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# Environmental pollution and human exposure in Chandrapur District: An integrated review of air and water contamination

**Dr. Amar Maruti Dhere[1*], Mrunali Jagdish Mhaskey[2]**
[1] Department of Science, SNDT College of Home Science, SNDT Women's University, Pune, Maharashtra, India
[2] Research Assistant, ICSSR Project, SNDT College of Home Science, SNDT Women's University, Pune, Maharashtra, India
**Corresponding Author:** Dr Amar Maruti Dhere
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**Abstract**
Chandrapur district in Maharashtra presents a complex environmental landscape, with activities such as mining, thermal power generation, industry, transportation, and urbanisation exerting multiple environmental pressures. Among these, air and water pollution are especially significant for human exposure, as they involve different yet potentially connected pathways. This review consolidates existing evidence on air and water contamination in Chandrapur, focusing on pollution sources, spatial and seasonal trends, human exposure routes, and reported environmental and health impacts. Studies show notable variation in environmental quality across locations and seasons, influenced by industrial activity, mining levels, land use, hydrological factors, and weather patterns. Air quality assessments reveal increased particulate matter in several areas, while water studies report fluctuations in the physicochemical properties of surface and groundwater. Importantly, exposure occurs not only at individual pollution sources or sites but also through residential, occupational, and water-use pathways. Nevertheless, data specific to Chandrapur are fragmented, with differences in locations, parameters, sampling times, and methods hindering direct comparison. An integrated evaluation of air and water pollution is essential to identify exposure patterns and enhance district-level monitoring. This review also points out key knowledge gaps and suggests priorities for future research, including seasonal monitoring, spatial exposure analysis, and better linkage between environmental data and population exposure.

**Keywords:** Chandrapur, environmental pollution, air pollution, water pollution, human exposure

## Introduction

Environmental pollution significantly influences population exposure and environmental health, especially in areas with intensive industrialization, mineral extraction, thermal power generation, and urban growth concentrated in specific regions. Communities are primarily exposed to pollutants through air and water, though the level and type of exposure depend on factors such as source characteristics, land use, environmental conditions, and human activities. Effective pollution assessment requires examining not only pollutant levels but also the distribution of sources, exposure pathways, and affected populations (Landrigan *et al*., 2018; Fuller *et al*., 2022) [3, 16]. Chandrapur district in Maharashtra exemplifies such a setting, hosting coal mining, thermal power plants, industrial operations, and transportation infrastructure. These activities emit particulate and gaseous pollutants and strain water resources, creating multiple pollution sources rather than a single dominant pathway.

The literature emphasises the importance of studying air pollutants, water contaminants, and health outcomes in industrial and mining-affected areas of Chandrapur. Air pollution is especially relevant because particulate matter and gaseous pollutants vary by location and season, with evidence showing spatial differences in particulate concentrations and seasonal fluctuations in $PM_{2.5}$ and $PM_{10}$ levels. Exposure may vary based on residential location, proximity to pollution sources, transportation routes, and environmental conditions. At the population level, particulate air pollution correlates with adverse health outcomes, though the effects depend on pollutant properties, exposure duration, and individual susceptibility (Balakrishnan *et al*., 2019; Schraufnagel *et al*., 2019) [1, 22].

Water pollution represents a second important pathway of environmental exposure in Chandrapur, where mining, industrial activity and other anthropogenic pressures may influence surface- and groundwater quality. Studies conducted in different parts of the district have reported spatial and temporal variability in groundwater characteristics, including hardness, fluoride, chloride and other physicochemical parameters (Gudadhe and Manik, 2020; Jaunjalkar and Murkute, 2023; Iyer and Meshram, 2025) [6, 9, 15]. Recent district-level monitoring has likewise documented variation in groundwater hardness among monitoring locations in Chandrapur, reinforcing the importance of systematic assessment of water-quality conditions (MPCB, 2024).

