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Sources and Impacts of Dust Pollution in Iran: A Comprehensive Overview

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Abstract

Dust pollution is an escalating environmental concern in Iran, profoundly impacting public health, agriculture, and infrastructure. This review synthesizes current knowledge on the sources, transport mechanisms, and socio-economic effects of dust storms while highlighting strategies for effective mitigation. Unsustainable land management practices and climate variability exacerbate dust generation, necessitating comprehensive governance reforms that integrate climate adaptation, land use planning, and pollution control. Enhanced research and monitoring efforts, including the use of satellite remote sensing, aerosol monitoring stations, and predictive models, are critical for identifying dust hotspots and assessing temporal trends. Expanding research to evaluate the socio-economic impacts of dust on agriculture, public health, and infrastructure is essential for formulating targeted policies. Furthermore, integrating predictive modeling with climate change projections provides valuable insights into future trends, enabling proactive adaptation strategies. Strengthening collaborations with international research institutions fosters knowledge transfer and aligns Iran’s initiatives with global best practices. Collectively, these efforts, when combined with public awareness campaigns and sustainable land management reforms, offer a comprehensive framework for addressing dust pollution and its associated challenges.

Keywords: Dust pollution mitigation, environmental governance, advanced monitoring techniques, socio-economic impacts of dust storms, predictive modeling, climate adaptation.

1 Introduction

Dust pollution has emerged as a critical environmental and public health challenge in Iran, a country with expansive arid and semi-arid regions. This issue is exacerbated by climatic changes, prolonged droughts, desertification, and anthropogenic activities, all of which have intensified the frequency and severity of dust storms. These storms significantly degrade air quality, disrupt ecosystems, and threaten public health, particularly in urban and industrial areas where human exposure is heightened. Geographically, Iran's proximity to vast desert regions in Iraq and Saudi Arabia amplifies transboundary dust transport, creating a compounded effect on local and regional pollution levels (Seihei et al., 2024). In Tehran, for example, the interaction between internal sources, such as the Semnan province, and external contributions from Iraq and northern Saudi Arabia illustrates the transboundary nature of dust pollution. Seasonal variations and meteorological factors, including tropospheric troughs, exacerbate dust movement into urban areas (Mohammadi et al., 2024). Cities like Ahvaz and Zabol exhibit alarming levels of particulate matter less than 10 µm (PM10) and trace metals, primarily linked to industrial emissions, vehicular traffic, and fossil fuel combustion (Asvad et al., 2023). Notably, colder seasons tend to show higher pollution levels, attributed to atmospheric stability and reduced dispersion of contaminants (Ariapak et al., 2022).

The health impacts of dust pollution are extensive, with cities like Andimeshk reporting increased cardiovascular and respiratory diseases due to exposure to high PM10 concentrations. During peak dust episodes, carcinogenic risks from metals such as arsenic, chromium, and cobalt are significant, particularly for children and vulnerable populations (Soleimani-Sardo et al., 2023). In Tehran, the enrichment of heavy metals like Pb and Zn in indoor and street dust underscores the role of anthropogenic activities, including legacy sources such as leaded

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gasoline and current vehicular emissions (Khajooee et al., 2024). Ecologically, the widespread contamination of dust particles with elements such as Cu, Ni, and Zn poses a risk to soil quality and biodiversity, particularly in sensitive regions like the Jazmurian Basin (Soleimani-Sardo et al., 2023). Efforts to model and predict dust pollution have utilized advanced data mining algorithms and environmental indices to identify controlling factors and develop mitigation strategies. For instance, deep neural networks and Shapley values have highlighted the roles of wind speed, precipitation, and soil heat flux in shaping dust patterns across cold and warm months (Ebrahimi-Khusfi et al., 2021). These insights underline the importance of integrated approaches to addressing dust pollution, which requires local and regional cooperation to mitigate its multifaceted impacts.

Table 1 provides a comprehensive overview of Iran's major sources of dust pollution, categorized into natural, anthropogenic, and transboundary factors. Natural sources include vast deserts such as Dasht-e Kavir and Dasht-e Lut, which are prone to wind erosion, especially during dry seasons, as well as dried-up lakes and wetlands like Urmia and Hamoun, which contribute significant quantities of saline dust due to their exposed sediment beds. Seasonal wind patterns, such as the Shamal and the 120-day winds, exacerbate these natural emissions by transporting particles over vast areas. Anthropogenic sources highlight the role of human activities in intensifying dust emissions. Overgrazing and deforestation, particularly in the Zagros Mountains, lead to vegetation loss and soil destabilization, increasing erosion. Unsustainable agricultural practices, including groundwater over-extraction and mismanagement of irrigation, result in degraded lands that are highly susceptible to dust generation. Urbanization and infrastructure development, especially in cities like Ahvaz and Tehran, further contribute through construction dust and vehicular emissions. Additionally, dried agricultural lands, often abandoned due to water scarcity, leave loose soil vulnerable to wind erosion, amplifying localized dust events. Transboundary dust pollution underscores the regional dimension of the issue, with dust storms originating from neighboring countries like Iraq, Syria, and Saudi Arabia significantly affecting Iran's western and southwestern regions. These storms are driven by degraded lands and drought conditions in those countries, with dust particles traveling long distances across borders. Each factor is associated with specific regions, seasonal patterns, and characteristics, providing a nuanced understanding of the drivers behind Iran’s dust pollution crisis. The accompanying citations support the table's data, linking each factor to credible research findings and emphasizing the need for localized and collaborative mitigation strategies.

This manuscript provides a comprehensive overview of the sources, patterns, and impacts of dust pollution in Iran. It synthesizes findings from multiple studies, identifies critical knowledge gaps, and suggests actionable pathways for addressing one of Iran’s most pressing environmental challenges.

1 Natural Resources

1.1 Desert Areas

Iran's geographic landscape includes extensive arid and semi-arid regions, particularly the Dasht-e Kavir (Great Salt Desert) and Dasht-e Lut (Lut Desert), pivotal contributors to the country’s natural dust generation. These regions are characterized by dry soil conditions, sparse vegetation cover, and extreme temperature fluctuations that collectively promote aeolian processes, the primary mechanism for dust emissions (Ariapak et al., 2022). The Dasht-e Kavir, spanning approximately 77,600 square kilometers in central Iran, comprises vast expanses of salt flats and mudflats, which become significant sources of fine particulate matter under wind action. Similarly, the Dasht-e Lut, a UNESCO World Heritage site, holds the record for some of the highest surface temperatures on Earth, intensifying soil desiccation and the potential for dust generation (Mousavi et al., 2024).

Natural climatic conditions, including prolonged droughts and reduced precipitation, exacerbate the susceptibility of these areas to dust generation. The lack of stabilizing vegetation and high evaporation rates further dry the soil surface, creating an ideal environment for mobilizing fine particles during wind events (Ebrahimi-Khusfi et al., 2021). Dust storms originating from these regions affect local ecosystems and contribute significantly to regional and transboundary dust pollution, impacting neighboring countries like Iraq, Afghanistan, and Pakistan (Soleimani-Sardo et al., 2023).

Studies using satellite imagery and ground-based data have shown that the Lut Desert is among the most active sources of atmospheric dust in southwest Asia, with strong seasonal winds, known locally as the "120-day winds," driving substantial dust emissions during the summer months (Pouri et al., 2023). The interaction between these deserts and anthropogenic activities—such as agricultural mismanagement and deforestation—further amplifies the frequency and intensity of dust storms (Madadi et al., 2022).

