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Review Article

Environmental Exposures and Women's Health: A Review of Climate Change, Air Pollution, and Heavy Metal Contamination

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Abstract

Women represent a vulnerable population facing disproportionate health impacts from environmental exposures, particularly in low- and middle-income countries. It is crucial to synthesize evidence on the health implications of environmental exposures—including climate change, air pollution, and heavy metal contamination—on women's health outcomes. Using data from systematic reviews and observational studies conducted in South Asia and East Africa, the relationship between maternal exposure to environmental stressors and adverse pregnancy outcomes, reproductive health complications, cardiovascular disease, and neurotoxic effects were examined. Key findings indicate that pregnant women exposed to high temperatures experience increased risks of gestational hypertension, preterm birth, and reduced infant birth weight. Air pollution exposure, particularly to fine particulate matter (PM2.5), correlates with adverse birth outcomes and cardiovascular dysfunction in women. Heavy metal contamination, predominantly through dietary pathways, poses significant risks for maternal health, including gestational diabetes and placental insufficiency. This review emphasizes the urgent need for region-specific public health interventions, water and air quality monitoring systems, and environmental remediation strategies to protect vulnerable female populations. Enhanced research capacity in understudied regions and targeted maternal health programs are essential for reducing environmental health inequities affecting women globally.

Keywords: Women's Health; Environmental Exposures; Climate Change; Air Pollution; Heavy Metals; Pregnancy Outcomes; Maternal Health

Introduction

Environmental health disparities significantly impact women, particularly in resource-limited settings where female populations experience compounded vulnerabilities due to socioeconomic status, limited access to healthcare, and cultural factors that restrict decision-making power in environmental and health matters [1]. Climate change, air pollution, and heavy metal contamination represent three critical environmental stressors affecting women's health through multiple exposure pathways. The World Health Organization estimates that environmental factors account for approximately 24% of global disease burden, with women and girls disproportionately affected due to their roles in household management, subsistence agriculture, and water collection in developing regions.

This comprehensive review synthesizes current evidence on the health impacts of environmental exposures on women, focusing on three major environmental stressors: climate change and meteorological factors, air pollution, and heavy metal contamination [1,2]. The review integrates findings from scoping reviews, systematic reviews, and observational studies conducted primarily in South Asia and East Africa—regions facing acute environmental challenges and limited research capacity. By examining exposure pathways, biological mechanisms, and health outcomes specific to women, this review identifies critical research gaps and proposes evidence-based interventions for environmental health protection in vulnerable female populations.

Environmental exposures and maternal health outcomes

Climate change impacts on pregnancy and birth outcomes

Climate change-related environmental stressors, including extreme weather events and shifts in meteorological patterns, substantially influence maternal health and fetal development [1]. Pregnant women in South Asia face heightened vulnerability due to geographic exposure to cyclones, flooding, and drought, combined with limited adaptive capacity and healthcare infrastructure [1].

Temperature exposure during pregnancy

Maternal exposure to elevated temperatures, particularly during specific gestational periods, significantly affects fetal growth and birth outcomes [1,8]. Research from Bangladesh documented that increased temperatures during the final month of pregnancy correlate with increased birth length after adjustment for maternal nutritional status [8]. Temperature elevation at mid-gestation shows positive association with increased birth weight [8]. However, these relationships demonstrate considerable variation based on maternal nutritional status, suggesting that temperature effects on fetal development are mediated by maternal physiological reserves and nutritional adequacy [8].

Elevated ambient temperatures during pregnancy are causally linked to increased infant mortality risk [12]. Studies utilizing district-level household survey data from India documented that exposure to high temperatures during pregnancy significantly increases infant death risk, with evidence of dose-dependent relationships between temperature elevation and adverse outcomes [12].

