 6: District-Specific Environmental Health Action Plan, [*Source: Conceptualize using AI (OpenAI), 2026*]**.**

Chandrapur

Chandrapur requires immediate and high-priority intervention due to the cumulative impacts of coal mining, coal-based thermal power generation, industrial emissions, and fly ash contamination. The district-specific environmental health plan for Chandrapur should focus on:

- Strengthening industrial emission control through mandatory installation and efficient operation of flue gas desulfurization (FGD) systems, electrostatic precipitators, and continuous emission monitoring systems in thermal power plants.
- Prioritizing mine reclamation, fly ash utilization, dust suppression technologies, and restoration of degraded land to reduce environmental contamination.
- Strengthening occupational health surveillance programs for miners and industrial workers, along with respiratory disease monitoring systems, to reduce long-term health risks associated with chronic air pollution exposure.

Nagpur

Nagpur, being the major urban, industrial, and administrative center of Vidarbha, requires an integrated urban environmental health management plan addressing vehicular emissions, industrial pollution, wastewater discharge, urban heat island effects, and municipal solid waste management. Strategic interventions should include:

- Expansion of public transportation systems and promotion of electric mobility.
- Urban greening initiatives, restoration of urban lakes and river systems such as the Nag River, and strengthening of sewage treatment infrastructure.
- Real-time integration of air quality monitoring with public health surveillance systems to support early warning mechanisms and environmental health advisories.
- Climate resilience measures including Heat Action Plans, cool roof technologies, and urban green corridors to reduce heat stress vulnerability among urban populations.

Yavatmal

Yavatmal requires a specialized agricultural environmental health plan due to intensive pesticide use, groundwater contamination, agrarian distress, and occupational exposure among farming communities. Priority interventions should focus on:

- Promoting Integrated Pest Management (IPM), organic farming practices, precision agriculture technologies, and farmer awareness programs on safe pesticide handling and storage.

- Strengthening groundwater quality monitoring for pesticide residues and nitrates, particularly in intensively cultivated cotton-growing regions.
- Establishing rural environmental health clinics and toxicological surveillance systems to support early diagnosis and management of pesticide-related illnesses among farmers and agricultural workers.

Akola and Washim

Akola and Washim require sustainable agricultural management strategies aimed at reducing soil degradation, agrochemical runoff, and groundwater stress associated with agricultural intensification. Environmental health plans in these districts should promote:

- Soil conservation measures, balanced fertilizer application, micro-irrigation systems, crop diversification, and groundwater recharge initiatives.
- Strengthening soil health monitoring and encouraging climate-resilient agricultural practices to improve long-term agricultural sustainability and reduce environmental contamination.

Amravati

Amravati requires integrated interventions addressing both urban environmental pollution and agricultural runoff. Priority actions include:

- Expansion of wastewater treatment systems, urban waste management infrastructure, and sustainable agricultural practices to reduce environmental contamination and improve regional environmental quality.
- Restoration of urban green spaces, strengthening groundwater management systems, and implementation of climate-adaptive urban planning measures to improve environmental resilience and public health outcomes.

Wardha

Wardha requires focused environmental health interventions related to groundwater contamination, agricultural runoff, and increasing water stress linked to changing climatic conditions. The district environmental health plan should prioritize:

- Watershed restoration, groundwater recharge programs, sustainable irrigation practices, and water quality surveillance systems.
- Promotion of low-chemical-input agriculture and rural sanitation infrastructure to support improvements in environmental quality and public health.

Bhandara

Bhandara requires focused intervention for mining-related environmental contamination, particularly associated with manganese mining activities. Environmental health management strategies should include:

- Systematic monitoring of heavy metals in soil, water, crops, and aquatic ecosystems.
- Implementation of mine waste management and soil remediation programs.
- Strengthening occupational health monitoring of mine workers and nearby communities to minimize neurological and respiratory health impacts associated with prolonged manganese exposure.

Gondia

Gondia, characterized by ecologically sensitive wetlands, forest ecosystems, and aquatic biodiversity, requires enhanced ecosystem protection and biomonitoring strategies. Environmental health planning in Gondia should emphasize:

- Wetland conservation, sustainable fisheries management, control of agricultural runoff into aquatic systems, and monitoring of contaminants in fish and surface waters.
- Community-based biodiversity conservation and climate-resilient watershed management practices to preserve ecosystem services and food security.