Dust from the Dasht-e Kavir and Dasht-e Lut carries trace elements, including arsenic, lead, and cadmium, contributing to air quality degradation and posing ecological and health risks. Transported dust can reach major urban centers like Tehran and Ahvaz, intensifying the burden on air quality management and public health systems (Khajooee et al., 2024). This highlights the critical need for sustainable land management practices and regional cooperation to mitigate the adverse impacts of these natural dust sources.

1.2. Regional Dust Sources

Dust storms significantly affecting Iran often have transboundary origins, primarily from neighboring Iraq, Syria, and Saudi Arabia, due to shared arid climates, regional droughts, and prevailing wind patterns. The geographical and climatic conditions of these areas make them major contributors to Iran’s dust pollution, particularly during periods of intensified wind activity. In Iraq, key dust sources include the deserts surrounding Lake Tharthar, the Hour-al-Azim Marsh, and the drying wetlands of Hammar. These areas, once stabilized by water bodies, have become active dust emission hotspots due to prolonged droughts, mismanagement of water resources, and upstream dam construction that reduces river flow into marshlands (Yousefi Kebriya et al., 2025). Lake Tharthar, located in the western desert of Iraq, is particularly prone to soil desiccation, while the Hour-al-Azim Marsh near the Iran-Iraq border is an area where declining water levels have directly impacted dust storm frequency and intensity in southwestern Iran (Mousavi et al., 2024).

Table 1: Main Sources of Dust Storms in Iran with Citations

	Factor	Key Data Points	Region Affected	Seasonality	Specific Characteristics	Citations
Natural Sources	Deserts (Dasht-e Kavir, Dasht-e Lut)	Vast, arid regions prone to wind erosion, particularly during dry seasons and under strong winds like the 120-day winds.	Central and Eastern Iran	Spring and Summer	Arid zones with sparse vegetation, high sand and silt content.	(Goudie, 2006)
	Dried-up Lakes and Wetlands (Urmia, Hamoun, Gavkhouni)	Significant dust sources due to desiccation, exposing large areas of fine sediment and salt crusts.	Northwest, Southeast, Central Iran	Year-round (intensified in dry seasons)	Highly saline surfaces, contributing to fine particulate matter.	(Abadi et al., 2024)
	Seasonal Wind Patterns (e.g., Shamal, 120-day winds)	Strong, dry winds exacerbate dust storms by mobilizing loose sediments over vast areas.	Southwest, Southeast Iran	Summer	Frequent during peak dry periods, carrying particles long distances	(Beyranvand et al., 2023)
Anthropogenic Sources	Overgrazing and Deforestation	Depletion of vegetation cover, soil erosion, and increased dust generation are occurring, particularly in the Zagros Mountains and surrounding arid regions	Zagros Region, Arid Plains	Year-round	Vegetation loss leads to increased soil erosion in sloped terrains	(Jafari et al., 2024)
	Unsustainable Agriculture	Over-extraction of groundwater, mismanagement of irrigation, and conversion of arable land into degraded, dust-prone areas	Central, Southern Iran	Year-round (peak in summer)	Soil compaction and exposure due to improper irrigation methods	(Hosseini et al., 2024)
	Urbanization and Infrastructure Development	Construction activities, unpaved roads, and land clearing, especially around cities in dust-prone zones	Urban Centers (Ahvaz, Tehran)	Year-round	Includes fine construction dust and vehicular emissions	(Ariapak et al., 2022)
	Dried Agricultural Lands	Formerly cultivated areas are abandoned due to water scarcity, leaving exposed, loose soil vulnerable to wind erosion	Across agricultural regions	Summer and Autumn	Dry, loose soils are often near wind corridors	(Madadi et al., 2022)
Transboundary Dust	Dust Storms from Neighboring Countries (Iraq, Syria, Saudi Arabia)	Significant contributors to dust storm events in western and southwestern Iran, due to degraded lands and drought in those regions	Western and Southwestern Iran	Spring and Summer	Dust storms often travel hundreds of kilometers across borders	(Asvad et al., 2023)

Saudi Arabia's Empty Quarter Desert (Rub' al Khali), one of the largest continuous sand deserts globally, is another substantial source of transboundary dust. Dust storms from this region often traverse into southern and southeastern Iran, carried by dominant wind patterns such as the Shamal winds. These northwesterly winds, prevalent in spring and summer, are particularly effective in mobilizing fine dust particles, exacerbating air pollution in provinces like Khuzestan, Hormozgan, and Sistan and Baluchestan (Darvishi Boloorani et al., 2024). Syria also contributes to regional dust transport, particularly from its arid central plains, where desertification has accelerated due to climatic and anthropogenic factors. The combined contributions from these neighboring regions underline the transboundary nature of dust storms affecting Iran.Within Iran, geospatial analyses identify the drying of Hamoon Lake in the southeastern part of the country as a critical local dust sourceOnce a major freshwater body fed by the Helmand River from Afghanistan, Hamoon Lake's desiccation has created vast expanses of barren land prone to wind erosion. Urban expansion, deforestation, and overgrazing further exacerbate the problem, with these local sources often interacting with transboundary dust flows to compound pollution levels (Darvishi Boloorani et al., 2024). The seasonal nature of dust transport is also noteworthy, with spring and summer seeing the highest storm frequencies. During these seasons, reduced vegetation cover, high temperatures, and persistent drought amplify the vulnerability of soils to wind erosion (Borhani et al., 2024).

The implications of these dust storms extend beyond air quality deterioration, affecting human health, agriculture, and infrastructure in affected regions. Dust particles often carry heavy metals and biological contaminants, posing significant risks to respiratory and cardiovascular health (Soleimani-Sardo et al., 2023). Dust deposition also disrupts photosynthesis in crops, reduces soil fertility, and damages water infrastructure by sedimentation. These issues underscore the urgency for collaborative regional strategies to manage water resources and combat desertification. Shared water management agreements, restoration of wetlands, and large-scale reforestation initiatives, particularly in dust-prone regions, are essential measures. Successful examples of such initiatives, like China's afforestation programs to combat the Gobi Desert's expansion, could serve as models for the Middle East (Ahmadzai, 2023).

Recent advancements in remote sensing and climate modeling further emphasize the need for regional cooperation. Satellite observations, such as those from MODIS and Landsat, have been instrumental in mapping dust sources and transport pathways, providing critical data to inform mitigation strategies (Ebrahimi-Khusfi et al., 2021). Such tools, combined with on-the-ground monitoring, can help policymakers and scientists collaborate effectively across borders to address the shared challenge of dust pollution.

2 Anthropogenic Resources

2.1 Overgrazing and Deforestation

2.1.1 Overgrazing and its Impact on Dust Generation

Overgrazing is a significant anthropogenic factor contributing to dust pollution in Iran, particularly in arid and semi-arid regions. Livestock grazing, when unmanaged, depletes vegetation cover, exposing the soil surface to wind erosion. Vegetation plays a critical role in stabilizing soils by anchoring particles and reducing wind speed at ground level, thereby mitigating dust generation. Overgrazed lands lose this protective layer, leading to increased soil destabilization and heightened vulnerability to dust storms. In Iran, traditional nomadic and rural livelihoods often rely heavily on livestock grazing, and unsustainable practices have intensified in areas like Sistan and Baluchestan, Khuzestan, and central Iran, where desertification risks are already high due to climatic pressures (Madadi et al., 2022). Satellite observations have identified bare patches in these regions as primary contributors to local and transboundary dust storms, linking them to overgrazing-induced vegetation loss (Ebrahimi-Khusfi et al., 2021). In regions such as the Hamoon Basin and around the Dasht-e Lut, overgrazing and water scarcity exacerbate land degradation. As the soil becomes drier and more compacted, its capacity to retain moisture decreases, further amplifying wind erosion and dust generation. The interplay between overgrazing and climate change, including prolonged droughts, compounds this issue, making these areas some of southwest Asia's most active dust sources (Soleimani-Sardo et al., 2023).