Monsoon rainfall and pregnancy outcomes

Extreme precipitation events, particularly heavy monsoon rains characteristic of South Asia, create multiple pathways through which pregnant women experience adverse health outcomes [1]. Research from Bangladesh identified maternal deaths occurring predominantly during rainy seasons in flood-affected areas, with causative factors including negligence of maternal healthcare, lack of appropriate healthcare services, communication and transportation problems, and unavailability of qualified health workers [1]. The study documented that maternal deaths in flood-affected communities resulted from disrupted emergency maternal care access during complications.

Prenatal exposure to natural disasters, specifically cyclone exposure, affects fetal neurodevelopment [1]. Pregnant mothers exposed to cyclone Sidr demonstrated higher likelihood of bearing children with neurodevelopmental impairments compared to unexposed mothers [1]. This association suggests mechanisms involving maternal stress responses, placental dysfunction, and potential direct fetal exposure to environmental toxins during disaster conditions.

Salinity contamination and blood pressure regulation

Drinking water with elevated saline concentrations, characteristic of coastal areas affected by rising sea levels and saltwater intrusion, associates with higher blood pressure in normotensive pregnant women [13]. A case-control study from Bangladesh involving 701 pregnant women demonstrated that consumption of high-salinity drinking water increases blood pressure elevation risk among previously normotensive pregnant women, representing a novel mechanism through which climate change impacts maternal cardiovascular health [13]. This finding has implications for coastal regions facing combined threats from rising sea levels and desertification-driven water scarcity.

Air pollution exposure during pregnancy

Fine particulate matter (PM2.5) and other air pollutants cross the placental barrier and directly affect fetal development through multiple mechanisms including intrauterine inflammation, placental dysfunction, and direct oxidative stress on fetal tissues [1,9].

PM2.5 exposure and birth outcomes

Prenatal exposure to elevated PM2.5 levels demonstrates significant associations with multiple adverse birth outcomes [9]. In utero exposure to high PM2.5 concentrations correlates with increased relative risk of stunting, wasting, underweight status, and small birth size in offspring [9]. Gender-specific vulnerability is evident, with female children showing significantly higher risk of stunting and underweight status compared to male children following identical prenatal PM2.5 exposure [9].

The timing of exposure differentially affects health outcomes [22]. Prenatal PM2.5 exposure shows strong correlation with stunting in male infants after adjusting for monthly seasonal variation, whereas postnatal PM2.5 exposure demonstrates strong correla-

tion with stunting in both male and female children [22]. These temporal patterns suggest critical windows of vulnerability during specific developmental periods.

Air pollution exposure during pregnancy associates with reduced birth weight, demonstrating inverse relationships between maternal air pollution exposure, particularly carbon dioxide emissions, and neonatal birth weight [10]. Studies from Pakistan utilizing data spanning 1975-2012 show that air pollution and greenhouse gas emissions significantly affect low birth weight outcomes [10].

Agricultural burning and respiratory health in pregnancy

Agricultural crop residue burning, practiced extensively in South Asia, creates acute air pollution episodes affecting pregnant women and their developing fetuses [11]. Women residing in districts with intense agricultural crop residue burning (greater than 100 fires daily) face higher risks of acute respiratory infections (ARI), with risk significantly higher among women than men in identical exposure conditions [11]. The adjusted relative risk of ARI attributed to agricultural crop residue burning was 3.08 (95% CI: 2.75-3.45) in women compared to 2.93 (95% CI: 2.64-3.25) in men, indicating gender-specific vulnerability to agricultural air pollution [11].

Heavy metal and metalloid contamination in pregnant women

Maternal exposure to heavy metals and metalloids represents a critical yet understudied pathway through which environmental contamination affects pregnancy outcomes and fetal development [2]. In East Africa, multiple anthropogenic sources including artisanal mining, industrial activities, and contaminated irrigation systems generate widespread heavy metal pollution affecting pregnant populations [2].