Gadchiroli

Gadchiroli requires an ecosystem-based environmental health management approach due to ongoing mining expansion, forest degradation, biodiversity loss, and the high vulnerability of tribal communities dependent on forest ecosystems. District-level strategies should prioritize:

- Forest conservation, afforestation, biodiversity restoration, watershed management, and community-based forest resource management programs.
- Mobile environmental health units and improved healthcare accessibility in remote tribal areas to strengthen environmental health resilience and reduce vulnerability to communicable diseases, nutritional stress, and environmental displacement.

Buldhana

Buldhana requires proactive environmental management measures focused on groundwater sustainability, climate-resilient agriculture, and soil conservation due to increasing agricultural pressures and recurrent drought conditions. Priority actions include:

- Improved watershed management, rainwater harvesting, micro-irrigation systems, and drought-resilient cropping practices to strengthen long-term environmental sustainability and reduce climate vulnerability among farming communities.

Overall, the district-specific environmental health action plans proposed for Vidarbha emphasize the need for decentralized environmental governance supported by scientific institutions, local administrations, public health agencies, and community participation. The integration of environmental monitoring, climate adaptation, sustainable agriculture, ecosystem restoration, and public health preparedness within district-level planning frameworks will be critical for improving environmental resilience, reducing regional disparities in environmental exposure, and supporting sustainable environmental health management across the Vidarbha region.

7.3.4. Integrated Regional Impact

Implementation of the above technological and ecological interventions will contribute to:

- Reduction of industrial and urban pollution loads
- Improved water and soil quality
- Enhanced agricultural sustainability
- Restoration of degraded ecosystems
- Improved resilience to climate change and extreme heat events
- Protection of public health and livelihoods

A coordinated approach involving government agencies, research institutions, local communities, and industry stakeholders will be essential to ensure the successful implementation of these interventions and to promote sustainable environmental management across the Vidarbha region (Folke et al., 2005; Ostrom, 2009)**.**

8. Policy and Governance Framework

India has established a strong legal and institutional framework to regulate environmental pollution and protect public health. Key national legislations such as the Environment (Protection) Act, 1986; Air (Prevention and Control of Pollution) Act, 1981; Water (Prevention and Control of Pollution) Act, 1974; Solid Waste Management Rules, 2016; Plastic Waste Management Rules, 2016; Biomedical Waste Management Rules, 2016; and Hazardous and Other Wastes Management Rules, 2016 provide regulatory mechanisms to control environmental pollution and ensure environmental quality standards (Government of India, 1986; MoEFCC, 2016). At the state level, the Maharashtra Pollution Control Board (MPCB) plays a central role in enforcing environmental regulations, monitoring industrial emissions, and ensuring compliance with pollution control norms (MPCB, 2020).

However, addressing complex environmental health challenges in Vidarbha requires integration of environmental policies with public health programs, urban governance, agricultural management, and ecosystem conservation strategies (WHO, 2016; UNEP, 2019)**.** Strengthening coordination between regulatory agencies, municipal bodies, public health departments, and research institutions is essential for translating environmental regulations into effective environmental health protection. The **Table 8** below illustrates how environmental pollution issues in Vidarbha are linked to environmental health risks and the corresponding policy and governance frameworks required to address them**.**

Table 8. Environmental Issues, Policy Frameworks, Implementing Agencies, and Governance Priorities for the Vidarbha Region.

Environmental Issue	**Relevant Policy / Regulatory Framework**	**Key Implementing Agencies**	**Governance Priorities for Vidarbha**
Air Pollution	Air (Prevention and Control of Pollution) Act, 1981; National Clean Air Programme (NCAP); Environment (Protection) Act, 1986	MPCB, Central Pollution Control Board (CPCB), Municipal Corporations	Strengthen emission monitoring in **Chandrapur and Nagpur**, enforce industrial emission standards, promote clean energy and electric mobility
Water Pollution	Water (Prevention and Control of Pollution) Act, 1974; National River Conservation Plan; Jal Jeevan Mission	MPCB, Municipal Corporations, Water Resources Department	Expansion of **sewage treatment infrastructure in Nagpur and Amravati**, monitoring of polluted rivers such as **Nag,**