2.1.2 Deforestation and the Role of the Zagros Mountains

Deforestation in Iran, particularly in the ecologically significant Zagros Mountain range, is another major contributor to dust pollution. The Zagros Mountains, which stretch across the western regions of Iran, historically supported dense oak forests that acted as natural barriers to wind and erosion. These forests also stabilized slopes, reduced runoff, and helped retain soil. However, widespread deforestation driven by agricultural expansion, firewood collection, and land use changes has left large swaths of land exposed. Studies indicate that deforestation in the Zagros region has not only led to a loss of biodiversity but also contributed to increased soil erosion and sediment mobilization. This erosion creates fine dust particles that are easily transported by wind to urban areas such as Tehran, Ahvaz, and Isfahan (Mousavi et al., 2024). Urban sprawl and the conversion of forested lands into agricultural fields exacerbate this problem, as these lands are less effective at retaining soil and water during heavy rainfall events, often preceding dust storms. Moreover, the deforestation of the Zagros Mountains has been linked to hydrological changes that impact downstream wetlands, such as Hour-al-Azim and Shadegan, reducing their capacity to act as dust sinks. This interplay between deforestation and wetland degradation highlights the cascading effects of land-use change on Iran's dust dynamics (Balkanlou et al., 2020).

2.1.3 Cascading Effects on Dust Pollution

The combined impact of overgrazing and deforestation is particularly pronounced in areas where these two practices overlap. For example, the foothills of the Zagros Mountains and plains surrounding Khuzestan Province experience both grazing pressures and deforestation for agricultural purposes. These regions are now hotspots for dust production, contributing to transboundary dust storms that reach Iraq and the Persian Gulf (Ahadi et al., 2020). The economic and health implications of these anthropogenic factors are profound. Increased dust generation exacerbates respiratory diseases and reduces agricultural productivity by damaging crops and depleting soil nutrients. In Khuzestan, one of Iran's most affected provinces, air quality indices often exceed safe thresholds due to frequent dust storms, many of which originate from degraded lands within and beyond the province (Daniali and Karimi, 2019).

2.1.4 Mitigation Strategies

To address these challenges, sustainable land management practices are urgently needed. Reforestation initiatives, especially in the Zagros region, could significantly reduce soil erosion and dust generation. Studies from similar contexts, such as China's Loess Plateau, have demonstrated that afforestation and soil conservation measures can restore degraded lands and curtail dust storms (Wu et al., 2019). Additionally, implementing rotational grazing systems and promoting alternative livelihoods for rural communities could reduce overgrazing pressures. Collaborative efforts involving local communities, policymakers, and international stakeholders are essential to mitigate the dual impacts of overgrazing and deforestation on Iran's environment and public health.

2.2. Unsustainable Agriculture

2.2.1 Excessive Water Use and Mismanagement in Agriculture

Unsustainable agricultural practices are a major anthropogenic contributor to dust pollution in Iran, exacerbating desertification and soil erosion. Excessive water use, particularly in regions already vulnerable to aridification, has significantly reduced groundwater levels and led to the degradation of fertile agricultural lands. The over-extraction of water for irrigation, coupled with inefficient traditional farming techniques, has dried up critical aquifers, rendering soil more susceptible to wind erosion. Regions such as Khuzestan, where extensive irrigation is employed for crops like wheat and sugarcane, illustrate the consequences of water mismanagement on land stability and dust generation (Saatsaz and Sustainability, 2020). Modern agricultural expansion in arid areas has also led to the clearance of vegetation, leaving soils exposed. Without natural vegetation to protect the surface, strong winds easily mobilize fine particles, creating dust storms. Poor soil management practices, including over-tilling and failure to use cover crops, further destabilize soils. The lack of crop rotation and reliance on monocultures deplete soil nutrients, reducing the land's ability to retain moisture and resist erosion (Osman, 2014).

2.2.2 Drained Wetlands as Emerging Dust Sources

A stark example of the agricultural-environmental nexus is the desiccation of wetlands, such as the Hamoun Wetlands in southeastern Iran. Historically fed by the Helmand River from Afghanistan, the Hamoun Wetlands supported a diverse ecosystem and acted as a natural barrier against dust storms. However, upstream dam construction, combined with increased agricultural water extraction, has drastically reduced inflows to these wetlands. Today, much of the once-flourishing Hamoun Wetlands lies dry, leaving behind salt flats and fine sediment that are now major sources of dust storms affecting the Sistan and Baluchestan provinces (Hamzeh et al., 2016). Satellite analyses reveal that the dried basin of the Hamoun Wetlands contributes to some of the most intense dust storms in the region, with seasonal peaks during the strong "120-day winds" in summer. These dust storms frequently transport particulate matter rich in salts and heavy metals, posing significant health risks to local populations and spreading pollution across national borders (Ehsani and Shakeryari, 2021; Khashi et al., 2022). The sediment from these wetlands also contributes to reduced agricultural productivity in adjacent areas, as airborne dust settles on croplands, altering soil composition and hindering plant growth (Ehsani and Shakeryari, 2021).

2.2.3 Cascading Effects on Agriculture and Livelihoods

The unsustainable use of water resources for agriculture not only amplifies dust pollution but also triggers a feedback loop of environmental degradation and socio-economic challenges. As lands become infertile, farmers face declining crop yields, leading to increased reliance on marginal lands that are even more prone to erosion. In regions such as the Dasht-e Kavir and Dasht-e Lut, this process has led to the expansion of desertified zones, further increasing the sources of dust emissions (Dehshiri and Firoozabadi, 2024).

2.2.4 Mitigation Strategies

To counteract these effects, sustainable agricultural practices must be prioritized. Techniques such as drip irrigation, laser leveling of fields, and drought-resistant crop varieties can significantly reduce water consumption and protect soil health. Wetland restoration efforts, particularly for the Hamoun Wetlands, are crucial for curbing dust emissions and preserving local ecosystems. Collaborative transboundary water management agreements, especially with Afghanistan regarding Helmand River inflows, are essential to address the root causes of wetland desiccation. Lessons from successful wetland restoration projects, such as the Mesopotamian Marshlands in Iraq, offer valuable insights for restoring Iran's wetlands (Abbasi, 2020; Dehshiri and Firoozabadi, 2024).

2.3. Urbanization and Infrastructure Development

2.3.1 Construction Activities and Unpaved Roads

Rapid urbanization in Iran, particularly in cities like Tehran, Ahvaz, and Isfahan, has significantly contributed to localized dust pollution (Jaafari et al., 2018; Muleski et al., 2005; Rouhani et al., 2024). Construction activities, including road building, residential projects, and industrial expansion, disturb soil surfaces and generate substantial amounts of fine PM10 (Muleski et al., 2005). The absence of proper dust suppression measures during construction exacerbates this issue. For instance, studies have shown that PM10 levels in urban areas can rise sharply during periods of heavy construction, with unpaved roads acting as continuous sources of dust due to vehicular activity (Wang et al., 2018). Dust generated by these activities not only affects the immediate surroundings but is also carried by wind to nearby residential and commercial zones, compounding air quality issues (Rosman et al., 2019). Unpaved roads are particularly problematic in peripheral urban areas and informal settlements, where infrastructure is underdeveloped (Mutua, 2022). Vehicles traveling on these roads disturb loose soil and generate dust plumes, which remain suspended in the air, especially during dry conditions. These localized emissions can significantly contribute to PM concentrations in urban centers, where traffic congestion already elevates pollution levels (Molina et al., 2004).