Lead exposure and pregnancy complications

Pregnant women in East African mining communities demonstrate elevated blood lead levels, with mean concentrations ranging from 3.5 to 12.8 μg/dL—values exceeding WHO thresholds of 5 μg/dL [2]. Maternal obesity and underweight status modify lead accumulation, with underweight, overweight, and obese pregnant women showing significantly increased plasma lead levels compared to women with normal body mass index [2].

Lead exposure during pregnancy correlates with multiple adverse maternal outcomes including gestational diabetes, gestational hypertension, placental abruption, and placental insufficiency [2]. At delivery, plasma lead levels in pregnant women substantially exceed prenatal period levels, with newborns demonstrating higher plasma lead concentrations than their mothers, indicating transplacental transfer and fetal accumulation of lead [2].

Lead exposure elevates preterm birth risk, with relative risk of 2.5 (95% CI: 1.8-3.4) for women with elevated prenatal lead exposure [2]. In infants, lead toxicity associates with developmental delays, cognitive impairments, and increased autism spectrum disorder risk [2].

Mercury exposure and reproductive outcomes

Maternal mercury exposure, predominantly through consumption of contaminated seafood, contributes to adverse pregnancy outcomes including spontaneous abortion, complicated fertility, altered reproductive cycles, and fatigue [2]. In utero mercury exposure associates with neurodevelopmental deficits in offspring, including cognitive impairments and motor skill deficiencies [2]. The mechanisms involve mercury-mediated disruption of critical developmental signaling pathways, particularly the Hedgehog signaling pathway essential for embryonic development.

Prenatal mercury exposure demonstrates genetic polymorphism effects on neurodevelopmental outcomes [20]. Elevated cord methylmercury levels associate with decreased mental development indices, particularly in children homozygous for specific genetic variants (C-allele), suggesting that genetic background modulates susceptibility to mercury neurotoxicity [20].

Cadmium and zinc toxicity in pregnancy

Cadmium exposure during pregnancy correlates with placental damage, reduced birth weight, and preterm birth [2]. Maternal consumption of seafood and vegetables contaminated with cadmium elevates risk of pregnancy complications [2]. Cadmium concentrations in soil and water exceed international safety limits by up to 300-fold in some East African regions, contributing to widespread maternal exposure [2].

Zinc toxicity, resulting from elevated dietary intake through contaminated foods, leads to placental insufficiency, premature birth, low birth weight, and increased miscarriage risk [2]. The mechanisms involve zinc-mediated disruption of placental development and function, reducing nutrient transfer capacity and oxygen perfusion to the developing fetus.

Multiple metal exposure and maternal complications

Pregnant women in artisanal mining communities face simultaneous exposure to cocktails of heavy metals and metalloids [21]. In Tanzania, pregnant women living in or working in areas with artisanal mining activities demonstrated significantly elevated urinary arsenic (23% elevation) and blood mercury levels (13.3% elevation) [21]. Living and working in artisanal mining areas correlated with 21.2% increase in arsenic concentrations and 142% increase in mercury concentrations [21].

Multi-metal exposure during pregnancy associates with adverse birth outcomes in 54.7% of women residing in artisanal mining areas, including premature delivery, stillbirth, spontaneous abortion, and congenital anomalies [17]. In utero exposure to elevated lead, arsenic, and mercury levels significantly associates with neurodevelopmental and speech impairment in children aged 6-12 months [17].

Cardiovascular and metabolic health effects in women

Household air pollution and atherosclerosis risk

Household air pollution exposure from indoor burning of biomass fuels represents a major cardiovascular risk factor in women [3]. A cross-sectional study from the Household Air Pollution Intervention Network trial involving adult women demonstrated that household air pollution exposure associates with significantly increased carotid intima-media thickness, a marker of subclinical atherosclerosis and cardiovascular disease risk [3]. The association persists after adjustment for demographic and socioeconomic factors, indicating direct harmful effects of household air pollution on vascular structure and function [3].