Environmental Issue	**Relevant Policy / Regulatory Framework**	**Key Implementing Agencies**	**Governance Priorities for Vidarbha**
			Wardha, and Wainganga
Soil and Agricultural Pollution	Insecticides Act, 1968; National Mission for Sustainable Agriculture; Soil Health Card Scheme	Department of Agriculture, State Agricultural Universities	Promotion of **Integrated Pest Management (IPM)** and sustainable agriculture in **Yavatmal, Akola, and Washim**
Mining and Industrial Contamination	Mines and Minerals (Development and Regulation) Act, 1957; Environmental Impact Assessment (EIA) Notification	Ministry of Environment, Forest and Climate Change (MoEFCC), Directorate of Mines Safety, MPCB	Strengthen environmental compliance and mine reclamation in **Chandrapur and Bhandara mining belts**
Solid Waste and Hazardous Waste	Solid Waste Management Rules, 2016; Hazardous and Other Wastes Rules, 2016; Plastic Waste Management Rules, 2016	Municipal Corporations, MPCB	Modernization of waste management systems in **Nagpur and Amravati**, improved landfill management and recycling infrastructure
Climate Change and Heat Stress	National Action Plan on Climate Change (NAPCC); State Action Plan on Climate Change (SAPCC)	State Disaster Management Authority, Urban Development Department	Development of **Heat Action Plans** and urban greening initiatives in **Nagpur and other urban centers**
Forest Degradation and Ecosystem Loss	Forest Conservation Act, 1980; Wildlife Protection Act, 1972; National Afforestation Programme	Forest Department, MoEFCC	Strengthen forest conservation and community forest management in **Gadchiroli, Gondia, and Chandrapur**
Public Health Surveillance and Environmental Health Monitoring	National Health Mission; Integrated Disease Surveillance Programme (IDSP)	State Health Department, Public Health Institutions	Integration of environmental monitoring data with **health surveillance systems** to identify pollution-related disease patterns

Along with the legal and institutional framework, addressing environmental health challenges in the Vidarbha region requires a coordinated policy and governance framework that links environmental regulation, public health protection, sustainable development planning, and institutional collaboration (WHO, 2016; Kumar & Reddy, 2020). Environmental pollution arising from industrialization, coal-based power generation, mining, intensive agriculture, urbanization, and waste mismanagement has a dominant impact on ecosystem integrity and human health (Landrigan et al., 2018). These environmental pressures can lead to increased risks of respiratory illnesses, waterborne diseases, chemical exposure, occupational hazards, and climate-related health impacts.

Policy regulations and environmental standards established by regulatory agencies should not be viewed merely as compliance thresholds, but as actionable public health triggers that guide timely intervention and risk mitigation (CPCB, 2022). In this context, the Air Quality Index (AQI) can serve as an effective decision-support tool linking environmental monitoring with public health response. AQI categories may be interpreted as follows:

- 0–50 (Good): Maintain baseline environmental controls and monitoring
- 51–100 (Moderate): Implement precautionary measures for sensitive populations
- 101–200 (Poor): Initiate emission reduction measures and public advisories
- 201–300 (Very Poor): Activate health alerts and restrict major pollution sources
- >300 (Severe): Implement emergency response measures and minimize public exposure

This approach enables alignment of air quality management with district-level governance, emergency preparedness, and health system response mechanisms.

8.1. Policy Prioritization and Implementation Framework

To move from analysis to action, a clear policy prioritization and implementation framework is needed. Proposed three-tiered structure includes:

a) Tier 1: Regulatory Enforcement & Compliance (Short-term): Focus on "low-hanging fruit" and urgent threats.

Action: Enforce existing emission norms for thermal power plants (Chandrapur, Koradi). Ensure compliance of industrial effluents (Butibori, Hingna, etc.).

Mechanism: MPCB to increase surprise inspections; NEERI to provide independent audit and monitoring support.

Trigger: AQI >300 or heavy metal levels >2x BIS limit in drinking water sources triggers immediate source apportionment and shutdown orders for major violators.

b) Tier 2: Green Infrastructure & Sustainable Practices (Medium-term): Shift from control to prevention.

Action: Mandate flue-gas desulfurization (FGD) systems in all power plants. Promote precision agriculture and Integrated Pest Management (IPM) in

Yavatmal/Akola. Invest in sewage treatment plants (STPs) for Nagpur and Amravati. Implement Heat Action Plans (HAPs) in all Tier 1 districts.

Mechanism: State and central subsidies linked to adoption. Urban local bodies to integrate green-blue infrastructure (parks, wetlands, green roofs).