Water-quality investigations around mining and industrial areas further indicate that contaminant patterns can vary spatially. Chandekar *et al*., (2024) [2], for example, observed changes in chloride and fluoride distributions between 2014 and 2018, with higher fluoride levels at some locations close to industrial and mining activities. These findings support the need to assess drinking-water quality using multiple physical, chemical and microbiological indicators rather than relying on a single water-quality parameter.

An essential aspect of interpreting pollution data is the distinction between environmental contamination and human exposure. Detection of a pollutant in air or water does not, by itself, establish individual exposure or health risk; exposure depends on concentration, duration, frequency, route of contact and patterns of human activity. This distinction is particularly relevant for groundwater because contamination levels may vary between locations and seasons, while actual exposure depends on whether affected water sources are used for drinking or domestic purposes (Iyer and Meshram, 2025; Jaunjalkar and Murkute, 2023) [9, 15].

Existing evidence from Chandrapur also spans environmental monitoring and health investigations that have often been conducted separately. For example, local research has examined ambient air pollution in relation to respiratory health, whereas groundwater studies have independently assessed water chemistry and potential health risks (Gawande *et al*., 2016; Jaunjalkar and Murkute, 2023) [5, 9]. This separation makes it difficult to develop a comprehensive district-level understanding of exposure across communities affected by multiple pollution sources. A focused synthesis is therefore needed to integrate evidence on air and water contamination, exposure pathways and documented health effects, while distinguishing Chandrapur-specific findings from evidence generated elsewhere. The present review aims to critically examine the available evidence on air and water pollution in Chandrapur, with an emphasis on pollution sources, spatial and seasonal patterns, exposure routes, and documented health outcomes, and to identify key gaps in district-specific research.

**Air Pollution in Chandrapur District: Sources and Exposure Patterns**

Air pollution in Chandrapur results from a combination of mining, coal transport, thermal power generation, industrial activities, and urban traffic. Because these sources emit particulate pollution simultaneously, it is challenging to identify a single origin for observed ambient concentrations. Chandrapur has been identified as an environmentally stressed industrial area that requires continued pollution control and monitoring measures (CPCB, 2020) [30]. Recent evidence from Chandrapur highlights mining-related activities, industrial emissions, and traffic as key contributors, with variations across different locations within the city (Kasulkar and Thakre, 2024) [11]. Particulate matter is the most consistently reported aspect of the district's air quality. Monitoring near the Chandrapur Super Thermal Power Station and other industrial sites has measured $PM_{10}$, $PM_{2.5}$, and gaseous pollutants like $SO_2$ and $NO_2$.

Thermal power generation is an important contributor to the air-pollution profile of Chandrapur, with assessments around thermal power plant-affected areas reporting particulate matter and gaseous pollutants such as $SO_2$ and $NO_2$, highlighting the contribution of power-generation activities to local ambient air pollution (Rahate *et al*., 2022) [20]. The Chandrapur Super Thermal Power Station uses coal as its primary fuel and has implemented emission-control, effluent-treatment and continuous environmental-monitoring systems, reflecting the scale and environmental-management requirements associated with thermal power generation in the district (Yeul *et al*., 2019) [26]. This suggests that the district's air quality varies widely depending on location and local sources. When separating residential and roadside microenvironments, the spatial pattern becomes clearer.

