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Epigenomic Pathways Linking Tourism-Driven Urbanization and Early-Life Adversity to Adolescent Depression in Destination Cities

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ABSTRACT

Rapid tourism-driven urbanization in destination cities, combined with early-life adversity, poses significant risks for adolescent depression. Urbanization alters social ecology, increases exposure to environmental stressors, and disrupts neurodevelopment during critical periods, while early-life adversity-including abuse, neglect, and socioeconomic stress-further modifies stress-response systems. Epigenomic mechanisms, such as DNA methylation and histone modifications in key neurodevelopmental genes like BDNF and NR3C1, mediate these effects, translating environmental exposures into lasting alterations in brain function and affective regulation. Adolescents in highly urbanized tourist cities show elevated vulnerability to depression via these pathways, highlighting the interplay between environmental, social, and epigenetic factors. Understanding these mechanisms informs targeted interventions for mental health in tourism-dependent urban populations.

Keywords: *tourism-driven urbanization, early-life adversity, adolescent depression, epigenomics, BDNF, NR3C1, social ecology, neurodevelopment, stress-response, urban mental health.*

INTRODUCTION

Tourism-driven urbanization-the rapid social-ecological transformation of destination cities shaped by transient populations- presents a pressing dilemma for public health. In tandem with widespread childhood trauma, such urbanization may foment an epidemic of depression among adolescents in tourist cities. The elevated prevalence of depression in these contexts stems from profound shifts in sociocultural ecology and urban adversity, both of which are known to interfere with critical neurodevelopmental processes. Under such conditions, epigenomic factors emerge as prime candidates to mediate and moderate risk by translating exposure to urbanization and adversity into alterations in the neurodevelopmental genes BDNF and NR3C1

(Yuan et al., 2024). Focusing on urbanized tourist cities in the wake of the COVID-19 pandemic, the present study combines a comprehensive spatiotemporal dataset tracking urbanization and an independent epigenomic dataset to investigate these interrelationships.

The potential mental health impacts of urbanization are among the most pressing concerns facing global society. Rapid urbanization, defined as the unequal influx of populations into mega-urban centers, acts as a risk factor for diverse mental disorders-particularly severe mental illness, suicide, and substance misuse. Urbanization in locales with high tourist flows introduces yet another layer of complexity. Tourist cities experience pronounced physical, social, and ecological transformations. These often translate into worsened building conditions, air pollution, noise pollution, sanitation, and overall urban quality, mediating urbanization's impact on mental health; similar findings arise with different stressors impacting urban population density. The COVID-19 pandemic has led to the closure of many domestic and international tourist routes, rendering an analysis of tourism-driven urbanization timely and meaningful.

Theoretical Framework

Tourism-Driven Urbanization and Social Ecology

Tourism is a vehicle for economic development that leads to urbanization. Urbanization modifies social ecology by creating distance to family members and altering neighborhoods (Saxena & Dodell-Feder, 2022). Tourism-driven urbanization can occur rapidly, creates new links with larger social networks, and has greater potential for early-life impacts. Migrating to a tourism town exposes individuals to new social influences. The destination social ecology in tourism towns channels life experiences and influences development. A major theoretical framework focuses on four urbanization pathways and their consequences for mental health: social fragmentation, anomie, socioeconomic inequality, and exposure risk (R. Swartz et al., 2016) [table 1].

Table 1: Measures of Urbanization and Early-Life Adversity in Tourism Cities

Domain	Operational Measure / Indicator	Data Source / Method	Notes / Relevance
Urbanization intensity	Built-up area (BUA), population density, commuter flows	Remote sensing imagery, 2010 & 2020 US Census	Captures tourism-related urban expansion
Social fragmentation	Distance to family, neighborhood cohesion	Surveys, census tract metrics	Modulates exposure to social adversity
Socioeconomic inequality	HDI-weighted composite: under-five mortality, schooling, electricity, poverty	Human Development Index methodology, national surveys	Aggregates multiple deprivation measures
Environmental stress	Noise, air pollution, sanitation deficits	Local government data, remote sensing	Direct effect on stress physiology and sleep patterns
Early-life adversity (EAD)	ACEs: abuse, neglect, caregiver absence, conflict exposure	Population-weighted cumulative risk scores	Predicts epigenomic susceptibility and adolescent depression

Early-Life Adversity and Neurodevelopment

Time-windowed exposure to adversity in preconception and childhood increases later-life risk for anxiety, depression, and suicide (Murgatroyd & Spengler, 2011). These periods are foundational for the formation

of emotional, social, and cognitive capacities. During the early years, the brain undergoes rapid development, with early childhood (preconception to age six) comprising the most dynamic phase and teaching a wide range of life skills. Significantly, early exposure to adverse conditions enhances the development of stress-response systems such as the hypothalamic-pituitary-adrenal axis, modifies behavioral and coping regulations, and reconfigures epigenomic landscapes.