Trigger: Persistent "Poor" AQI category for 30 days or detection of rising disease trends (e.g., 20% increase in paediatric asthma admissions) activates green infrastructure investment acceleration.

c) Tier 3: Adaptive Governance and Community Resilience (Long-term): Build systemic resilience.

Action: Integrate environmental health into all district development plans. Establish formal cross-departmental committees (Health, Environment, Agriculture, Water Resources) at the district level. Operationalize the Spatial Risk Atlas and Monitoring Dashboard.

Mechanism: District Magistrate-led Environmental Health Task Force with quarterly reviews. Community-based monitoring programs (e.g., citizen science for water quality).

Trigger: Not applicable; this is a continuous process of adaptive management.

8.2. Climate Resilience and Adaptive Governance

The IPCC (2022) and recent studies confirm that Vidarbha is increasingly vulnerable to climate shocks. Climate resilience must be mainstreamed into environmental health governance. This involves:

- **District-Level Heat Action Plans:** Nagpur leads, but all major cities require plans focused on early warning systems, cooling centers, and public awareness.
- **Ecosystem-Based Adaptation:** Restoring tree cover and conserving water bodies are cost-effective resilience strategies.
- **Adaptive Governance:** Institutions must learn to manage uncertainty. This requires flexible funding mechanisms, continuous learning loops (monitoring-evaluation-action), and decentralized decision-making authority to district-level task forces.

8.3. One Health Governance

Formalizing the One Health perspective requires operational convergence. The National One Health Mission provides a framework, but at the state and district level, Vidarbha needs:

- **Inter-sectoral Zoonotic Committees:** Mandated collaboration between Health, Animal Husbandry, Forest, and Municipal Corporation departments, particularly in high-risk districts like Chandrapur (Tadoba Tiger Reserve) and Gadchiroli.
- **Integrated Surveillance:** Linking data from human health (IDSP), veterinary labs, and environmental monitoring (NEERI's wastewater surveillance) into a single early warning system.

9. Strategic Recommendations

Reducing environmental health risks in the Vidarbha region requires integrated and actionable strategies that combine technological innovation, ecosystem restoration, policy strengthening, and community engagement (UNEP, 2019; Smith et al., 2019). Environmental pollution in Vidarbha arising from coal-based energy production, industrialization, intensive agriculture, mining, urban waste generation, and climate-related stressors**,** directly affects human health, ecosystem services, and regional sustainability (Landrigan et al., 2018; IPCC, 2022)**.**

Strategic interventions should therefore focus not only on pollution control but also on reducing exposure pathways, improving environmental quality, strengthening health resilience, and promoting sustainable resource management. Given the diversity of environmental challenges across Vidarbha, district-specific and sector-oriented strategies are essential to effectively mitigate environmental health risks and support long-term sustainable development.

Recommendation 1: Develop a Vidarbha Spatial Risk Atlas and Environmental Health Dashboard

Lead Agency: CSIR-NEERI, in collaboration with MPCB, Health Department, and GIS experts

Action: Integrate all monitoring data (air, water, soil, climate, health) into a single, publicly accessible, real-time web-based platform. Include layers for pollution hotspots, vulnerable populations, and health infrastructure.

Purpose: Enable hotspot identification, evidence-based policy prioritization, and public awareness.

Recommendation 2: Institutionalize District-Level Integrated Governance and One Health Task Forces

Lead Agency: District Magistrate (Collector), with members from Health, Environment (MPCB), Agriculture, Water Resources, Urban Local Bodies. As technical advisors: CSIR-NEERI, AIIMS, MGIMS, VNIT, CICR, RTMNU etc.

Action: Mandate quarterly meetings to review dashboard data, Inter-sectoral Zoonotic Committees, assess policy implementation framework progress, and coordinate rapid response to emerging environmental health threats, including disease outbreaks linked to environmental contamination.