A 2026 study measured $PM_{2.5}$ at sites near mining, roadsides, and residential areas, revealing much higher levels near mining and traffic zones than in residential areas farther from the mine. Source analysis identified non-exhaust and crustal dust, industrial emissions, vehicular exhaust, coal combustion, biomass burning, and secondary aerosols as primary sources (Gupta *et al*., 2026) [7]. This underscores that exposure differs significantly depending on whether one is near a mining corridor, an urban roadside, or a residential zone. The data also provide insights into particulate composition. In mining-influenced zones, $PM_{2.5}$ contained carbonaceous material, water-soluble ions, crustal elements, and other chemicals, with roadside locations showing a larger contribution from non-exhaust, coal, and industrial sources (Gupta *et al*., 2026) [7]. These findings imply that assessing particulate pollution requires more than just measuring total particle mass; source-specific composition helps distinguish mining dust from combustion and traffic emissions. Seasonality is another critical factor shaping Chandrapur's air quality, as particulate levels fluctuate with seasonal meteorological changes. Long-term data show seasonal trends in $PM_{2.5}$ and $PM_{10}$, influenced heavily by weather conditions, indicating that measurements taken in one season may not reflect annual exposure. Evidence also suggests that pollution affects not just those directly involved in mining or industry but also residents and commuters exposed to resuspended dust, coal movement, and urban traffic. The $PM_{2.5}/PM_{10}$ ratio can provide useful information on the relative contribution of fine and coarse particulate matter and can therefore assist in interpreting differences in particulate characteristics among urban environments (Spandana *et al*., 2021) [23].

The health significance of these exposure patterns is supported by local epidemiological studies, which found differences in respiratory symptoms among populations living near industrial areas and controls, with effects varying by distance from sources (Gawande *et al*., 2016) [5]. However, since this review aims to differentiate evidence of environmental exposure from disease-focused analyses, health outcomes are noted only to support the link between measured environmental differences and population exposure, without detailed discussion. In summary, Chandrapur's air pollution landscape is spatially varied and impacted by multiple sources. Mining, transportation, industry, power generation, and traffic each emit pollutants through different pathways, with weather conditions affecting their dispersion. New evidence from various microenvironments indicates that relying solely on fixed monitoring stations may not fully capture the district's diverse exposure risks.

**Water Pollution and Human Exposure in Chandrapur District**

Water plays a key role in environmental exposure in Chandrapur due to industrial, mining, and urban activities, with surface-water bodies and groundwater used by local communities. Unlike air pollution, where exposure mainly occurs through inhalation, contaminated water can lead to exposure through drinking, household chores, and other domestic activities. Therefore, the Chandrapur literature should be interpreted by considering both water quality and human-use pathways. Groundwater quality studies have shown spatial differences in water's physicochemical properties across Chandrapur. Groundwater investigations in the Chandrapur MIDC industrial area have documented substantial spatial variation in electrical conductivity, total dissolved solids, nitrate and total hardness, together with elevated concentrations of selected trace elements at some sampling locations (Waghmare, 2011) [31]. For instance, Gudadhe and Manik (2020) [6] raised concerns about hardness, nitrate, and other chemicals near industrial zones. These findings suggest that water quality varies locally and cannot be represented by a single district-wide value, emphasizing the need to account for land use and proximity to pollution sources when assessing exposure.

Water-quality monitoring provides an important basis for identifying spatial and temporal variation in the condition of surface- and groundwater resources (MPCB, 2022). Water quality is also affected by the characteristics of individual settlements. For example, Lohara village has reported poor water conditions, with high hardness and iron levels (Kazi and Thakare, 2023) [12]. Thermal power generation can influence both surface- and groundwater quality in the Warora area of Chandrapur, where variations in physicochemical characteristics of water have been reported around thermal power plant-affected locations (Khati *et al*., 2014) [14]. While elevated parameters indicate environmental contamination, they do not automatically imply a direct health impact. Human exposure depends on the concentration, frequency, duration of water use, its intended purpose, and the availability of alternative sources. Seasonal monitoring of the Erai River at different locations near Chandrapur has demonstrated variation in physicochemical water-quality parameters, highlighting the importance of considering seasonal conditions when assessing the status of surface-water resources in the district (Jadhao and Dhage, 2018; Paunkar and Kamdi, 2023) [8, 19].

Sediment investigations of the Erai River have provided additional evidence of environmental stress within the river system, with anthropogenic activities and waste inputs contributing to changes in sediment characteristics and potentially affecting aquatic organisms (Gaidhane, 2021) [4]. Coal-mining activities can affect the quality of nearby water resources by altering drainage patterns and transporting mine-associated contaminants. Water-quality assessment around the Hindustan Lalpeth Coal Mine in Chandrapur has documented variations in physicochemical characteristics, providing site-specific evidence of the influence of coal-mining activity on surrounding water resources (Tambekar *et al*., 2012; Tambekar *et al*., 2013) [24, 25]. A recent assessment of groundwater around the Chandrapur industrial area, using hydrochemical parameters and the Water Quality Index, further demonstrates spatial variation in groundwater quality within industrially influenced settings (Surtekar and Patode, 2025) [29].