Microplastic exposure and cardiovascular dysfunction

Emerging evidence demonstrates microplastic infiltration in human cardiovascular tissues, with particles identified in coronary blood samples from patients with myocardial infarction [16]. Among 142 patients with myocardial infarction, detectable microplastic levels were found: polystyrene (48 patients), polyethylene (79 patients), polyvinyl chloride (105 patients), and polyamide 66 (68 patients) [16]. Higher polyvinyl chloride particle levels correlate with increased odds of major adverse cardiac events, with particles triggering elevation in proinflammatory cytokines including interleukin-1, interleukin-6, interleukin-18, and tumor necrosis factor-alpha [16].

Microplastic-associated toxicity triggers abnormal heart rate, myocardial injury, vascular thrombosis, and cardiac fibrosis [6]. Polystyrene microplastics promote collagen proliferation in cardiac tissue through myocardium apoptosis and fibrosis-related Wnt-catenin signaling pathway activation [6]. These mechanisms suggest that chronic microplastic exposure may substantially increase cardiovascular disease risk in women.

Additionally, microplastics identified in human brain tissues show increasing accumulation trends, with polyethylene being the dominant polymer [16]. The accumulation of microplastics in the brain elevates neuroinflammation in the hippocampus region, leading to impaired learning and memory functions [16].

Regional variations and geographic disparities in women's environmental health

South Asian vulnerability context

South Asia, comprising Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka, houses approximately 1.84 billion people with 65% residing in rural areas accounting for 29% of global extreme poverty [1]. The region demonstrates extraordinary vulnerability to climate change effects, having experienced consistent warming with temperature increases ranging from 0.09°C to 0.27°C between 1990 and 2010 depending on country [1]. The Bay of Bengal region shows 20% increase in cyclonic events, with total natural disasters in the region increasing from 133 during 1990-1994 to 166 during 2000-2004 [1].

Women in South Asia disproportionately experience climate change impacts through cultural norms restricting resource access and decision-making power [1]. Women and girls often consume food last and in smaller quantities, reducing nutrient intake critical during pregnancy [1]. Extreme weather events disrupt crop yields and reduce supply of essential nutrients including folate, calcium, thiamine, and pyridoxine, all critical during pregnancy [1].

East african mining and environmental contamination

East Africa, particularly regions with artisanal mining activities, faces acute heavy metal contamination affecting vulnerable populations [2]. The Democratic Republic of Congo produces approximately 68% of global cobalt production (nearly 130,000 tons reported in 2022), while Uganda hosts numerous mines including copper operations in Kilembe-Kasese district and niobium mining in Sukulu [2]. Mining activities generate widespread soil and water contamination affecting subsistence farming communities and irrigation systems [2].

Pregnant women in these regions consume vegetables and seafood heavily contaminated with heavy metals, establishing primary exposure pathways [2]. Contaminated irrigation schemes obtain water from industrialized areas and mining operations containing substantial heavy metal concentrations [2]. Mwea Irrigation Scheme (Kenya), Olweny Swamp Rice Irrigation (Uganda), and Kilombero Irrigation Scheme (Tanzania) all demonstrate heavy metal accumulation in vegetables above WHO maximum permissible limits [2].

Health inequities and vulnerable populations

Socioeconomic status as risk modifier

Maternal education level and age represent critical effect modifiers in environmental health disparities affecting pregnancy outcomes [1]. Older mothers and those with lower education levels demonstrate stronger associations between extreme weather exposure and childhood undernutrition [1]. This pattern aligns with global evidence from non-South Asian regions showing that children born to less educated mothers experience higher undernutrition risk when exposed to drought [1].

Household economic status modifies air pollution health effects [1]. Children living in slums experience greater adverse health effects from identical air pollution exposure compared to children residing outside slum areas, suggesting that poverty-associated factors including malnutrition, concurrent infections, and limited healthcare access amplify pollution toxicity.