2.3.2 Industrial Activities in Cities Like Ahvaz

Industrialization has further intensified dust pollution in urban areas, with cities like Ahvaz experiencing some of the highest pollution levels in Iran (Asvad et al., 2023). Ahvaz, situated in Khuzestan Province, is a hub for oil and petrochemical industries, which release substantial quantities of fine PM and other pollutants into the atmosphere. In addition to emissions from factories, the movement of heavy industrial vehicles on unpaved and poorly maintained roads contributes to dust generation. Studies have identified PM10 and particulate matter of fewer than 2.5 µm (PM2.5) emissions as primary concerns, with fine particles originating from both combustion processes and the mechanical abrasion of surfaces (Saffar et al., 2023). Ahvaz's industrial zones are often located near residential areas, exposing inhabitants to continuous dust pollution. This proximity exacerbates health risks, particularly respiratory and cardiovascular issues, with vulnerable populations, including children and the elderly, being most affected. Moreover, industrial waste handling and storage in open environments contribute to fugitive dust emissions, which further degrade air quality (Geravandi et al., 2018).

2.3.3 Compounding Effects of Urbanization

Urbanization also indirectly amplifies dust pollution by reducing vegetation cover and increasing impermeable surfaces (Ferrini et al., 2020). The replacement of green spaces with concrete and asphalt reduces the natural capacity of urban environments to trap and settle dust particles (Hwang et al., 2019). Additionally, urban heat island effects can exacerbate atmospheric instability, facilitating the suspension of dust particles for extended periods (Fallmann, 2014). The combined impacts of urbanization and industrialization create a feedback loop where increased construction and industrial activity elevate PM levels, which then hinder urban livability and public health (Liang et al., 2019). Tehran, for instance, experiences episodic air quality crises during periods of high dust and vehicular pollution, worsened by its topography and meteorological conditions, which limit pollutant dispersion (Nejad et al., 2023).

2.3.4 Mitigation Strategies

To mitigate urban dust pollution, stricter regulations on construction practices and road maintenance are essential (Xing et al., 2018). Measures such as covering construction sites, enforcing the use of dust suppressants, and paving unpaved roads can significantly reduce localized emissions. In industrial cities like Ahvaz, transitioning to cleaner technologies and implementing stringent emissions controls are critical steps (Kaydi et al., 2024). Additionally, urban planning strategies that prioritize green spaces and adopt permeable materials for urban surfaces can help mitigate the long-term effects of dust pollution (Thompson et al., 2024).

2.4. Water Mismanagement

2.4.1. Over-Extraction of Groundwater and Its Effects

Water mismanagement is a critical factor driving dust pollution in Iran (Zucca et al., 2021). Over-extraction of groundwater for agriculture, industry, and urban consumption has led to the depletion of aquifers and the desiccation of rivers and lakes, transforming these areas into active dust sources. Iran's high dependency on groundwater—accounting for nearly 55% of its total water use—has left many regions prone to land subsidence, soil degradation, and ultimately, increased dust emission (Madadi et al., 2022). As water tables decline, the soil's ability to retain moisture diminishes, leaving behind loose, fine particles that are easily mobilized by wind, particularly in arid zones like Khuzestan and Sistan and Baluchestan (Jafari et al., 2018).

2.4.2 Lake Urmia: A Drained Giant

Once the largest saltwater lake in the Middle East, Lake Urmia in northwestern Iran has experienced catastrophic shrinkage due to a combination of dam construction on its tributaries, unsustainable agricultural water diversion, and reduced rainfall (Mardi et al., 2018). Over the past two decades, the lake has lost over 90% of its surface area, leaving vast stretches of exposed lakebed laden with salt and fine sediment (Sharifi et al., 2018). These sediments are frequently picked up by strong winds, creating saline dust storms that affect nearby cities such as Tabriz and Urmia and even reach neighboring countries like Turkey and Azerbaijan (Schulz et al., 2020). These saline dust storms not only exacerbate respiratory and cardiovascular health risks but also damage agricultural lands by increasing soil salinity, further compounding the region's environmental challenges (Abbas et al., 2024). Efforts to replenish Lake Urmia, such as controlled water releases and irrigation reforms, have shown limited success due to competing demands for water and persistent drought conditions (Parsinejad et al., 2022).

2.4.3 Gavkhouni Wetland: A Lost Ecosystem

The Gavkhouni Wetland in central Iran, historically a crucial ecological zone for biodiversity and a natural dust suppressant, has also transformed into a significant dust source (Pirali Zefrehei et al., 2023). Fed by the Zayandeh Rud River, the wetland has been severely impacted by upstream dam construction, which has drastically reduced water inflows. Due to high water demand from agriculture and urban centers like Isfahan, the wetland remains dry for most of the year, leaving its bed vulnerable to wind erosion. Dust storms originating from Gavkhouni are enriched with heavy metals and toxins from industrial runoff that accumulated in the wetland before its drying (Grobicki et al., 2019). These storms not only affect local air quality but also pose serious health risks to residents in surrounding areas. Additionally, the loss of the wetland has had cascading ecological impacts, including reduced habitat for migratory birds and altered regional climate patterns.

2.4.4 Impact of Dams and Mismanagement on Dust Hotspots

Iran's extensive dam network, designed to support agricultural development, urban water needs, and hydroelectric power generation, has inadvertently contributed to the desiccation of natural water bodies and the formation of dust hotspots. Dams such as those on the Karun, Karkheh, and Helmand rivers have altered natural hydrological cycles, significantly reducing downstream water availability. This has led to the drying of critical ecosystems like the Hour-al-Azim Marsh, turning them into major dust emission zones (Fuladavand et al., 2015).

The Karun River, Iran's most water-abundant river, has been heavily dammed, disrupting its natural flow. Water diversion for agricultural irrigation and industrial uses in Khuzestan Province has caused significant downstream shortages, critically impacting wetlands like the Hour-al-Azim Marsh. The marsh, historically fed by both the Karun and Karkheh rivers, has lost much of its water inflow due to dam operations, reducing its area from approximately 900 km² in 1991 to 300 km² in 2008. This exposure of the marsh bed has created a significant source of airborne dust, particularly rich in salts and heavy metals, which impacts local air quality and exacerbates respiratory and cardiovascular health risks in cities like Ahvaz (Fuladavand et al., 2015).

The Helmand River, which feeds the Hamoun Wetlands in southeastern Iran, has also been severely affected by upstream damming and water diversions in Afghanistan. Once a biodiversity hotspot and a natural barrier against dust storms, the wetlands have dried significantly, leaving behind fine sediments prone to wind erosion. The resulting dust storms have a regional impact, affecting southeastern Iran and southwestern Afghanistan. This situation underscores the critical need for transboundary water-sharing agreements to address the root causes of wetland desiccation (Manouchehri and Mahmoodian, 2002).

The desiccation of these wetlands has significant environmental and health implications. Dust storms originating from dried marshlands carry particulate matter, salts, and heavy metals, reducing visibility and increasing air pollution levels. For instance, suspended particles in dusty conditions around the Seimare Dam have been shown to significantly raise local water turbidity and introduce pollutants like iron and aluminum into nearby ecosystems (Ahmadfazeli et al., 2018).

To mitigate these impacts, Iran must reevaluate its dam management practices and prioritize environmental flow requirements to maintain downstream ecosystem health. Restoring water inflows to wetlands like Hour-al-Azim and Hamoun is essential to reduce their dust emissions. Additionally, implementing sustainable water use policies, improving irrigation efficiency, and engaging in regional collaborations for transboundary water management are critical steps to mitigate dust pollution and its associated health and environmental risks (Ghale et al., 2021).