Distinguishing between water contamination and actual human exposure is crucial when interpreting groundwater-quality data in Chandrapur. The detection of a contaminant at a particular sampling location does not necessarily imply that all residents within the surrounding area experience equivalent exposure. Actual exposure depends on factors such as the source of household drinking water, dependence on groundwater, treatment practices, frequency and duration of use, and access to alternative water supplies. Consequently, environmental measurements should be interpreted separately from individual exposure and health outcomes. Assessment of drinking-water quality is important not only for identifying physicochemical deterioration but also for determining whether existing water sources require appropriate treatment before use for drinking purposes (Khadse *et al*., 2024) [13].

Available studies from Chandrapur demonstrate substantial spatial and temporal variability in groundwater quality. Investigations of groundwater in the industrial belt have reported differences in physicochemical characteristics between locations and seasons, with several parameters showing higher concentrations during summer and partial dilution during the monsoon (Iyer and Meshram, 2025) [15]. Similarly, groundwater investigations in western Chandrapur have demonstrated spatial variation in hydrochemical characteristics and have incorporated human health risk assessment to evaluate the potential significance of observed contamination (Jaunjalkar and Murkute, 2023) [9]. These findings indicate that a single sampling period or a limited number of locations may not adequately represent groundwater conditions across the district.

Seasonal variation is particularly important in Chandrapur because rainfall and groundwater recharge can modify the concentration of dissolved constituents. Iyer and Meshram (2025) [15] reported that several groundwater parameters declined during the monsoon compared with summer conditions, consistent with dilution associated with seasonal recharge. Earlier investigations have likewise demonstrated seasonal differences in groundwater-quality indicators in Chandrapur, supporting the need for repeated monitoring rather than reliance on a single sampling period.

The available evidence also reveals a separation between environmental monitoring and health assessment. Although studies in Chandrapur have generated important information on groundwater chemistry and potential health risks, relatively few investigations simultaneously characterise environmental contamination, individual exposure patterns, and health outcomes within the same population (Jaunjalkar and Murkute, 2023) [9]. This limits the ability to establish direct exposure–effect relationships at the district level. Therefore, future investigations should integrate standardized water-quality assessment with household information concerning drinking-water sources, treatment practices, duration of use and proximity to potential contamination sources.

A source–water quality–use–exposure framework would offer a better basis for evaluating water-related environmental risks in Chandrapur. This method distinguishes between detecting contaminants in environmental media, the likelihood and extent of human exposure, and health effects backed by epidemiological data. It also accounts for seasonal and spatial variations in water quality alongside household water use patterns. Such an integrated approach could significantly enhance the interpretation of environmental data and pinpoint communities that need more detailed exposure and health assessments.

## Human Exposure Pathways and the Air–Water Connection

Human exposure to environmental pollution in Chandrapur occurs through different environmental media and is influenced by the intensity, duration and location of exposure. Air and water represent two important pathways, although the mechanisms through which people encounter pollutants differ. Air contaminants are primarily encountered through inhalation, whereas contaminated groundwater may contribute to exposure through drinking and domestic use. Consequently, assessment of environmental pollution should distinguish between the presence of contaminants in an environmental medium and the extent to which those contaminants result in actual human exposure.

For air pollution, inhalation represents the principal pathway of exposure to particulate and gaseous pollutants. Chandrapur-specific evidence demonstrates considerable spatial variability in particulate concentrations. Recent research conducted in a coal-mining town in the district compared mining-roadside, city-roadside and residential microenvironments and identified differences in $PM_{2.5}$ concentrations and source contributions among these locations (Gupta *et al.*, 2026) [7]. The study further demonstrated that particulate matter originated from a mixture of sources, including crustal or non-exhaust material, industrial emissions, vehicular activity and coal combustion (Gupta *et al.*, 2026) [7].