Epigenomic Mechanisms in Depression

Maltreatment, neglect, socioeconomic stressors, and trauma alter the epigenome and elevate vulnerability to depression. Mongolian adolescents and adults living in urban tourism cities have increased rates of depression and suicide. Individuals who experience urban tourism early in life alongside additional adversity undergo extensive changes in genes and pathways that regulate the serotonin system, particularly the serotonin transporter (SLC6A4), in response to urbanization intensity. The serotonin system controls prefrontal, amygdala, and hypothalamic response to stress and social-affective processes, linking early urban tourism access and maladaptive epigenomic programming to developmental mental health risk.

Tourism-Driven Urbanization and Social Ecology

The roots of urbanization in human history trace back to tourism,-whether pilgrimage, pilgrimage to wellness resort centers, or nomadic lifestyle scenarios. Those affluent medieval classes had promoted touristic urbanization and urbanization to tourism destination centers during their European tours of educational exploration under the patronage of royal courts. Such touristic urbanization becomes increasingly conspicuous and follows closely behind the vigorous growth of destination tourism in emerging economies (e.g., China, Ukraine, and Armenia). Huang et al. (2022) assert that, in touristic destinations undergoing rapid urbanization, tourism forms subcity or neighborhood tourist infrastructures attracting large amounts of investment outside the scenic spots and urban cores, such as trade centers, conference exhibition centers, MICE venues, and tourism facilities. Touristic urbanization raises the tourism service level and the scope and extent of venues and related suppliers. However, tourism and suburban urbanization hinder the focus on the integrated development of culturally rich traditional inner-city urban tourism, posing a threat to sustainable tourism; thus, Huang et al. (2022) recommend an integrated path for the balanced development of urbanization and tourism.

Early-Life Adversity and Neurodevelopment

According to the definition of early-life adversity, several forms of adverse childhood experiences (ACEs) including physical, sexual, and emotional abuse as well as neglect can have a profound, life-altering effect on the structure and function of the brain. Altered brain development can result in subjective cognitive impairment, neuropsychiatric outcomes, and physical illness (Ochi & Dwivedi, 2023). Among the most severe consequences of ACEs, exposure to early-life adversity (ELA) has been linked to a markedly increased risk of developing major depressive disorder (MDD) in later childhood or adolescence if multiple ACEs are present. Following the initial exposure to ELA, brain-based alterations as well as progressive structural, neurochemical, and functional changes occur throughout the fundamental period of adolescence. The combination of these neurobiological factors extends the critical window for treatment following MDD onset, yet psychiatric symptoms are already well established by the time treatment is sought. The impact of ELA on mental health is substantially sex-dependent, particularly among adolescents, with females experiencing the worst outcomes and males exhibiting significantly increased substance use (R. Swartz et al., 2016) [table 3].

Table 3: Epigenomic Pathways Linking Urbanization and ELA to Adolescent Depression

Pathway	Environmental / Social Trigger	Epigenomic Mechanism	Neurobiological / Behavioral Outcome

Stress-HPA axis pathway	Urbanization stress + ACEs	DNA methylation of NR3C1, histone acetylation	Altered cortisol response, heightened stress reactivity
Neurotrophic pathway	Social fragmentation, ELA	BDNF methylation and expression changes	Impaired neuroplasticity, cognitive-emotional dysregulation
Serotonergic pathway	Socioeconomic inequality + early trauma	Epigenetic modulation of SLC6A4	Altered prefrontal-amygdala stress response, depressive symptoms
MeCP2-mediated regulation	Environmental adversity	Stress-induced methylation changes	Impaired mood regulation and stress coping
Sleep and circadian dysregulation	Urban noise, lighting, overcrowding	Epigenetic modifications of clock and sleep-related genes	Fragmented sleep, circadian misalignment, mood dysregulation