Reproductive health and mental health impacts

Pregnant women exposed to extreme weather events face increased risks of physical injury, eviction from dwellings, difficulty accessing adequate water for drinking and cooking, and maintaining personal hygiene and sanitation [1]. Women experience heightened vulnerability to domestic violence and physical and sexual harassment during disaster conditions [1]. Yet systematic reviews document severe research gaps concerning mental health impacts on women exposed to climate disasters, with qualitative studies representing only 2.4% of literature on climate change and women's health in South Asia [1].

Mechanisms of environmental toxicity in women

Oxidative stress and inflammatory pathways

Heavy metals induce toxicity through generation of reactive oxygen species (ROS) and subsequent oxidative stress [2]. Lead, mercury, and cadmium generate ROS leading to oxidative DNA damage, mutation, inhibition of DNA repair enzymes, chromosomal alterations, and chronic inflammation [2]. These mechanisms directly damage placental tissues and restrict nutrient transfer to developing fetuses [2].

Air pollution particulates, particularly fine particles capable of transplacental transfer, trigger oxidative stress and intrauterine inflammation [1,9]. Maternal exposure to particulate matter may represent critical risk factors for intrauterine inflammation, which subsequently impacts placental growth, development, and function [1].

Endocrine disruption and metabolic effects

Heavy metals function as endocrine disruptors interfering with hormone production and circulation [2]. Lead impairs hormonal production and disproportionately alters selenium metabolism, impacting thyroid hormone concentrations [2]. This mechanism explains associations between lead exposure and gestational diabetes, as thyroid dysfunction during pregnancy restricts metabolic regulation necessary for glucose homeostasis.

Microplastics and associated plastic additives, including phthalates and brominated diphenyl ethers, exacerbate neurotoxic and reproductive toxicity outcomes [6]. These compounds breach biological barriers and accumulate systemically, interfering with endocrine signaling critical for pregnancy maintenance and fetal development.

Transplacental transfer and fetal accumulation

Heavy metals easily traverse the placental barrier, particularly at late gestation when permeability peaks [2]. Mercury, cadmium, and lead concentrate in fetal tissues at levels exceeding maternal plasma concentrations, indicating active accumulation in developing organs [2]. Prenatal heavy metal exposure during critical windows—particularly during organogenesis—generates congenital anomalies including neural tube defects, cleft palate, cardiovascular malformations, and growth restriction [2,18]. The summary of key findings in the studied literature are summarized in the table below.

Exposure Type	Primary Finding	Study Population	Outcome Measure	Health Impact	Reference
Temperature elevation during pregnancy	Mid-gestation temperature increase	Bangladesh (n = 4,436 pregnant women)	Increased birth weight	Positive fetal growth	[8]
Heavy rainfall and floods	Increased extreme precipitation	Bangladesh/India	Increased maternal mortality	54.7% adverse birth outcomes in mining areas	[1]
Lead exposure	Blood Pb: 3.5-12.8 μg/dL	East Africa (pregnant women)	Gestational hypertension	2.5× increased preterm birth risk	[2]
Mercury exposure	Elevated cord methylmercury	Seychelles (n = children)	Decreased mental development index	Genetic polymorphism effects evident	[20]
$PM_{2·5}$ exposure (prenatal)	High $PM_{2·5}$ levels	Bangladesh/India (n = 23,187)	Stunting, underweight	Female children higher risk	[9]
Agricultural burning	ACRB >100 fires/day	India (rural districts)	Acute respiratory infection	aRR 3.08 (95% CI: 2.75-3.45) in women	[11]
Household air pollution	Biomass fuel burning	Multiple South Asian countries	Carotid intima-media thickness	Subclinical atherosclerosis marker	[3].
Microplastics (blood)	Cardiovascular tissue infiltration	MI patients (n = 142)	Major adverse cardiac events	Elevated proinflammatory cytokines	[6,16]
Salinity in drinking water	High saline concentration	Bangladesh (n = 701 pregnant women)	Blood pressure elevation	Hypertension risk in normotensive women	[13]
Multiple metal exposure	Arsenic and mercury elevation	Tanzania (pregnant women)	Adverse birth outcomes	54.7% preterm delivery, stillbirth, miscarriage	[17,21]

Table 1: Summary of key findings from the studied literature.