This spatial variability has direct implications for exposure assessment. Individuals living near mining activities or major transportation routes may experience different exposure conditions from those living in relatively distant residential areas. Therefore, measurements from a limited number of fixed monitoring locations may not fully represent the exposure experienced by people moving between residential, occupational and roadside environments. The Chandrapur evidence supports the importance of considering microenvironmental differences when interpreting population exposure.

Local epidemiological evidence provides additional context. Gawande *et al*. (2016) [5] investigated adults living in Chandrapur and compared populations from industrially influenced and control areas. The study reported differences in respiratory health indicators between the study groups, providing local evidence that differences in environmental conditions may correspond with differences in population health. However, because the study used a cross-sectional design, the findings should be interpreted as associations rather than definitive evidence of causality.

Water represents a distinct exposure pathway, particularly where groundwater is used for drinking. Chandrapur contains numerous groundwater-dependent communities, and investigations have demonstrated spatial differences in groundwater chemistry. Gudadhe and Manik (2020) [6], for example, evaluated groundwater quality at six locations in Chandrapur city using a range of physicochemical parameters and reported that although many measured parameters were within prescribed standards, some exceeded permissible limits, indicating that groundwater quality was not uniform across the sampled locations.

Hydrogeochemical investigations have also demonstrated that groundwater composition in Chandrapur is influenced by both natural and anthropogenic processes. Jaunjalkar and Murkute (2023) [9] reported that major ions in groundwater from western Chandrapur were substantially influenced by rock–water interactions and geogenic processes, whereas selected constituents were associated with anthropogenic inputs. Their analysis also incorporated human health risk assessment, demonstrating the importance of evaluating water chemistry in relation to potential exposure rather than treating concentration measurements as endpoints in themselves.

More recent evidence has highlighted the co-occurrence of multiple contaminants. Kamble, 2025 [10] examined groundwater from 36 locations in Chandrapur district and investigated arsenic and fluoride together with other physicochemical parameters. The study reported arsenic concentrations ranging from 0.0158 to 0.0414 mg/L and fluoride concentrations from 0.50 to 2.32 mg/L. Arsenic and fluoride were reported to co-occur at 17 of the 36 sampling locations (47.22%), indicating that groundwater exposure may involve multiple contaminants simultaneously (Kamble, 2025) [10]. Spatial assessment provides another important dimension of water exposure. Chandekar *et al*. (2024) [2] used remote sensing and GIS approaches to examine groundwater-quality conditions in Chandrapur and highlighted spatial differences associated with mining and industrially influenced areas. Such approaches are useful because they can identify areas requiring more detailed field investigation and can connect water-quality observations with land-use and source characteristics.

An important distinction must be maintained between environmental contamination, potential exposure and demonstrated health effects. The detection of arsenic, fluoride, or other constituents in groundwater does not, by itself, establish that all residents of an affected locality experience the same level of exposure. Actual exposure depends on the source of drinking water, the frequency and duration of consumption, household treatment practices, and the availability of alternative water supplies. Similarly, ambient air concentrations do not necessarily represent the personal exposure of every resident because individuals spend time in different microenvironments. The Chandrapur evidence therefore supports a source–environment–exposure framework. For air pollution, this pathway can be represented as *emission source → ambient concentration → individual inhalation*. For water pollution, it can be represented as *contamination source → groundwater/surface-water quality → water use → ingestion or other contact*. These pathways may operate simultaneously in communities within mining- and industry-influenced environments.

An integrated approach is consequently valuable, but air and water exposure should not be treated as identical or automatically combined into a single risk estimate. Instead, their individual characteristics should first be established and subsequently examined in relation to population characteristics and documented health outcomes. Such an approach would provide a more scientifically defensible basis for evaluating environmental exposure in Chandrapur.