Purpose: Break down sectoral silos and enable adaptive governance for climate resilience.

a) Air Pollution Management in Industrial and Power Generation Zones

Priority Districts / Locations: Chandrapur, Nagpur (Koradi, Khaparkheda, Butibori MIDC)

Key Environmental Issues: Emissions from coal-based thermal power plants, industries, and vehicular pollution

Recommended Strategic Actions:

- Installation of flue gas desulfurization (FGD) systems, electrostatic precipitators, and continuous emission monitoring systems
- Promotion of electric mobility
- Development of urban green belts and air quality forecasting systems
- Environmental Health Impact Reduction: Reduced exposure to particulate matter and toxic gases, leading to lower incidence of respiratory diseases, asthma, and cardiovascular disorders

b) Water Resource Protection and Pollution Control

Priority Districts / Locations: Nagpur, Amravati, Wardha, Bhandara

Key Environmental Issues: Untreated sewage, industrial effluents, and agricultural runoff

Recommended Strategic Actions:

- Expansion of sewage treatment plants
- Industrial effluent treatment
- Watershed management and rainwater harvesting
- River restoration programs
- Environmental Health Impact Reduction: Improved drinking water quality and reduced risk of waterborne diseases and chemical exposure

c) Sustainable Agriculture and Pesticide Risk Reduction

Priority Districts / Locations: Yavatmal, Akola, Washim, Amravati

Key Environmental Issues: Excessive pesticide use and soil degradation in cotton-growing regions

Recommended Strategic Actions:

- Promotion of Integrated Pest Management (IPM)
- Biological pest control and organic farming practices
- Farmer training on safe pesticide use
- Environmental Health Impact Reduction: Reduced pesticide exposure among farmers and consumers, improving food safety and occupational health

d) Mining Environmental Management and Land Restoration

Priority Districts / Locations: Chandrapur, Bhandara, Gadchiroli

Key Environmental Issues: Land degradation, heavy metal contamination, and dust pollution from mining activities

Recommended Strategic Actions:

- Mine site reclamation and reforestation
- Soil stabilization
- Monitoring of heavy metals in soil and water
- Adoption of cleaner mining technologies
- Environmental Health Impact Reduction: Reduced exposure to toxic metals and dust, improving community health and ecological restoration

e) Urban Waste Management and Circular Economy Approaches

Priority Districts / Locations: Nagpur, Amravati, Akola

Key Environmental Issues: Municipal solid waste accumulation, landfill pollution, and plastic waste

Recommended Strategic Actions:

- Source segregation and recycling infrastructure
- Composting of organic waste
- Waste-to-energy systems
- Improved landfill management
- Environmental Health Impact Reduction: Reduced groundwater contamination and vector-borne disease risks, along with improved urban sanitation and environmental quality

f) Climate Adaptation and Heat Stress Mitigation

Priority Districts / Locations: Nagpur, Chandrapur, Amravati

Key Environmental Issues: Urban heat island effect and extreme summer temperatures

Recommended Strategic Actions:

- Implementation of Heat Action Plans
- Urban greening programs
- Restoration of urban lakes
- Climate-resilient building designs
- Environmental Health Impact Reduction: Reduced heat-related illnesses such as heat stroke, dehydration, and cardiovascular stress

g) Forest Conservation and Ecosystem-Based Interventions

Priority Districts / Locations: Gadchiroli, Gondia, Chandrapur

Key Environmental Issues: Deforestation, biodiversity loss, and ecosystem degradation

Recommended Strategic Actions:

- Community-based forest management
- Afforestation programs
- Protection of wildlife corridors
- Sustainable forest resource management
- Environmental Health Impact Reduction: Enhanced ecosystem services including clean air, water regulation, climate moderation, and improved community health resilience

h) Environmental Health Surveillance and Research Integration

Priority Districts / Locations: All districts of Vidarbha

Key Environmental Issues: Limited integration between environmental monitoring and public health data

Recommended Strategic Actions:

- Strengthening disease surveillance systems
- Integrating environmental monitoring with health databases
- Promoting environmental health research

- Environmental Health Impact Reduction: Early detection of pollution-related diseases and improved evidence-based public health interventions

Integrated Environmental Health Benefits

Implementation of these strategic recommendations under the framework of Recommendations 1 and 2 will contribute to:

- Reduction of pollution exposure pathways (air, water, soil, and food chains)
- Lower incidence of pollution-related diseases including respiratory, waterborne, and occupational illnesses
- Improved environmental quality and ecosystem restoration
- Enhanced climate resilience and heat stress management
- Strengthened public health protection and sustainable development

A coordinated implementation strategy involving government agencies, research institutions, local communities, industries, and technical organizations will be essential for translating these recommendations into measurable and sustainable improvements in environmental health across the Vidarbha region.