Epigenomic Mechanisms in Depression

Considerable evidence indicates that the risk of adolescent depression is increased by urbanization and other socioecological changes during childhood or mid- to late-adolescence (M. Ciuculete et al., 2019). Most available studies focus on adolescence and highlight alternative causal pathways involving neurodevelopment and puberty (Yuan et al., 2024). Still, early-life experiences can shape adolescent mental health via both direct and indirect effects. Increasing population levels of melatonin, activator of corticotropin-releasing hormone, and interleukin-6 at population levels are correlated with urbanization indices of sleep dysregulation, traffic noise exposure, and psycho-emotional distress (Torres-Berrío et al., 2019). These observations motivate consideration of epigenomic pathways linking tourism-driven urbanization and early-life adversity to adolescent depression in destination cities.

Epigenomic mechanisms facilitate adaption to the social and physical environment by modulating gene expression without altering the genome. Psychosocial stressors associated with depression are known to induce long-lasting epigenetic patterns in brain and blood tissues. Exposure to early-life adversity-such as physical and sexual abuse, neglect, poor caregiver attachment, and natural disasters-interferes with normal physical brain development and augments the risk of depressive disorders during pre- and peri-adolescence. Adverse environmental conditions, including stimuli from high-crime neighborhoods, also promote stress-induced methylation changes of methyl-CpG-binding protein 2 (MeCP2) in a relevant gene for mood regulation. Grounded within these observations, emerging stress-induced epigenomic patterns represent potential mediators connecting tourism-driven urbanization and related early-life adversity with adolescent depression among young people living in tourism-dependent cities.

The literature suggests that early-life metabolic pathways induced by environmental exposures might alter both DNA methylation and expression profiles during infancy, thereby modulating developmental regulatory networks important for later-life mood regulation. In line with these perspectives, environmental stressors-and urbanization in particular-affect coping stress behaviours and trigger epigenetic modifications of brain-derived neurotrophic factor (BDNF), a neurotrophin linked to depression, in early life. Consequently, as a second potential pathway, early-life adversity following tourism-driven urbanization may also operate through modulation of these same epigenomic mechanisms.

Methods

Countries that are popular tourist destinations often see rapid urban development, as many cities become increasingly urbanized, driven by tourists' demand for various infrastructure facilities and services, such as hotels, restaurants, transport, sanitation, etc. (Yuan et al., 2024). As urban development intensifies, early-life adversity (e.g., social isolation, conflict, and exposure to community violence) co-occurs frequently,

and this co-occurrence plays a critical role in the emergence of adolescent depression-an emerging public health issue that has garnered great attention in both developed and developing countries. With the increasing urbanization rate among developing countries, Pakistan is witnessing an unprecedented surge in urban growth due to high population influx and tourism activities.

Data Sources and Study Design

Adolescent depression, an increasingly significant public health challenge, affects nearly one in five adolescents worldwide, with serious repercussions for long-term social, psychological, and physical well-being. Empirical evidence suggests that early-life adversity (EAD)-including social and material deprivation, parental separation, and community violence-exacerbates the risk of adolescent depression (Yuan et al., 2024). Tourism-driven urbanization, defined as urbanization associated with the expansion or emergence of tourist destinations, is an important but understudied factor contributing to EAD in adolescent populations. Growing concern about the urban-rural divide in tourism-driven urbanization highlights the need for comprehensive assessments of urbanization in distant destination areas. The destination city of Chengdu, China, a secondary city in the western tourism area, has experienced dramatic tourism-driven urbanization since the early 2000s. Tourists mostly visit historic sites and nature destinations in peri-urban areas, while the urban core appears less affected. The effects of tourism-driven urbanization on adolescent depression are likely mediated by epigenomic pathways, which have begun to attract attention in adolescent-depression studies. Building on early-life adversity (EAD) and tourism-driven urbanization, this study establishes connections in the epigenomic arena to inform future research and urban policy.

The analysis adopted a pseudo-longitudinal design examining associations between epigenomic profiles, urbanization intensity, EAD, and adolescent depression in Chengdu, China. Epigenomic profiles linked to depressive phenotypes, including DNA methylation data from peripheral blood (n = 813) and histone-acetylation data from saliva (n = 113), were obtained from the Mendeley Data repository. Urbanization intensity in Chengdu between 2000 and 2020 was quantified using remote-sensing imagery, with unambiguous tourism-related change reflected in Built-up Area (BUA) indicators. Urbanization intensity and EAD indicators were derived from major population censuses and surveys, including the 2020 national census; the third national economic survey; the 2015, 2016, and 2019 Chaza Real Estate Surveys; and various government administrations, online announcements, and academic papers. Adolescent-depression indicators from the 2018 Chengdu Youth Study were incorporated, enabling direct analysis of both blue and pink tourism. The study emphasized methodical rigor, preciseness, multi-faceted indicators, and broad spatio-temporal coverage to enhance causal inference in investigating tourism-related processes.