Research gaps and future directions

Understudied geographic regions and populations

Substantial geographic disparities exist in environmental health research affecting women [1,2]. Most South Asian research focuses on India (54.8%) and Bangladesh (33.3%), with minimal representation from Nepal (9.5%), Pakistan (2.4%), and no studies from Afghanistan, Bhutan, Maldives, or Sri Lanka despite documented environmental exposures in these regions [1]. Similarly, East African research concentrates in Uganda (45.2%) and Kenya (16.1%), with limited coverage of Tanzania (9.7%), Democratic Republic of Congo (9.7%), Ethiopia (6.5%), Rwanda (6.5%), and Seychelles (6.5%) [2].

Remote coastal areas face combined threats from rising sea levels and extreme weather events yet remain substantially understudied [1]. These populations experience elevated vulnerability to saltwater intrusion affecting drinking water supplies, increasing salinity-related hypertension risk in pregnant women [1].

Mental health and psychosocial impacts

Mental health impacts of environmental exposures in women remain severely understudied despite documented associations between climate disasters and psychological distress [1]. Research systematically addressing anxiety, depression, post-traumatic stress disorder, and other mental health outcomes in environmentally exposed women populations is critically needed.

Longitudinal and mechanistic research

Most published research utilizes cross-sectional designs, limiting causal inference and longitudinal trajectory assessment [1,2]. Prospective cohort studies following pregnant women through environmentally exposed pregnancies, examining placental function, birth outcomes, and long-term child health trajectories remain sparse [1]. Such studies require substantial investment in research capacity development in resource-limited regions.

Policy recommendations and public health interventions

Water and air quality monitoring systems

Comprehensive national monitoring systems for heavy metal contamination in drinking water, soil, and agricultural products must be established in regions with mining activities and industrial pollution [2]. Real-time air quality monitoring networks should expand beyond provincial capitals to rural areas and regions with agricultural burning [1,5].

Maternal health protection strategies

Targeted prenatal screening and health education programs should address environmental exposures specific to pregnant women [2]. In mining regions, prenatal blood lead and mercury screening should be implemented with clinical protocols for chelation therapy when indicated [2]. Healthcare providers require training in environmental health history assessment and environmental exposure risk reduction counseling.

Environmental remediation and pollution control

Urgent implementation of green mining practices, industrial emission controls, and agricultural burning restrictions represents essential public health infrastructure investment [2]. Phytoremediation using plants capable of heavy metal absorption offers cost-effective soil remediation for subsistence farming communities [2]. Wastewater treatment systems preventing heavy metal discharge into irrigation water supplies are critical investments [2].

Conclusion

Environmental exposures including climate change, air pollution, and heavy metal contamination substantially impact women's health through multiple pathways affecting pregnancy outcomes, reproductive health, cardiovascular function, and long-term health trajectories [1-3]. Geographic evidence concentration in India, Bangladesh, and Uganda with minimal representation from other South Asian and African countries indicates critical research capacity gaps impeding comprehensive environmental health assessment in vulnerable regions [1,2]. Pregnant women face disproportionate risks from environmental stressors through biological mechanisms including transplacental toxin transfer, oxidative stress induction, and endocrine disruption [1,2].

Addressing environmental health inequities affecting women requires region-specific interventions integrating water and air quality improvement, heavy metal contamination remediation, maternal health protection, and mental health support [1,2]. Enhanced research capacity development in understudied regions, longitudinal study designs, and interdisciplinary collaboration among environmental scientists, public health professionals, and clinicians are essential for protecting women's health in the context of global environmental change [1,2].

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