10. Conclusion

The Vidarbha region of Maharashtra represents a complex environmental landscape where industrial development, coal-based energy production, mining activities, intensive agriculture, urban expansion, and climate variability collectively influence environmental quality and public health (Kumar, 2019; Singh & Pandey, 2020). This white paper highlights that the environmental health challenges in Vidarbha are interconnected and multidimensional, involving air pollution from thermal power plants and industries, contamination of surface and groundwater resources, soil degradation from agrochemical use, mining-related land disturbance, waste management challenges, and increasing climate-related heat stress (CPCB, 2022; IPCC, 2022; FAO, 2021).

Districts such as Nagpur and Chandrapur experience significant environmental pressures associated with industrialization and coal-based power generation, while Yavatmal, Akola, and Amravati face challenges related to pesticide-intensive agriculture and groundwater contamination (Deshpande, 2015; Narayanamoorthy, 2019). Similarly, Bhandara and Gadchiroli are influenced by mining activities and forest ecosystem dynamics (IBM, 2020; FSI, 2021). These pressures create multiple exposure pathways that contribute to respiratory illnesses, waterborne diseases, pesticide-related health risks, occupational hazards, and climate-sensitive health impacts, thereby emphasizing the need for integrated environmental health management (WHO, 2018; Landrigan et al., 2018).

The findings of this white paper demonstrate that addressing environmental health risks in Vidarbha requires a science-based, interdisciplinary, and region-specific approach that integrates environmental monitoring, technological innovation, ecosystem restoration, policy enforcement, and public health interventions (Nieuwenhuijsen, 2015; Smith et al., 2019). Moving beyond fragmented, sector-specific responses toward integrated air–water–soil–climate–health management is essential for effective policy implementation and long-term sustainability. In this context, district-wise vulnerability assessments, environmental health risk mapping, and evidence-based prioritization frameworks will play a critical role in identifying hotspots and guiding targeted interventions.

The proposed **Vidarbha Spatial Risk Atlas and Environmental Health Dashboard** can serve as the technological foundation for integrated environmental governance by enabling real-time monitoring, hotspot identification, and data-driven decision-making. Simultaneously, the establishment of District-Level Integrated Governance and **One Health Task Forces** can strengthen coordination among environmental regulators, public health institutions, research organizations, and local governance bodies, thereby improving adaptive governance and climate resilience (WHO, 2016; Folke et al., 2005). The continued involvement of scientific institutions such as **CSIR-NEERI** will further support evidence generation, technical guidance, and policy translation.

Overall, the evidence presented in this white paper underscores the urgent need for sustained institutional coordination, policy commitment, scientific engagement, and investment in environmental health infrastructure across the Vidarbha region. Implementation of the recommended interventions can significantly reduce pollution exposure pathways, improve ecosystem health, strengthen climate resilience, and enhance public health outcomes. A coordinated and integrated approach involving government agencies, industries, research institutions, and local communities will be essential for achieving a healthier, more resilient, and environmentally sustainable future for the Vidarbha region.

11. Way Forward (2026–2047)

Achieving sustainable environmental health outcomes in the Vidarbha region will require long-term strategic planning, institutional coordination, technological innovation, and sustained investment in environmental infrastructure, ecological restoration, and public health systems (UNEP, 2019; IPCC, 2022). The proposed roadmap is aligned with the national vision of Viksit Bharat 2047, which emphasizes sustainable development, climate resilience, technological advancement, environmental protection, and improved public health systems. The period from 2026 to 2047 represents a critical transition phase for strengthening environmental governance, reducing pollution loads, improving ecosystem resilience, and promoting climate-resilient and sustainable development pathways across the region (**Table 9**).

The long-term environmental health strategy for Vidarbha should focus on the phased implementation of integrated environmental monitoring systems, pollution control technologies, sustainable industrial and agricultural practices, ecosystem restoration programs, climate adaptation measures, and advanced environmental-health surveillance frameworks. Central to this strategy will be the operationalization of the **Vidarbha Spatial Risk Atlas and Environmental Health Dashboard led by CSIR-NEERI**, along with the establishment of **District-Level Integrated Governance and One Health Task Forces** to strengthen interdepartmental coordination, adaptive governance, and evidence-based decision-making.

The initial phase (2026–2030) should prioritize establishing baseline environmental and health datasets through full deployment of the Environmental Health Monitoring Dashboard, integration of real-time air, water, soil, climate, and health monitoring systems, and GIS-based pollution hotspot mapping. Simultaneously, institutional governance mechanisms must be strengthened through formal notification and operationalization of district-level integrated task forces involving environmental, health, agriculture, urban development, and disaster management agencies. Targeted interventions should focus on high-risk districts, including aggressive air pollution control measures in the Chandrapur–Nagpur industrial and thermal power corridor, pesticide risk reduction strategies in Yavatmal and Akola, and restoration of urban lakes and drainage systems in Nagpur. Climate resilience measures, particularly district-level Heat Action Plans, urban greening initiatives, and climate-sensitive public health preparedness, should be implemented across all high-vulnerability districts.