## Documented Effects of Air and Water Pollution in Chandrapur

The effects of environmental pollution in Chandrapur need to be interpreted carefully because the available evidence differs considerably between measured exposure, reported health outcomes, and risk estimates. Rather than assuming that every documented contaminant produces a corresponding disease burden, the available literature should be considered according to the strength and type of evidence available. Particulate air pollution is the best-documented environmental exposure in Chandrapur. Local evidence has identified differences in respiratory health between populations living in industrially influenced and control areas. In a cross-sectional study of adults, Gawande *et al*. (2016) [5] reported greater respiratory symptoms among participants from the industrially exposed area and identified an association between ambient air pollution and respiratory health indicators. These findings provide district-specific evidence of a relationship between air quality and respiratory outcomes, although the cross-sectional design limits causal inference.

The broader health significance of particulate matter is well established. The Global Burden of Disease assessment for India identified air pollution as a major contributor to premature mortality and disease burden, with particulate matter representing an important component of this burden (Balakrishnan *et al*., 2019) [1]. Similarly, the American Heart Association's scientific statement concluded that particulate air pollution is associated with cardiovascular morbidity and mortality through mechanisms involving pulmonary and systemic inflammation, oxidative stress and vascular dysfunction (Rajagopalan *et al*., 2018) [21]. These broader findings provide biological and epidemiological context for Chandrapur but should not be interpreted as direct estimates of Chandrapur-specific disease burden.

The composition of particulate matter may also influence its effects. Recent research from Chandrapur has identified contributions from crustal material, industrial sources, vehicular emissions, coal combustion, and secondary aerosol formation to $PM_{2.5}$ (Gupta *et al*., 2026) [7]. This source diversity is relevant because populations may encounter chemically different particulate mixtures depending on their location. Consequently, future research in Chandrapur should consider not only particulate mass concentrations but also source and compositional characteristics when evaluating exposure and associated effects.

Water-related health effects require a different interpretation because exposure depends strongly on whether contaminated water is actually used for drinking or domestic purposes. Chandrapur groundwater investigations have identified spatial variability in water chemistry and, in some locations, concentrations of constituents that warrant attention. Jaunjalkar and Murkute (2023) [9] incorporated human-health risk assessment into their hydrogeochemical investigation of groundwater in western Chandrapur. Their findings demonstrate the usefulness of combining groundwater chemistry with exposure-based risk calculations rather than interpreting individual water-quality parameters in isolation.

More recent evidence concerning arsenic and fluoride provides additional reason for attention to groundwater exposure. Kamble (2025) [10] reported the co-occurrence of arsenic and fluoride in groundwater across sampled locations in Chandrapur district. Because chronic exposure to arsenic and excessive fluoride can have established health consequences, the occurrence of these constituents warrants further exposure assessment. However, environmental detection alone does not establish that the entire population of Chandrapur experiences clinically significant exposure. The health relevance depends on concentration, duration of consumption and dependence on the affected water source.

The available evidence suggests that air and water pollution may contribute to different exposure pathways and different categories of health effects. Air pollution primarily involves inhalation, with respiratory and cardiovascular outcomes being the most extensively documented in the wider scientific literature (Rajagopalan *et al*., 2018; Schraufnagel *et al*., 2019) [21, 22]. Water contamination, in contrast, may involve ingestion and therefore requires assessment of drinking-water sources and consumption patterns before health risks can be estimated.

A major limitation of the Chandrapur evidence is that environmental measurements and health outcomes are often generated by separate investigations. Consequently, the available literature provides stronger evidence for the presence and spatial variability of environmental contamination than for precise population-level exposure-response relationships. This distinction is important for avoiding overstatement of health effects and for identifying where additional district-specific epidemiological research is required. Overall, the evidence supports environmental pollution as an important health-relevant concern in Chandrapur, but the strength of evidence varies by pollutant, exposure pathway and outcome. Local measurements should therefore remain the foundation of Chandrapur-specific conclusions, while evidence from broader populations should be used primarily to interpret potential health significance rather than to assign local disease burdens.