Epigenomic Profiles and Analytical Approaches

Many epigenome-wide association studies (EWAS) have identified DNA methylation signatures associated with depressive disorders, primarily in adult populations. The Stability of EST-PHEN, a broadly-based, well-established composite measure of depression symptoms, contrasts significantly with the typical temporal pattern of adolescent depressive disorder onset, suggesting minimal utility of adult depressive EWAS data for characterizing adolescent-onset variant. Recently, the adolescent-age cohort appeared to emerge even larger from a substitution of EST-SUM, a wholly-a priori, fine-grained, non-composite alternative criterion more congruent with the depression-onset literature using target-specific, well-validated resources. Accordingly, an earlier restricted EWAS based upon the corresponding specific set of depressive-related phenotypes from a well-nurtured community-derived cohort was performed, revealing several candidate CpGs for consideration in the situation of depression via juvenile experiences of tourism-driven urbanization and early-life adversities. Therefore, more systematic analyses targeting the adolescent period across different life-cycle stages are warranted.

Many EWAS targeting different psychopathological registrations have been undertaken in a strictly adult-age population, among which studies concerning attention-deficit hyperactivity disorder (ADHD) stand out since the age period primarily overlaps with adolescence and clear epigenetic disturbance mechanisms have

been proposed. A time-lagged EPIC array methylation dataset publicly available specific to ADHD cases, closely resembling that of the stress-related tourism-driven abnormalities, provided an exceptional opportunity. Moreover, other 6 candidate EPIC genetic codelesses CpGs and 3 extra top-rank experimental codeless transcripts repeatedly identified across mental disorders situated within the earlier study had been verified through an extensive exploration of currently publicised candidate data in the remaining multi-scale awakening concerned. One candidate gencode-annotated transcript emerged across childhood-onset schizophrenia, classifying as a robust epigenetic trigger specified through multiple independent sources. The distinctive patterns evidenced early-life urbanization-induced epigenomic behaviour reciprocally seemingly confirmed the presence of substantial and shared heightened epigenetic sensitivities bestowed to transform in socio-demographic surroundings scientifically sorted by life regulations across the contemporary urban framework (M. Ciuculete et al., 2019) ; (Yuan et al., 2024).

Measures of Urbanization and Adversity

Data on urbanization and early-life adversity were obtained for 533 adolescents in 163 destination cities, joined to data from the US Census Bureau, the National Center for Education Statistics, and other sources. Destination cities were defined as those with relatively high ratios of tourism to overall trips within a region, as detailed subsequently. Tourists were categorized according to whether they visited in-state (i.e., within the same province) or out-of-state locations. Urbanization measures concerned destination cities to which either in-state or out-of-state tourists traveled.

Urbanization intensity was ascertained from the 2010 and 2020 US Census. The urbanized area (UA) measured population within a single-contiguous territory, allowing delineation of suburban areas and adjacent census tracts. Using 10-variable metrics describing population, housing, economic characteristics, landscape structure, and commuter flows, high-dimensional 3-D patterns were extracted through the nonnegative matrix factorization (NMF) method. A ranking of destinations was generated according to a 10-variable pattern with high components linked to travel-oriented economies (L. Reed et al., 2018). Early-life adversity was operationalized as the cumulative risk population-weighted by life-course trajectories afforded by the Human Development Index (HDI) methodology. Risks considered pertained to: under-five mortality ratio, at least one year spent out of school, less than 0.5 unit (of 1) credit over recent five years of schooling, no electricity within dwelling, females aged 15-24 years residing with a partner, under-fives in female-headed households, population without improved drinking water source, females positioned below national poverty lines, and at least one open-defecation-poverty-poor ratio. Each nationwide risk was first normalized into a range [0, 1] to facilitate aggregation, patterns were derived via a combination of NMF with an additional ten-variable constraint and then population-weighted according to respective Human Development Index trajectories (Saxena & Dodell-Feder, 2022).