Over the medium-term period (2030–2040), the focus should shift toward sustainable industrial transition, ecosystem restoration, climate adaptation, and resource-efficient development. This includes the adoption of cleaner energy technologies, strengthening circular economy systems, modernization of wastewater and solid waste management infrastructure, promotion of sustainable agriculture and precision farming technologies, and implementation of mine reclamation, afforestation, wetland restoration, and biodiversity conservation programs. Expansion of integrated environmental-health surveillance systems linking environmental monitoring data with epidemiological and occupational health databases will further support evidence-based policymaking and early-warning systems for environmental health risks.

During the long-term phase (2040–2047), Vidarbha should move toward smart environmental governance and integrated public health resilience through AI- and GIS-based environmental forecasting systems, climate-smart infrastructure, circular economy and zero-waste systems, and advanced environmental-health risk prediction frameworks. Continued investments in scientific research, technological innovation, environmental-health data integration, and community participation will be essential for sustaining long-term environmental quality and resilience.

In parallel, strengthening technical capacity, environmental awareness, citizen-science initiatives, interdisciplinary research, and community-based environmental management programs will remain critical throughout all phases of implementation. Effective collaboration among regulatory agencies, research institutions, industries, local governments, and communities will be necessary to ensure successful implementation of environmental health interventions across the region.

Table 9. Phased Roadmap for Environmental Health Improvement and Sustainable Development in Vidarbha (2026–2047)

Timeline	Strategic Focus Areas	Major Actions	Implementation agencies	Expected Environmental Health Outcomes
2026–2030	Baseline environmental health assessment, integrated governance, pollution hotspot management, and climate resilience	Deployment of the Vidarbha Environmental Health Monitoring Dashboard; establishment of District-Level Integrated Governance and One Health Task Forces; expansion of real-time air, water, soil, climate, and biomonitoring networks; GIS-based pollution hotspot mapping; pollution control measures in Chandrapur–Nagpur industrial zones; pesticide risk reduction programs in Yavatmal and Akola; restoration of urban lakes in Nagpur; implementation of Heat Action Plans and urban greening initiatives	• CSIR-NEERI • MPCB • CPCB • Municipal Corporations • Health Department • Other institutions (AIIMS, VNIT, MGIMS etc.)	Improved identification of pollution hotspots and exposure pathways; strengthened environmental-health surveillance and governance; reduction in industrial emissions and pesticide exposure; improved urban environmental quality; enhanced climate preparedness and heat resilience
2030–2040	Sustainable industrial transition, ecosystem restoration, climate adaptation, and	Adoption of cleaner and renewable energy technologies; modernization of sewage treatment and solid waste management infrastructure;	• Urban Development Department • Agriculture Department • Forest Department • District Administrations	Improved ecosystem resilience and environmental quality; reduction in air, soil, and water contamination; enhanced

Timeline	Strategic Focus Areas	Major Actions	Implementation agencies	Expected Environmental Health Outcomes
	sustainable agriculture	implementation of mine reclamation, watershed restoration, wetland conservation, afforestation, and biodiversity restoration programs; promotion of sustainable agriculture, precision farming, and water-efficient irrigation systems; expansion of integrated environmental-health databases and early-warning systems		agricultural sustainability; improved climate adaptation capacity; strengthened evidence-based environmental health management
2040–2047	Smart environmental governance, circular economy systems, and integrated public health resilience	Deployment of AI- and GIS-based environmental forecasting and decision-support systems; implementation of circular economy and zero-waste approaches; development of climate-smart infrastructure and sustainable urban systems; integration of environmental, occupational, and public health risk prediction frameworks;	• State Government • Disaster Management Authority • Health Department • Research Institutions • District Environmental Task Forces	Sustainable environmental quality and ecosystem stability; reduced pollution-related disease burden; improved resource efficiency and climate resilience; strengthened long-term public health protection, environmental governance, and quality of life

Timeline	Strategic Focus Areas	Major Actions	Implementation agencies	Expected Environmental Health Outcomes
		expansion of community-based environmental stewardship and citizen-science programs		