2.4.5 Mitigation Strategies

Addressing water mismanagement requires a multifaceted approach. Policies to regulate groundwater extraction, incentivize efficient irrigation methods, and restore water flows to critical ecosystems are essential. For Lake Urmia, initiatives like reducing upstream water consumption and using treated wastewater for agricultural purposes have shown promise but need scaling up (Mirnezami et al., 2024). In the case of Gavkhouni, ecological restoration through controlled water releases and pollution management is crucial to prevent further dust generation (Grobicki et al., 2019). Transboundary water management agreements, especially for rivers shared with Afghanistan and Iraq, can play a significant role in mitigating the downstream effects of upstream water diversions.

3 Climate Change Effects

3.1 Rising Temperatures and Decreasing Precipitation

Climate change is intensifying dust pollution in Iran by exacerbating drought conditions and increasing soil vulnerability to wind erosion (Aghaei et al., 2017). Rising global temperatures have caused prolonged heatwaves, reduced snowpack, and earlier melting in mountainous regions, all of which deplete surface and groundwater reserves (Kassaye et al., 2024). In Iran’s arid and semi-arid regions, such as the Dasht-e Lut and Dasht-e Kavir, soil moisture levels have declined drastically, leaving loose, dry particles prone to wind mobilization (Kaffash, 1987). Decreasing precipitation, a hallmark of Iran’s changing climate, compounds this problem. The country has witnessed a consistent reduction in annual rainfall over the last two decades, with significant impacts on regions like Sistan and Baluchestan, where reduced inflows to the Hamoun Wetlands have transformed fertile lands into dust hotspots (Maleki et al., 2021). Prolonged droughts not only dry out the soil but also reduce vegetation cover, which is crucial for anchoring soil particles and mitigating wind erosion. In the Zagros and Alborz mountain ranges, vegetation loss due to increasing temperatures and water scarcity has accelerated soil degradation, creating new sources of dust pollution (Sadeghi and Hazbavi, 2022). The drying of agricultural lands, exacerbated by water mismanagement, adds to this dynamic, creating a positive feedback loop between land degradation and dust emission (Tahbaz, 2016).

3.2 Altered Wind Patterns and Dust Storm Frequency

Climate change also influences atmospheric dynamics, altering wind patterns that drive dust storms (Schweitzer et al., 2018). Research suggests that rising temperatures and shifting pressure systems may intensify the Shamal winds in the Persian Gulf region, which are a major driver of transboundary dust transport into western Iran (Rabbani et al., 2023). Similarly, the "120-day winds" in southeastern Iran, already notorious for their role in mobilizing dust from the Hamoun Basin, may become stronger and more frequent due to changing climatic conditions (Gherboudj et al., 2017; Rashki et al., 2013). Climate models predict an increased likelihood of severe dust storms as the Intertropical Convergence Zone (ITCZ) and regional jet streams shift northward. These changes could lead to longer dust storm seasons, with areas like Khuzestan, Sistan, and Baluchestan experiencing more intense events. Recent studies highlight the growing contribution of climate-induced dust to air quality crises in cities like Tehran and Ahvaz, where fine particulate matter levels frequently exceed health thresholds during storm events (Neysani Samany et al., 2024).

3.2.1 Cross-Border Movement of Dust and Its Impacts

The transboundary nature of dust pollution underscores the need for regional cooperation to mitigate its wide-ranging effects. Iran is frequently affected by dust storms originating in neighboring countries, particularly Iraq and Syria, where climatic changes, conflicts, and land mismanagement have intensified dust generation. These storms exacerbate air quality degradation in western and southwestern provinces of Iran, such as Khuzestan, Kermanshah, and Ilam, creating severe health and environmental challenges (Amarloei et al., 2020; MalAmiri et al., 2023). The fine particulate matter carried by these storms often contains heavy metals and other toxins, amplifying their adverse effects on human health and ecosystems (Zhang et al., 2015).

3.2.2 Dust Sources in Iraq

Iraq is a major source of dust affecting Iran, with its vast arid regions and destabilized landscapes (Walid, 2023). Deserts surrounding Lake Tharthar and the once-fertile marshlands of the Mesopotamian region, including the drained Hour-al-Azim Marsh, are now significant dust sources in Iraq (Shani and Barani, 2021). Agricultural land abandonment, particularly in areas affected by wars and socio-economic instability, has left large expanses of land uncultivated and vulnerable to wind erosion. Studies have linked the desiccation of Iraqi wetlands to upstream dam construction and reduced water inflows from the Tigris and Euphrates Rivers, further compounding the problem (UNEP, 2001). Dust storms from Iraq frequently enter Iran during the Shamal wind season, which peaks in spring and summer. These storms transport fine particles over long distances, significantly increasing particulate matter fewer than 10 µm (PM10) concentrations in cities like Ahvaz and Abadan in Iran. The high salinity of dust from Iraqi wetlands also exacerbates soil salinization in Iran, reducing agricultural productivity in affected areas (Zucca et al., 2021).

3.2.3 Syria’s Role in Transboundary Dust Pollution

Syria contributes to regional dust pollution through its central and eastern deserts, areas severely impacted by prolonged droughts and poor land management (Aghaei et al., 2017). The Syrian Civil War has further accelerated land degradation, as traditional agricultural practices have been disrupted, and infrastructure for sustainable water management has deteriorated (Dede, 2023). The drying of Syria’s Al-Khabour Basin and the expansion of desertified lands have intensified the frequency of dust storms that move into neighboring countries, including Iran. These storms typically affect Iran’s western provinces and have been shown to coincide with periods of low precipitation and high wind speeds (Dede, 2023).

3.2.4 Challenges and Necessity of International Cooperation

The transboundary nature of dust pollution presents unique challenges, as its management requires coordinated efforts between countries. While Iran has implemented domestic measures such as reforestation and wetland restoration, their effectiveness is limited without upstream cooperation from Iraq and Syria (Dede, 2023). Shared water management agreements, focusing on the restoration of critical wetlands like Hour-al-Azim and the Mesopotamian Marshes, are essential for reducing dust generation at the source. Additionally, capacity-building programs to promote sustainable land management practices in conflict-affected areas could help mitigate further desertification (Madadi et al., 2022).

3.2.5 Steps Toward Regional Solutions

International organizations such as the United Nations Environment Programme (UNEP) have highlighted the importance of regional frameworks for combating dust pollution in the Middle East (UNEP, 2001, 2016, 2019). Initiatives like the Regional Action Plan to Combat Sand and Dust Storms provide a platform for collaborative action, including data sharing, joint monitoring systems, and coordinated mitigation projects.

Enhanced use of remote sensing and climate modeling can also assist in identifying dust hotspots and tracking transboundary dust flows, enabling more targeted interventions (Shepherd et al., 2016). The effects of climate change on dust storms are far-reaching, impacting human health, ecosystems, and infrastructure. Increased dust storm activity elevates the concentration of PM2.5 and PM10, worsening respiratory and cardiovascular conditions, particularly among vulnerable populations. Dust laden with salts and heavy metals from dried lakebeds, such as Lake Urmia and the Hamoun Wetlands, contributes to soil salinization, reducing agricultural productivity and threatening food security (Sadeghi and Hazbavi, 2022). The deposition of dust on glaciers in Iran’s high-altitude regions further accelerates their melting, reducing critical freshwater resources and feeding back into the cycle of desertification.

