$PM_{2.5}$ and Adolescent Mental Well-Being

AP Seminar

Individual Research Report

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"In 2021, 99% of the world population was living in places where the WHO's strictest 2021 air quality guideline levels were not met." (United Nations Environment Programme, 2021) This widespread environmental crisis carries long-lasting costs for early adolescents between the ages of 10 and 14 far beyond physical health. According to the World Health Organization, adolescence is a unique developmental stage that lays the foundation for lifelong mental health, as early adolescents "undergo rapid physical, cognitive, and psychosocial growth, making them especially vulnerable to environmental threats." (WHO) In heavily industrialized urban areas, long-term exposure to fine particulate matter, or $PM_{2.5}$, has emerged as a major environmental risk to young people's minds. However, the mechanism of this harm remains controversial: some studies attribute the increase in mental disease to reduced outdoor activity and disrupted sleep, while other researchers, represented by Tota et al. (2024) from Wrocław Medical University's Department of Psychiatry, argue that chronic $PM_{2.5}$ pollution directly damages the developing emotional and stress-regulation systems of young teens. This report examines the impact of sustained $PM_{2.5}$ exposure on early adolescents' mental well-being in industrialized cities from developmental, behavioral, and psychological resilience perspectives. Only after understanding the negative influence of $PM_{2.5}$ can people realize the severity of this environmental issue and take action to protect the mental well-being of early adolescents.

Early adolescents are uniquely vulnerable to the mental health impacts of $PM_{2.5}$, largely because their biological and neurological systems are still developing. Unlike adults, teenagers in early adolescence are "owing to the juvenility of the brain," (Newbury et al., 2019, p. 615) especially in regions responsible for emotional regulation, decision-making, and stress responses. According to Newbury et al. (2019), a cross-disciplinary team of leading researchers from King's College London and Imperial College London, the developing blood-brain barrier is less effective at blocking harmful particles, allowing $PM_{2.5}$ to penetrate neural tissue more easily and trigger inflammation (p. 619). This perspective is consistent with the view that "$PM_{2.5}$ can overcome the alveolar-capillary barrier and reach other organs," causing systemic inflammation and oxidative stress that directly affect the central nervous system, and young people's immune and neurological systems have not fully matured (Tota et al., 2024, pp. 4-6). Similarly, Waxman and Manczak, from the University of Denver, added that adolescence represents a sensitive phase in brain development, "suggesting increased susceptibility to the negative impacts of environmental exposure," which means environmental toxins can disrupt healthy developmental trajectories (p. 2). Together, these studies consistently show that developmental immaturity is a

fundamental mechanism explaining why early adolescents suffer stronger mental health consequences from $PM_{2.5}$ exposure than older populations or adults.

Although researchers agree that $PM_{2.5}$ is linked to poorer mental health in adolescents, debate continues over whether these effects operate directly through biological damage or indirectly through changes in teenagers' behavior. One perspective supports the indirect pathway, citing a 2023 observational study by Yu Hongjun (Tsinghua University) and Zhang Heran (General Administration of Sport of China). Using accelerometer data from 206 Chinese children, the authors demonstrate that increased $PM_{2.5}$ concentrations are significantly associated with decreased daily moderate-to-vigorous physical activity (MVPA). Specifically, "10 μg/m³ increase in air pollution concentration in daily PM2.5 was associated with a 7.51-minute reduction in daily MVPA." (pp. 4-6) This implies that $PM_{2.5}$ itself does not harm the brain but merely limits healthy activities. Nevertheless, the study relies on observational designs that cannot rule out relevant factors like socioeconomic status, and the sample is limited to a single kindergarten, restricting generalizability. Moreover, multiple studies provide strong evidence for direct mental effects. For instance, Lin et al. (2019) demonstrated that "the higher the concentration level of $PM_{2.5}$ in a district, the more likely youths from that same district claimed to feel unhappy." (pp. 5-6) Notably, this result is found after "controlling for important individual- and district-level covariates." Apart from these two perspectives, a large national study by Hu et al. (2025) of nearly 20,000 Chinese adolescents asserted that $PM_{2.5}$ exposure and unhealthy lifestyle act together to increase depression and anxiety, with their combined harm stronger than either factor alone. This view supports both direct biological effects and indirect behavioral pathways. Consequently, the findings do not deny that reduced outdoor time may play a role, but they clearly show that direct physiological damage is the dominant pathway.

However, not all studies agree on the same conclusion regarding $PM_{2.5}$ and adolescent mental health. For example, Waxman and Manczak, though aligned with Newbury et al. (2019), Tota et al. (2024), and Lin et al. (2019) when discussing adolescents' particular susceptibility to air pollutants, yielded conflicting results of the link between $PM_{2.5}$ and early adolescents' mental health, arguing that $PM_{2.5}$ did not significantly predict adolescent depression (p. 9). This discrepancy can be largely attributed to methodological weaknesses rather than a real absence of effect. Their cross-sectional design only captures cross-sectional correlations and cannot establish causality. In contrast, studies with more rigorous designs provide more reliable

evidence. Newbury et al. (2019), using a longitudinal twin cohort design with 1,116 twin pairs and following for 18 years, effectively eliminated genetic and family environmental confounding variables. Their results confirmed that air pollutants, including $PM_{2.5}$, significantly increase the risk of psychotic-like experiences and general psychological distress in adolescents. Lin et al. (2019) also used robust population-based methods and reported a clear dose-response relationship. Therefore, the claim that $PM_{2.5}$ is unrelated to adolescent mental health lacks sufficient scientific support and is contradicted by higher-quality evidence.

Psychological resilience is a widely recognized protective factor that helps adolescents cope with stress, trauma, and adversity. Research on Turkish adolescents shows that individuals with higher resilience can better regulate negative emotions and recover faster from challenging situations (Cakir et al., 2024). At first glance, resilience might seem capable of reducing or even preventing mental health damage caused by $PM_{2.5}$. Nevertheless, a 2024 review editorial by Wang and Liu from the School of Education of Tianjin University, notes that environmental stressors like chronic $PM_{2.5}$ pollution create a persistent and heavy psychological burden that can overwhelm even strong resilience (p. 204). Continuous exposure to poor air quality acts as a long-term environmental stressor, gradually draining cognitive and emotional resources, and thus the effectiveness of resilience weakens as stress accumulates. Empirical evidence further supports this limitation. Tota et al. also found that mental health outcomes remain worse in polluted areas, regardless of individual coping resources. This finding carries important implications which is that supporting mental health alone is insufficient, so reducing air pollution becomes necessary to truly protect adolescent well-being.

In conclusion, $PM_{2.5}$ exposure severely threatens the mental health of adolescents by direct neurological damage and indirect behavioral disruption, with their developing brains making them uniquely vulnerable. To address adolescent mental health risks linked to $PM_{2.5}$ pollution, a combined intervention strategy is strongly supported by Hu et al. (2025), requiring both strengthening air pollution control and promoting healthy lifestyles. This integrated strategy is evidence-based and addresses both environmental and behavioral risks. However, the limitation is that policy-level air quality improvement requires long-term efforts and governmental cooperation, while lifestyle interventions rely heavily on family and school participation, making full implementation difficult. Since chronic $PM_{2.5}$ can overwhelm adolescent resilience, only

combining pollution reduction and healthy lifestyle promotion can effectively protect young people’s mental health.

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