Long-Term Vision:

By 2047, the Vidarbha region can progress toward a sustainable environmental health framework characterized by cleaner air and water resources, restored ecosystems, climate-resilient infrastructure, reduced pollution exposure, sustainable industrial and agricultural systems, and strengthened public health resilience. The proposed roadmap is aligned with the national Vision Viksit Bharat 2047 framework and supports India's long-term goals of sustainable development, environmental sustainability, climate resilience, technological innovation, and improved quality of life. The integration of environmental monitoring, spatial risk assessment, One Health governance, and climate-resilient planning can enable a transition toward evidence-based and adaptive environmental management across the region. Achieving this vision will require continued scientific research, technological advancement, policy innovation, institutional cooperation, and active community participation to ensure that environmental protection, economic development, and public health progress together in a balanced and sustainable manner.

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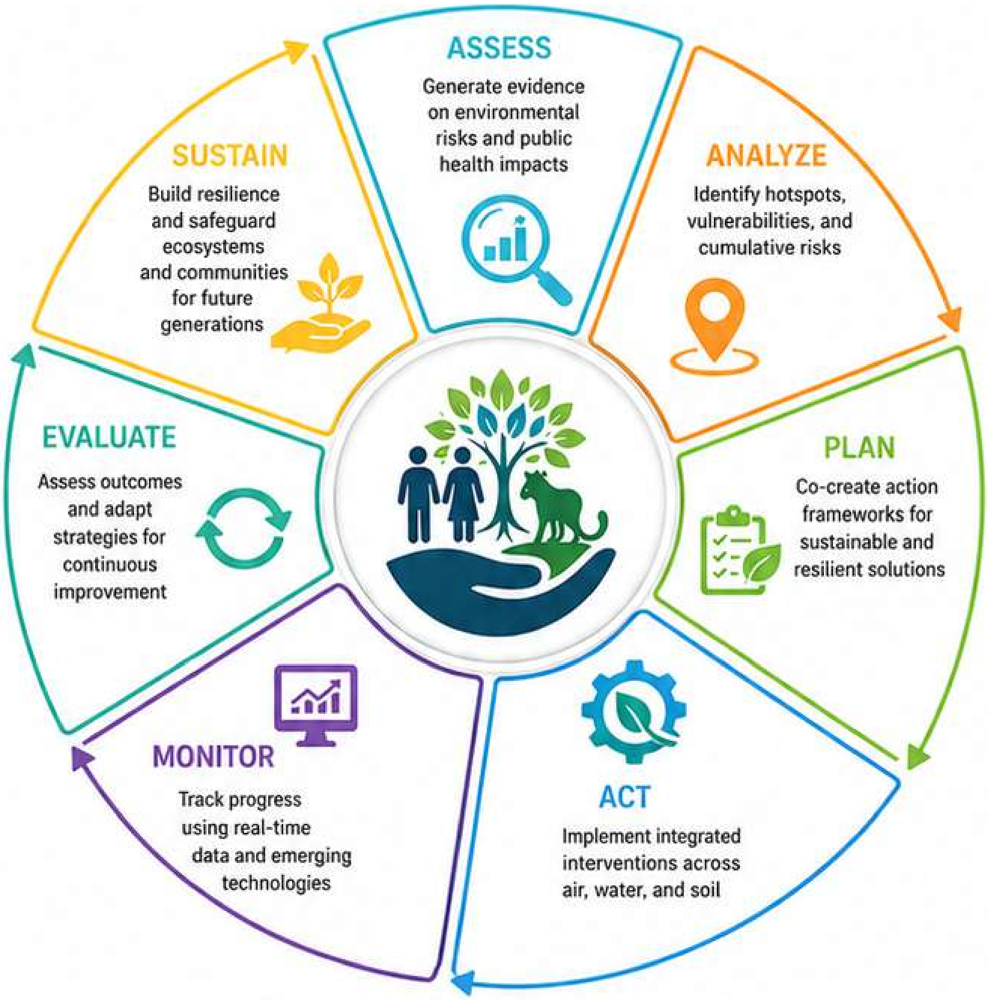
Environmental Health Risk Atlas and Action Framework for the Vidarbha Region, India

Integrating Air, Water, Soil, Climate, and Public Health for Sustainable Development



An integrated, evidence-based cycle for protecting environmental health and advancing sustainable development in the Vidarbha Region.

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