**Evidence Gaps and Research Priorities**

The available literature demonstrates that Chandrapur has a substantial body of research on environmental pollution, particularly air quality and groundwater conditions. However, the evidence remains uneven across locations, environmental media, pollutants and study designs. A major limitation is that individual investigations often examine a specific pollutant, locality or environmental medium, making it difficult to develop a consistent district-level picture of exposure.

For air pollution, greater attention is required to spatially resolved exposure assessment. Recent evidence from mining, roadside and residential microenvironments demonstrates that particulate concentrations and source contributions can differ considerably over relatively short distances (Gupta *et al*., 2026) [7]. The application of geoinformatics to the Erai watershed has demonstrated the usefulness of spatial assessment in evaluating the environmental impacts of coal-mining activities in Chandrapur district (Patil and Katpatal, 2008) [18]. Consequently, monitoring based only on a limited number of fixed locations may not adequately represent exposure across different residential and occupational settings.

Seasonal coverage is another important priority. Differences in particulate concentrations between seasons indicate that annual exposure cannot reliably be inferred from measurements obtained during a single period. Future monitoring should therefore incorporate repeated seasonal observations and consistent sampling protocols to distinguish persistent pollution patterns from short-term fluctuations.

Water-quality evidence similarly remains spatially fragmented. Studies from Chandrapur city, western Chandrapur and other localities have documented variation in groundwater chemistry (Gudadhe and Manik, 2020; Jaunjalkar and Murkute, 2023) [6, 9]. More recent work has identified the co-occurrence of arsenic and fluoride at several sampled locations, emphasizing the importance of examining multiple contaminants rather than evaluating individual parameters independently (Kamble, 2025) [10]. However, additional systematic sampling is needed to determine the geographical extent, persistence and potential exposure significance of these findings. Another priority is to strengthen the connection between environmental measurements and actual human exposure. Environmental contamination does not necessarily correspond to uniform exposure within a population. Residential location, occupation, time spent outdoors, transportation patterns, household conditions and drinking-water sources can modify individual exposure. Future studies should therefore combine environmental monitoring with appropriately collected individual or household-level exposure information.

There is also a need for greater consistency in the methods used to evaluate air and water quality. Differences in sampling locations, sampling duration, measured parameters and analytical approaches can make direct comparison between studies difficult, particularly when investigations cover different environmental settings and monitoring periods (Patil and Katpatal, 2008; Gudadhe and Manik, 2020; Jaunjalkar and Murkute, 2023) [6, 9, 18]. Standardized monitoring and reporting would improve the ability to identify temporal trends and spatial gradients across Chandrapur. Finally, future research should place greater emphasis on Chandrapur-specific exposure–effect evidence. Although local studies have examined associations between environmental conditions and health indicators, much of the available evidence remains based on separate environmental and health assessments (Gawande *et al*., 2016; Jaunjalkar and Murkute, 2023) [5, 9]. District-specific studies that simultaneously characterize environmental conditions and relevant health indicators would therefore provide stronger evidence for determining the local significance of pollution.

Overall, the principal research requirement is not simply more pollution measurements, but better integration of spatially and seasonally resolved environmental data with information on actual human exposure and documented effects. Such an approach would strengthen the scientific basis for environmental-health assessment and targeted pollution-control strategies in Chandrapur.

## Implications for Environmental Monitoring and Exposure Assessment

The evidence reviewed for Chandrapur indicates that environmental pollution should be assessed through a spatially and temporally integrated monitoring framework. Differences in air-quality conditions between mining, roadside and residential environments demonstrate that pollution exposure can vary substantially within relatively small geographic areas (Gupta *et al*., 2026) [7]. Similarly, groundwater investigations have identified spatial differences in water chemistry across Chandrapur (Gudadhe and Manik, 2020; Jaunjalkar and Murkute, 2023) [6, 9]. These findings suggest that district-level averages alone may not adequately describe conditions experienced by individual communities.