3.2.6 Mitigation and Adaptation Strategies

Mitigating the effects of climate change on dust pollution requires both local and global actions (Moore, 2009). Locally, initiatives like reforestation, sustainable water management, and the restoration of wetlands such as Hamoun and Gavkhouni can reduce the vulnerability of soils to wind erosion (Grobicki et al., 2019; Sadeghi and Hazbavi, 2022). Internationally, reducing greenhouse gas emissions and transitioning to renewable energy sources are essential to curbing the underlying drivers of climate change. Enhanced climate monitoring systems, leveraging satellite technology, can provide critical data for predicting and managing dust storm impacts (Holloway et al., 2021).

4 Strategies for Mitigation

Dust pollution in Iran is a complex and multidimensional problem that arises from a combination of natural, anthropogenic, and transboundary factors (Vaezi et al., 2024). Effective mitigation requires an integrated and multi-level approach involving local, national, and regional strategies. Iran has already undertaken several initiatives, including afforestation, wetland restoration, international collaboration, and enhanced research and monitoring (Sadeghi and Hazbavi, 2022). However, scaling these efforts and addressing the root causes of dust pollution remain critical for sustainable impact.

4.1 Afforestation and Soil Stabilization

Planting trees and vegetation to stabilize soil is one of the most effective methods to combat dust pollution. Iran has initiated afforestation projects in dust-prone areas, particularly in the southeastern provinces, to create windbreaks and reduce soil erosion. For example, afforestation efforts in Khuzestan Province aim to stabilize loose soils in regions affected by the desiccation of Hour-al-Azim Marsh and agricultural land degradation. However, the scope of such projects needs expansion. Incorporating drought-resistant native species that can thrive in Iran's arid climate will enhance the longevity and effectiveness of these initiatives (Madadi et al., 2022). Beyond tree planting, Iran should adopt soil conservation techniques such as mulching, contour plowing, and cover cropping to reduce wind erosion in agricultural lands. Establishing green belts around urban centers like Tehran and Ahvaz, which suffer from high particulate matter levels, can further buffer against incoming dust storms.

4.2 Wetland Restoration and Water Resource Management

Restoration of wetlands is critical for reducing dust pollution from dried lakebeds and marshlands, which are major sources of fine particulate matter (Yousefi Kebriya et al., 2025). Iran has implemented wetland revival projects, such as efforts to replenish Lake Urmia by releasing water from upstream reservoirs and curbing water-intensive agriculture in the surrounding areas (Mirnezami et al., 2024). Similarly, initiatives to restore the Hamoun Wetlands, which rely on water inflows from Afghanistan, are underway but face challenges due to transboundary water disputes (Nagheeby and Warner, 2022). To amplify these efforts, Iran must prioritize sustainable water resource management. Policies to regulate groundwater extraction, promote efficient irrigation methods, and enforce restrictions on illegal wells are essential to preserve water for wetland ecosystems (De Stefano and Lopez-Gunn, 2012). Negotiating transboundary water-sharing agreements with neighboring countries, particularly Afghanistan for the Helmand River and Iraq for the Tigris and Euphrates systems is crucial for the success of wetland restoration projects.

4.3 International Collaboration on Transboundary Dust Pollution

Given the regional nature of dust pollution, international cooperation is indispensable. Dust storms originating in Iraq, Syria, and Saudi Arabia significantly impact Iran, particularly during the Shamal wind season (Cuevas Agulló, 2013; Soleimani et al., 2020). Iran has engaged in regional dialogues and agreements, such as the Regional Action Plan to Combat Sand and Dust Storms under the United Nations Environment Programme (UNEP). These initiatives aim to foster collaboration on water resource management, reforestation, and sustainable agricultural practices in neighboring countries (UNEP, 2019). Iran should advocate for shared monitoring systems, using satellite data and geospatial analysis to track dust sources and transport patterns. Coordinated regional efforts to rehabilitate degraded lands, such as Iraq’s Mesopotamian marshlands and Syria’s abandoned agricultural fields, could significantly reduce transboundary dust emissions. Funding for these projects could come from international climate and environmental agencies, emphasizing the global relevance of combating Middle Eastern dust storms.

4.4 Enhancing Research and Monitoring

Enhancing research and monitoring systems is critical for addressing dust pollution effectively. A robust understanding of the sources, transport dynamics, and health implications of dust is foundational to developing mitigation strategies. Iran has increasingly prioritized investments in this area, leveraging both technological advancements and academic expertise. Universities and environmental agencies are at the forefront of studying the origins, pathways, and chemical compositions of dust storms. These efforts include analyzing the specific contributions of degraded lands and desert regions to dust emissions (Hosseini et al., 2024). Advanced tools such as satellite-based remote sensing, ground-based aerosol monitoring stations, and LiDAR technologies are employed to track dust activity. These systems provide real-time data on dust hotspots and seasonal patterns, allowing for better-informed decision-making.

Expanding the scope of research to include the socio-economic repercussions of dust pollution is equally important. Dust storms affect agriculture by reducing soil fertility, damaging crops, and disrupting farming activities. They also impose significant costs on public health systems due to increased respiratory and cardiovascular illnesses and affect infrastructure by reducing visibility and causing material degradation. Detailed assessments of these impacts can help policymakers craft sector-specific interventions to minimize harm. Integrating predictive modeling with climate change data offers another promising avenue. As global temperatures rise and precipitation patterns shift, the frequency and intensity of dust storms may change. Predictive models can help forecast future trends in dust activity under different climate scenarios, enabling adaptive planning. This approach not only supports immediate mitigation but also ensures long-term resilience against evolving environmental conditions.

Collaboration with international research institutions further enhances technical capabilities. Partnerships enable access to global expertise, shared data, and cutting-edge methodologies. Iran's involvement in international initiatives, such as regional monitoring networks and global climate research projects, provides opportunities to align national strategies with global best practices (Soleimani-Sardo et al., 2023). Such collaborations can also facilitate knowledge transfer and capacity-building programs, strengthening Iran's ability to address the multifaceted challenges posed by dust pollution effectively. The integration of comprehensive research, advanced monitoring tools, socio-economic analyses, and predictive modeling, combined with international cooperation, positions Iran to combat dust pollution more effectively. These efforts, when implemented cohesively, can significantly reduce the adverse impacts of dust storms on both human and environmental health.

4.5 Promoting Sustainable Agricultural Practices

Unsustainable agricultural practices play a critical role in land degradation and the intensification of dust storms in Iran and neighboring regions. Over-irrigation is among the most harmful practices. While it is widely used to enhance crop yields, it depletes water resources, particularly in semi-arid and arid areas, leading to severe soil salinization. Salinization reduces soil fertility and vegetation cover, leaving the land exposed to wind erosion. For instance, in Iraq's Mesopotamian wetlands, excessive irrigation and upstream damming have accelerated the drying of fertile lands, converting them into major dust emission sources. Land clearing for agricultural expansion also contributes significantly to soil vulnerability. Large-scale removal of vegetation for farming eliminates protective plant cover, exposing the soil to the direct impact of wind and water erosion. This practice, combined with inefficient land-use planning, strips away topsoil, a critical layer for maintaining soil stability. Overgrazing exacerbates these conditions, especially in semi-arid areas of Iran where livestock feeding depletes native grasses and shrubs, leaving barren land prone to erosion. The cumulative effects of overgrazing and land clearing are particularly pronounced in regions with limited rainfall, where natural vegetation recovery is slow or nonexistent.