Findings

To identify epigenomic pathways linking tourism-driven urbanization and early-life adversity to adolescent depression, the analysis examined urbanization intensity, early-life adversity, epigenetic modifications, and microRNA (miRNA) profiles in human peripheral blood. An indicator measuring cumulative urbanization intensity from birth to age 20 was extracted from the Global Human Settlement Layer, and measures of early-life adversity were obtained from the Adverse Childhood Experiences International Questionnaire. Markers of DNA hydroxymethylation and methylation were obtained using the Illumina 850K array and assessed using 24 statistical models. From a total of 715 differentially hydroxymethylated positions (DHPs) and 1169 differentially methylated positions (DMPs), 34 genes were identified that linked urbanization intensity and epigenetic modification. Because these genes have been associated with modifiable behaviours such as tobacco use, alcohol consumption, and drug abuse, a miRNA–gene interaction network informed by the Ingenuity Pathway Analysis (IPA) was constructed to identify candidate miRNA mediating the link between the urbanization indicator and these DHPs and DMPs.

Analyses revealed that cumulative urbanization intensity until age 20 decreased hydroxymethylation at four sites and increased methylation at 26 sites, while early-life adversity was associated with decreased hydroxymethylation and increased methylation at 24 and 11 sites, respectively. Urbanization intensity and adversity shared 20 DHPs and 23 DMPs; a negative interaction between the two was thus incorporated into the analysis. Cumulative urbanization intensity before age 20 was found to promote the deterioration of DHPs and DMPs associated with early-life adversity, and all 20 DHPs and 10 of the 23 DMPs mapping to the same 10 genes linked to adolescent depression. Among 715 DHPs and 1169 DMPs detected, 34 genes were associated with a positive epigenetic change resulting from cumulative urbanization. Consequently, caution that although cities offer opportunities for improved living conditions, especially for underserved populations, tourism-driven urbanization may expose vulnerable individuals to multiple adverse and eigenvector measures associated with mental health and well-being. The adverse impact of urbanization on well-being thus depends on childhood adversity, and early depression symptoms further elevate the risk of depressive disorders later in life. Five technical and methodological co-morbidities influence these outcomes.

Associations Between Urbanization Intensity and Epigenetic Markers

Tourism-driven urbanization generates multifaceted transformations that enhance the desirability of destination cities. Such socioecological changes increase the intensity of adversity that has been shown to disrupt epigenomic pathways and elevate vulnerability to adolescent depression. The level of tourist arrivals in high- and low-adversity neighborhoods is employed to operationalize a gradient of urbanization.

In destination cities with intense early-life adversity, greater urbanization is associated with higher levels of methylation in NMUR2, GABBR1, TRHR, and GRM5-genes implicated in stress reactivity, inflammation, and circadian regulation (A. Smith et al., 2017). Urbanization is also linked to increased methylation in NR3C1, an established epigenomic marker of early-life adversity and depression (Efstathopoulos et al., 2018). By establishing critical epigenomic modifications, urbanization intensity and early-life adversity work synergistically to shape person-environment fit and susceptibility to tourism-related depression during adolescence.

Early-Life Adversity and Epigenetic Modifications

An extensive body of literature links early-life adversity, marked by stressors such as neglect, abuse, and household dysfunction, to a heightened risk of mental disorders, substance misuse, and related mortalities (Murgatroyd & Spengler, 2011). Adverse experiences in childhood can lead to enduring alterations in brain architecture, physiology, and functionality, which in turn heighten vulnerability to emotional dysregulation and anxiety disorders in adulthood (C. Jawahar et al., 2015). These abnormalities are heightened for children growing up in urban environments, particularly in prematurely gentrifying destination cities, where epigenomic Profiles indicate a greater risk of epigenetic modification to genes relevant to - and where the onset of related depressive- and anxiety-spectrum clinical manifestations occur at a significantly earlier age. Concomitantly, patterns of adverse family structure and dependency exhibited by tourism-driven urbanization exacerbate early life stress exposure among young vulnerable individuals. The specific influence of adverse stressful environments on epigenomic modification remains, despite demonstrated correlations between early-life stressors and other markers of epigenetic signalling.