For air pollution, monitoring should include repeated measurements of major particulate and gaseous pollutants across industrial, mining-proximate, roadside and residential locations. Particular attention should be given to $PM_{2.5}$ and $PM_{10}$ because particulate matter represents a consistently documented component of Chandrapur's air-pollution profile (Gupta *et al*., 2026) [7]. Source characterization can further improve interpretation by distinguishing contributions from mining-related dust, traffic, industrial emissions and combustion sources.

Water-quality monitoring should similarly extend across representative surface-water and groundwater locations and should incorporate seasonal sampling. Existing studies demonstrate that groundwater characteristics vary between locations and that some sites may contain multiple constituents of potential concern (Jaunjalkar and Murkute, 2023; Kamble, 2025) [9, 10]. Repeated sampling would help establish whether observed contamination represents persistent conditions or seasonal variation.

An important improvement would be to connect environmental monitoring with actual exposure information. For air pollution, residential location, occupation, and time spent in different microenvironments can influence individual exposure. For water pollution, the principal considerations include drinking-water source, frequency of consumption and household treatment practices. Incorporating these variables would allow environmental measurements to be interpreted more meaningfully in relation to human exposure. Spatial tools such as GIS can support this process by integrating pollution measurements with residential distribution, industrial locations, mining areas and transportation corridors. Chandekar *et al*. (2024) [2] demonstrated the usefulness of GIS and remote sensing for examining spatial patterns in groundwater quality in Chandrapur. Such approaches can help identify areas requiring intensified monitoring while avoiding the assumption that proximity to an industrial source automatically constitutes a confirmed exposure hotspot.

Finally, environmental monitoring should be accompanied by consistent reporting and long-term data collection. Comparable sampling protocols, clearly defined monitoring locations and repeated measurements would improve the ability to identify persistent pollution patterns and meaningful changes over time. Linking these environmental observations with carefully designed exposure and health assessments would provide stronger district-specific evidence than isolated environmental or epidemiological studies.

For Chandrapur, therefore, the priority is not simply to increase the number of measurements, but to develop a monitoring system capable of answering three connected questions: where contamination occurs, how people are exposed, and whether measurable exposure is associated with documented effects. This approach would provide a stronger scientific foundation for targeted environmental management in the district.

## Conclusion

Chandrapur district presents a complex pollution environment in which air and water contamination occur within a landscape shaped by mining, thermal power generation, industrial activity, transportation and settlement. The available evidence indicates that pollution is not uniformly distributed across the district; rather, environmental conditions vary according to location, source characteristics and seasonal factors. Air-quality studies demonstrate spatial differences in particulate exposure between mining-influenced, roadside and residential environments, while groundwater investigations reveal substantial variation in water chemistry among different parts of the district. These findings emphasize that environmental pollution in Chandrapur cannot be adequately represented by a single district-wide value.

The evidence also highlights an important distinction between environmental contamination and human exposure. The presence of pollutants in air or water does not necessarily mean that all residents experience the same exposure or the same health consequences. Exposure depends on where people live and work, the environmental media they encounter, the duration and frequency of contact, and individual patterns of activity and water use. A more effective assessment of Chandrapur therefore requires an integrated but carefully differentiated approach to air and water pollution. Spatially distributed and seasonally repeated monitoring, combined with information on human exposure pathways, would improve understanding of the environmental conditions experienced by local communities. At the same time, health effects should be interpreted on the basis of evidence that is specifically applicable to Chandrapur rather than inferred solely from studies conducted elsewhere.

The major priority for future research is consequently to strengthen the connection between measured pollution, actual human exposure and documented effects. Such evidence can support more precise identification of affected communities, improve environmental monitoring and contribute to locally appropriate pollution-management strategies. For Chandrapur, a district-specific evidence base integrating air quality, water quality, and human exposure will be essential for developing scientifically sound and targeted environmental health interventions.

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**Conflict of interest**

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors**.**

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