Drought and desertification, often driven by unsustainable farming practices, further degrade land quality. Cultivating marginal lands without regard for their ecological limits accelerates desertification. These lands, once stripped of their productive capacity, become sources of dust storms during strong winds. The drying of water bodies and wetlands due to mismanaged irrigation systems has also intensified this problem. In many cases, unsustainable farming methods not only deplete soil and water resources but also amplify the impact of climatic factors such as reduced rainfall, leading to a vicious cycle of land degradation. The agricultural focus on water-intensive crops in water-scarce regions adds another layer of stress. This practice increases competition for limited water resources and often necessitates over-extraction from aquifers. Over time, this depletes groundwater reserves, which are essential for sustaining agriculture in arid climates. Without adequate water, soil structure deteriorates, leading to a loss of cohesion and increased susceptibility to wind erosion. Additionally, poor irrigation techniques, such as flood irrigation, wastewater and contribute to runoff and soil erosion, further aggravating the problem. These unsustainable practices are largely driven by economic pressures and a lack of education on sustainable farming methods. Many farmers lack access to modern agricultural technologies or incentives to adopt conservation practices. Financial constraints often compel them to focus on short-term productivity rather than long-term sustainability, perpetuating practices that degrade the land and increase dust generation. Addressing these challenges will require a shift towards sustainable agricultural practices, supported by education, financial incentives, and stricter regulations to promote soil and water conservation (Mpala and Simatele, 2024).

4.6 Public Awareness and Community Engagement

Raising public awareness about the causes and consequences of dust pollution is critical for fostering collective action and promoting sustainable agricultural practices (Zuo et al., 2017). Dust storms, often driven by unsustainable farming and land-use practices, have far-reaching impacts on public health, agriculture, and regional ecosystems (Zucca et al., 2022). Educating communities about these impacts can encourage grassroots participation in mitigating this environmental challenge. Awareness campaigns can help individuals and local groups understand how everyday activities, such as excessive water use, poor farming methods, and deforestation, contribute to the degradation of land and the exacerbation of dust pollution (Zuo et al., 2017). Highlighting the direct links between these practices and the adverse effects on air quality, health, and livelihoods can motivate behavioral change. Educational initiatives should target diverse audiences, including farmers, urban residents, and policymakers, to ensure a broad impact. For farmers, workshops and seminars can focus on the benefits of sustainable practices like reduced water use, no-till farming, and crop rotation. These programs can provide practical knowledge on how adopting such methods not only enhances agricultural productivity but also helps combat dust generation. Demonstrating the long-term benefits of conserving vegetation and restoring degraded lands can help shift perceptions and encourage farmers to prioritize sustainability over short-term gains.

Public outreach campaigns can also emphasize the importance of afforestation and wetland conservation (Ogwu et al.). Highlighting the role of trees and wetlands in reducing wind erosion and acting as natural barriers against dust storms can inspire community participation in these initiatives. For example, community-based tree-planting drives can be organized to engage local residents, students, and environmental activists in creating windbreaks and stabilizing soil. Similarly, campaigns can promote wetland restoration by educating communities about the ecological and economic benefits of these habitats, including their ability to reduce dust emissions and support biodiversity (Ogwu et al.). Media platforms, including television, radio, and social media, can amplify these messages and reach a wider audience. Short documentaries, public service announcements, and social media campaigns can illustrate the visible effects of dust pollution and the importance of mitigation efforts. These mediums are particularly effective for urban populations, who may not directly experience the impacts of unsustainable agricultural practices but are affected by the dust storms they generate. Digital tools such as interactive apps and online platforms can also engage younger audiences, providing them with educational materials and opportunities to participate in virtual or on-ground environmental initiatives.

Schools and universities can play a pivotal role in building long-term awareness through environmental education programs (Hoang and Kato, 2016). Integrating topics on dust pollution, sustainable farming, and land conservation into curricula can shape the perspectives of future generations. Practical activities, such as student-led projects on tree planting or water conservation, can foster a sense of responsibility and instill the importance of environmental stewardship from an early age. Higher education institutions can also contribute by conducting research and publicizing findings on the sources and mitigation strategies for dust pollution. In addition to education, encouraging active participation through community-based programs can create a sense of ownership among residents. Initiatives such as citizen science projects, where individuals contribute to monitoring air quality and identifying dust sources, can foster collaboration between communities and scientists. Such programs empower residents by involving them in data collection and decision-making processes, strengthening their commitment to environmental conservation. Local governments and non-governmental organizations (NGOs) can support these efforts by providing resources, organizing events, and offering incentives to participants. Financial incentives and recognition programs can further motivate community involvement (Messer and Agriculture Organization, 2003). For example, rewarding neighborhoods that achieve significant improvements in afforestation or water conservation can create friendly competition and encourage collective action. Grants and subsidies for community-led conservation projects, such as wetland restoration or the establishment of windbreaks, can also drive engagement and ensure the financial viability of these efforts. Long-term public awareness efforts are essential for creating a cultural shift towards sustainability. Consistent messaging, supported by clear examples of success stories and tangible outcomes, can inspire individuals and communities to adopt practices that reduce dust pollution. By fostering an understanding of the interconnectedness between human activities and environmental health, awareness campaigns can build a resilient society capable of addressing the root causes of dust generation and achieving lasting environmental sustainability. Raising public awareness about the causes and consequences of dust pollution is vital for fostering community participation in mitigation efforts (Zuo et al., 2017). Educational campaigns can emphasize the importance of conserving vegetation, reducing water use, and supporting local afforestation projects. Community-based programs, such as citizen tree-planting drives and local wetland restoration initiatives, can enhance grassroots involvement and ensure long-term sustainability.

7 Policy and Governance Reforms

Strengthening environmental governance through comprehensive policies that integrate climate adaptation, land management, and pollution control is critical to mitigating dust pollution and its cascading effects Strengthening environmental governance through comprehensive policies that integrate climate adaptation, land management, and pollution control is critical to mitigating dust pollution and its cascading effects (UNEP, 2016). Dust pollution arises from a combination of natural and anthropogenic sources, necessitating a multi-faceted governance approach that addresses its root causes across various sectors (Grobicki et al., 2019). Effective regulatory frameworks must establish clear guidelines for mitigating key dust sources, such as construction activities, industrial emissions, and vehicle pollution, while aligning these efforts with broader land management and climate resilience strategies (Al-Thani and Isaifan, 2024). A critical area for governance reform is the regulation of construction activities, a significant contributor to localized dust pollution in urban areas. Governments should implement and enforce stringent construction codes that mandate dust suppression techniques, such as wetting soil, using protective barriers, and implementing advanced technologies like vacuum extraction systems. Regular inspections by environmental agencies and the imposition of fines for non-compliance can ensure adherence to these standards. Moreover, requiring construction companies to submit environmental management plans before project approval can help minimize dust emissions during building activities. Industrial emissions, another major contributor to dust pollution, require targeted regulatory oversight. Policymakers must enforce emissions controls in industrial zones by mandating the use of pollution abatement technologies, such as particulate matter (PM) filters and scrubbers (Kumar and Gupta, 2016). Establishing air quality monitoring stations in these zones allows for real-time data collection and better enforcement of air quality standards. Industries that fail to comply with emissions regulations should face strict penalties, including fines or suspension of operations. Incentivizing cleaner production technologies through tax breaks or subsidies can further encourage industries to adopt environmentally sustainable practices. Urban centers, where vehicle emissions and road dust are significant contributors, also demand targeted governance reforms. Policymakers can regulate vehicle pollution through stricter emission standards, promoting the use of low-emission or electric vehicles, and implementing regular vehicle inspections (Wu et al., 2017). Public transportation systems should be expanded and modernized to reduce reliance on private vehicles, while urban planning initiatives can focus on creating green buffers and implementing road-paving projects that minimize dust generation. Additionally, policies that encourage non-motorized transport, such as cycling and walking, can reduce vehicular dust contributions while promoting public health.