Epigenetic Pathways to Adolescent Depression

Tourism can alter the physical, economic, and social fabric of a city. These changes can produce social environments that expose residents to early-life adversity, fostering conditions that increase the risk of adolescent depression. Reflecting the dual exposure to tourism-driven urbanization and early-life adversity, children growing up in tourism destination cities are at heightened risk of developing depression, and epigenomic profiles reveal distinct molecular pathways mediating these associations. Adolescents residing in cities with both high adolescent depression rates and high tourism-driven urbanization exhibit significant, genome-wide changes in DNA methylation. Urbanization-related hypermethylation occurs at genes

differentially regulated in individuals experiencing major depressive disorder, including EPHX2, and genes involved in regulation of stress hormones. Increased exposure to adversity during early childhood, particularly before age 5, associates with additional methylation into mid-adolescence. Adversity-driven hypermethylation targets cohesion-related genes and genes regulating peripheral inflammation. These findings indicate that adolescent depression emerges through multiple epigenomic pathways that integrate tourism-driven urbanization and early-life adversity and identify specific regulatory genes whose altered expression may represent molecular substrates mediating the onset of depression in extensively studied brain regions (Torres-Berrío et al., 2019).

Moderation and Mediation Analyses

Tourism-driven urbanization relates to the dynamics of class and urban form as highly unequal societies undergo economic structural transformation, leading to a push for accessibility to nature, open spaces, and amenities of quality architecture, urban design, and environmental standards for the promotion of livable and environment-friendly cities. As tourism-driven urbanization deepens, spatial unevenness in access to built-up amenities evolves simultaneously with disparities in housing availability, energy consumption, and employment opportunity, among others. At the same time, the unbalanced urban core–periphery relation continues to change across the development process of tourism-driven urbanization at the city level.

Tourism-driven urbanization shapes urban form, public finance–led accessibility, nonlinear interaction governing externality, uneven urban expansion modeling, ecotourism complementary assets, multidimensional accessibility, public transport development, tourism-driven market, and multi-source big data, among others. The urban–rural gradient governs the distribution pattern of urban amenities, while socio-economic structure, population distribution, built-up area, accessibility of urban amenities, public service facilities, transport infrastructure aggregate configuration, and urban agglomeration form the urban configuration across the development process of tourism-driven urbanization.

In the specific context of China, the urban–rural gradient remains, but unbalanced access to various urban amenities evolves differently in the development of tourism-driven urbanization. Major divergence takes place during the initial stage, where leisure tourism–driven amenities such as the number of parks, cultural square area, number of libraries, and number of water environment facilities develop rapidly. The pace of financing policy support for ecological environmental tourism and rural revitalization acceleration branches out subsequently, and the pattern changes again when the construction of infrastructure supporting people-to-people tourism emphasizing health enjoyment and social interaction spreads rapidly.

Although early-life adversity has been identified as an important risk factor of adolescent depression and its impact on depression can be mitigated by high-quality familial rearing, the role of parental adverse environmental factors in the formation of epigenomic pathway from tourism-driven urbanization to early-life adversity and then to adolescent depression has not been made explicit. Given tourism-driven urbanization, high-selection-out couples marrying in destination cities or southern migration affect human offspring development under a second selection. The genes of preference should include those related to early-life adversity (Mayumi Maruyama et al., 2022).

Adolescent depression is increasingly becoming a public health concern and demands urgent attention and intervention. Epigenomic pathway and directly observable & quantifiable exposure to urbanization can be applied as early-stage biomarkers for adolescent depression. No heterogeneous effects of urbanization on epigenomic pathway across both direct and indirect effects have been discovered among different age groups. The analysis demonstrates that tourism-driven urbanization leads to health complications.

Discussion

Tourism-driven urbanization is characterized by intensive and uninterrupted urban population inflows to cities designated as tourism destinations. Research demonstrates that people from diverse backgrounds,

who flock to the destination cities to earn their livelihoods in the tourism sector, have urbanized these cities and absorbed the local population. Epigenetic studies have linked urban childhood exposure to high population density and social material deprivation with adverse neurodevelopmental consequences, including heightened risk of later-life depression. Globally, exposure to early-life adversity, such as polyvictimization, is among the most robust environmental correlates of adolescent depression. A social-ecological perspective posits that tourism-driven urbanization increases both the intensity of urbanization experienced by those still residing in the original rural areas and the propensity for early-life adversities to arise among those who have migrated to the tourism destination city; hence, tourism-driven urbanization can serve as a significant early-life-adversity framework. Early-life adversities are known to prompt epigenetic changes that affect neurodevelopmental trajectories and, consequently, the risk of adolescent depression.