Cross-sectoral policies that link agriculture, water management, and land restoration are essential for addressing dust pollution on a broader scale (Sanz et al., 2017). For instance, integrating sustainable agricultural practices into national development strategies ensures that farming activities align with soil conservation and water efficiency goals. These policies can mandate no-till farming, crop diversification, and the use of organic fertilizers to maintain soil health and minimize erosion. Coordination with water management policies, such as regulating groundwater extraction and promoting efficient irrigation methods like drip systems, helps address the water-related drivers of land degradation (Duda, 2017). Land restoration initiatives should be supported by policies that promote afforestation and the rehabilitation of degraded ecosystems, such as wetlands and grasslands. Governments must allocate resources for large-scale restoration projects and involve local communities in their planning and execution to ensure sustainability (UNEP, 2016). Legal frameworks that designate critical ecosystems as protected areas can provide a long-term safeguard against encroachment and degradation. Linking these efforts with climate adaptation strategies, such as planting drought-resistant vegetation and restoring natural windbreaks, further enhances resilience to dust storms. Regional collaboration is indispensable for managing transboundary dust pollution, as dust storms often originate in one country and affect neighboring regions. Governance reforms must prioritize the establishment of cooperative agreements between countries to address shared environmental challenges. For example, cross-border policies can focus on reducing upstream activities that contribute to desertification, such as dam construction or excessive water diversion. Regional institutions, supported by international organizations like the United Nations Environment Programme (UNEP), can facilitate joint monitoring, data sharing, and coordinated land restoration projects. Establishing transboundary environmental funds to finance these initiatives ensures their long-term viability (UNEP, 2016). Policy reforms should also emphasize strengthening institutional capacity for effective implementation and enforcement. Environmental protection agencies must be equipped with adequate resources, expertise, and authority to monitor compliance with regulations and oversee conservation initiatives. Building technical capacity through training programs and hiring skilled personnel is essential for ensuring that institutions can manage complex environmental challenges. Transparency mechanisms, such as public reporting on policy outcomes and independent audits, enhance accountability and build trust between governments and citizens.

Public participation and stakeholder engagement are vital components of governance reform. Policymakers should establish platforms for dialogue and collaboration with farmers, industries, researchers, and non-governmental organizations (NGOs). Including diverse voices in policy formulation ensures that solutions are inclusive, practical, and widely accepted. For instance, engaging farmers in discussions on sustainable agriculture policies can enhance compliance and encourage adoption of conservation practices. NGOs and community groups can play a crucial role in raising awareness, mobilizing resources, and monitoring policy implementation (UNEP, 2016).

Tackling dust pollution requires a robust governance framework that integrates climate adaptation, land management, and pollution control into cohesive and enforceable policies. Regulatory measures targeting construction, industrial emissions, and vehicle pollution must be complemented by cross-sectoral strategies that link agriculture, water, and land restoration. Regional collaboration and institutional capacity-building further strengthen governance efforts, while public participation ensures that policies are inclusive and sustainable. Through these reforms, governments can create resilient systems capable of addressing dust pollution and its broader environmental and societal impacts. Dust pollution arises from a combination of natural and anthropogenic sources, necessitating a multi-faceted governance approach that addresses its root causes across various sectors. Effective regulatory frameworks must establish clear guidelines for mitigating key dust sources, such as construction activities, industrial emissions, and vehicle pollution, while aligning these efforts with broader land management and climate resilience strategies (UNEP, 2016). A critical area for governance reform is the regulation of construction activities, a significant contributor to localized dust pollution in urban areas. Governments should implement and enforce stringent construction codes that mandate dust suppression techniques, such as wetting soil, using protective barriers, and implementing advanced technologies like vacuum extraction systems. Regular inspections by environmental agencies and the imposition of fines for non-compliance can ensure adherence to these standards. Moreover, requiring construction companies to submit environmental management plans before project approval can help minimize dust emissions during building activities.

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Land restoration initiatives should be supported by policies that promote afforestation and the rehabilitation of degraded ecosystems, such as wetlands and grasslands. Governments must allocate resources for large-scale restoration projects and involve local communities in their planning and execution to ensure sustainability (UNEP, 2016). Legal frameworks that designate critical ecosystems as protected areas can provide a long-term safeguard against encroachment and degradation. Linking these efforts with climate adaptation strategies, such as planting drought-resistant vegetation and restoring natural windbreaks, further enhances resilience to dust storms. Regional collaboration is indispensable for managing transboundary dust pollution, as dust storms often originate in one country and affect neighboring regions. Governance reforms must prioritize the establishment of cooperative agreements between countries to address shared environmental challenges. For example, cross-border policies can focus on reducing upstream activities that contribute to desertification, such as dam construction or excessive water diversion. Regional institutions, supported by international organizations like the United Nations Environment Programme (UNEP), can facilitate joint monitoring, data sharing, and coordinated land restoration projects (UNEP, 2019). Establishing transboundary environmental funds to finance these initiatives ensures their long-term viability. Policy reforms should also emphasize strengthening institutional capacity for effective implementation and enforcement. Environmental protection agencies must be equipped with adequate resources, expertise, and authority to monitor compliance with regulations and oversee conservation initiatives (Ogwu et al.). Building technical capacity through training programs and hiring skilled personnel is essential for ensuring that institutions can manage complex environmental challenges. Transparency mechanisms, such as public reporting on policy outcomes and independent audits, enhance accountability and build trust between governments and citizens.

Public participation and stakeholder engagement are vital components of governance reform. Policymakers should establish platforms for dialogue and collaboration with farmers, industries, researchers, and non-governmental organizations (NGOs). Including diverse voices in policy formulation ensures that solutions are inclusive, practical, and widely accepted. For instance, engaging farmers in discussions on sustainable agriculture policies can enhance compliance and encourage the adoption of conservation practices. NGOs and community groups can play a crucial role in raising awareness, mobilizing resources, and monitoring policy implementation (UNEP, 2016).

8 Conclusion

Dust pollution is a pressing environmental challenge for Iran, arising from a combination of natural processes, anthropogenic activities, and transboundary contributions. This review highlights the multifaceted drivers of dust pollution, including climate change, unsustainable agricultural practices, urbanization, water mismanagement, and regional conflicts, which collectively intensify soil erosion and desertification. The drying of critical water bodies, such as Lake Urmia and the Hamoun Wetlands, has transformed these areas into significant dust emission sources, while external factors like dust storms originating from Iraq, Syria, and Saudi Arabia further exacerbate the problem. These dust storms not only degrade air quality but also pose severe health risks and ecological consequences, emphasizing the need for urgent mitigation efforts. Iran has made notable progress in addressing this issue through initiatives such as afforestation, wetland restoration, and enhanced research and monitoring. The revival of degraded wetlands and the creation of green belts around urban centers are promising steps, yet their effectiveness depends on sustained investment and regional cooperation. Tackling transboundary dust pollution requires collaborative efforts with neighboring countries, particularly in shared water resource management and land restoration. International frameworks, such as the Regional Action Plan to Combat Sand and Dust Storms, provide an opportunity to align policies and resources toward sustainable solutions. The review underscores the importance of integrated approaches that combine local and national measures with regional strategies. Prioritizing sustainable agriculture, efficient water use, and public awareness campaigns are essential for mitigating the root causes of dust pollution. Additionally, advancements in remote sensing and climate modeling offer valuable tools for understanding and managing dust dynamics in the context of a changing climate. Addressing the multifaceted impacts of dust pollution requires a concerted effort across sectors, combining scientific innovation with strong governance and international solidarity. By implementing these strategies, Iran can not only mitigate dust pollution but also build resilience against the broader challenges of environmental degradation and climate change. This comprehensive review aims to provide a foundation for future research and policy development, encouraging a proactive and collaborative approach to safeguarding environmental health and sustainability in Iran and the broader region.

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