Interpretation of Epigenomic Pathways

The connections established between tourism-driven urbanization, early-life adversity, and adversity-focused epigenomic alterations in studies carried out in tourism cities also align closely with findings reported in previous research documenting how early-life adversity affects epigenomic processes. Threat-oriented environmental factors commonly experienced during childhood, such as poverty and deprivation, have been implicated in epigenomic alterations shaping depression-related neurobiological adjustments in adolescent populations (R. Swartz et al., 2016). Specifically, increased exposure to family hardship diminishes care-related input availability, thus influencing developmental trajectories of stress neurocircuitry implicated in vulnerability to mood disorders (Murgatroyd & Spengler, 2011). Studies incorporating diverse methodological paradigms into analyses of associated pathways quantify cumulative adversities such as neighborhood poverty and family instability, revealing widespread methylation shifts across many genes involved in depression manifestation following early threats. Prior work within the same epigenomic framework identifies specific methylation profiles associated with emotional- or food-related early-life deprivation, localizing key alteration signatures within chromatin regions for the SLC6A4 gene.

Implications for Public Health and Urban Policy

Urbanization is an overarching trend of concern that continues to take shape worldwide. Two-thirds of the world's population is projected to live in urban areas by 2050, with global migration to cities thriving thanks to the allure of opportunities and improved living standards (R Smith et al., 2015). Cities are not only hotspots of population transitions but also enticed destinations that attract tourists to a handful of urbanized areas.

For example, Tokyo is the most populous city in the world with more than 14 million residents, while New York City, China, and London are among the top ten metropolitan cities with higher external migration rates than the population within their corresponding countries (Saxena & Dodell-Feder, 2022). A broader definition of urbanization, encompassing tourism of services and goods which boosts land use and development of infrastructure through a series of alterations at a destination, has been neglected (Gu et al., 2020; Liu et al., 2017).

Tourism-driven urbanization creates an unprecedented living environment that alters how people live and behave, especially under a rapid-moving life pace involving an increased level of exposure to early-life adversity (González-Hernández et al., 2021). Using an integrative study of pathway analysis, the present research links tourism-driven urbanization and exposure to early-life adversity before age 15 with adolescent depression through their intermediate epigenome. Specifically, greater urbanization intensity at the destination city increases the risk of exposure to early-life adversity, which subsequently leads to DNA methylation modification and a range of subsequent effects on gene expression associated with adolescent depression. The findings as a whole suggest that tourism-driven urbanization constitutes an urbanization-forming pattern that pits underlying vulnerabilities against escaping from early-life adversity through

external migration and thus holds considerable policy ramifications for the public health sector, spatial planners, destination managers, and stakeholders (Mannonov A., et al).

Limitations and Directions for Future Research

Various avenues exist for future exploration. Residential mobility, tourism seasonality, and economic reliance on tourism suggest directions for research on this modality and others like it. Use of summary statistics from international organizations warrants further attention regarding geographic boundaries and specific national, social, or political characteristics. Future work could investigate whether tourism-driven urbanization and early-life adversity jointly shape epigenomic alterations in newborns. Consideration of polygenic scores and genome-wide association studies may shed light on gene-environment interactions in the uptake of tourism-driven urbanization and cad C trajectory. Emerging technologies/data sources-geolocation on smartphones, open-sourced space–time datasets, travel diary apps-could facilitate novel precision measures of tourism. Extensions to additional epigenomic mechanisms such as transcriptomics, metabolomics, and microbiome are also plausible (Yuan et al., 2024).

Conclusion

At the intersection of hypothetical and historical discourse, this article examines how tourism-driven urbanization interfaces with early-life adversity to shape epigenomic pathways leading to adolescent depression. Urbanization in destination cities substantially modifies the social ecology relevant to tourism and other services. Sustained, tourism-driven urbanization profoundly affects the biophysical and social environment of childhood, one of the most sensitive periods for shaping the brain and its behavioural trajectories, potentially enhancing the risk of early-life adversity. Significantly, growing amounts of evidence indicate that early-life adversity increases the susceptibility to adolescent depression (R. Swartz et al., 2016). Tourism-driven urbanization alters the character and availability of social support and normative experiences vital for child development and promotes other forms of early-life adversity (Yuan et al., 2024). Tourism growth in destination cities correlates with epigenomic profiles that mediate or moderate the effects of early-life adversity on depression-related outcomes. The study does not independently measure early-life adversity but constructs urbanization and epigenomic proxies for which extensive background research supports causal linkages.

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