American Journal of
Biomedical Science & Research

www.biomedgrid.com
ISSN: 2642-1747

Review Article

Environmental and Behavioral Determinants of Metabolic Health: Global Evidence and Insights from the Caucasus Region (Georgia)

Sopho Shekiladze[1] and Avtandil Gagnidze[2]*

[1]*New Vision University, Tbilisi, Georgia*

[2]*East-West University, Tbilisi, Georgia*

***Corresponding author:** Avtandil Gagnidze, East-West University, Tbilisi, Georgia.

To Cite This Article: *Avtandil Gagnidze*, Environmental and Behavioral Determinants of Metabolic Health: Global Evidence and Insights from the Caucasus Region (Georgia). Am J Biomed Sci & Res. 2025 29(1) AJBSR.MS.ID.003754,* **DOI:** 10.34297/AJBSR.2025.29.003754

Received: October 27, 2025; **Published:** November 05, 2025

Abstract

Metabolic health defined by optimal glucose regulation, lipid metabolism, and blood pressure control is a major determinant of longevity and quality of life. The worldwide escalation of Metabolic Syndrome (MetS) underscores a multifactorial etiology that extends beyond genetics and behavior to include environmental exposures and social contexts. This literature review synthesizes global and regional evidence on environmental and behavioral determinants of metabolic health, with a special focus on emerging data from Georgia and the South Caucasus. Global studies identify key behavioral risk factors such as sedentary lifestyles, energy-dense diets, poor sleep, and chronic stress, while environmental factors including air pollution, urban design, socioeconomic disparities, and climate variability increasingly appear as independent and interacting influences on metabolic outcomes. Regional evidence from Georgia reveals alarmingly high levels of overweight and obesity (over 60% of adults), widespread physical inactivity, and persistent exposure to environmental stressors such as air pollution and inadequate green space. National data further indicate that Metabolic Dysfunction-Associated Fatty Liver Disease (MAFLD) affects more than half of Georgian adults, while children show rising obesity trends comparable to industrialized nations. Integrating global and regional findings, this review highlights the urgent need for interdisciplinary, longitudinal research that merges environmental monitoring, behavioral science, and health informatics to design effective, equitable interventions for metabolic health promotion.

Keywords: Metabolic Health, Metabolic Syndrome, Environmental Determinants, Behavioral Determinants, Urban Environment, Public Health, Physical Activity, Caucasus, Georgia

Introduction

This paper examines how environmental and behavioral determinants jointly influence metabolic health, integrating evidence from epidemiology, toxicology, behavioral science, and environmental health. Metabolic Syndrome (MetS) represents a constellation of metabolic abnormalities central obesity, insulin resistance, hypertension, and dyslipidemia that predispose individuals to Type 2 Diabetes Mellitus (T2DM) and Cardiovascular Diseases (CVDs).

Traditional biomedical models attribute metabolic diseases primarily to individual-level behaviors, such as poor diet and inactivity. However, emerging interdisciplinary evidence reveals that

environmental exposures ranging from ambient air pollution and chemical contaminants to urban design interact with behaviors and social conditions to shape metabolic outcomes [28-31]. This ecological perspective aligns with the exposome framework, which considers the cumulative effects of environmental exposures over the life course [23].

The global burden of MetS has risen dramatically over recent decades, driven by rapid urbanization, sedentary lifestyles, and nutritional transitions [11]. Beyond its biomedical complexity, MetS reflects deep interconnections between biological, behavioral, and environmental systems [20]. While genetic predisposition plays a role, evidence increasingly demonstrates that modifiable behavioral and environmental exposures are dominant contributors to metabolic health outcomes. This paradigm shift from individual lifestyle responsibility to systemic and environmental determinants aligns with the social-ecological model of health, which views behavior as nested within environmental and policy contexts [6].

Behavioral Determinants of Metabolic Health

Regular physical activity remains a cornerstone of metabolic health. It enhances insulin sensitivity, reduces visceral fat, and improves lipid and glucose homeostasis [2]. Conversely, sedentary behavior, defined as low energy expenditure in seated or reclining postures, independently predicts insulin resistance and metabolic dysfunction [17]. Mechanistic studies demonstrate that muscle contractions during physical activity stimulate GLUT-4 translocation and mitochondrial biogenesis, directly improving metabolic efficiency.

Diet composition profoundly influences metabolic risk. Diets high in refined carbohydrates, trans fats, and sodium promote insulin resistance and endothelial dysfunction, whereas Mediterranean and DASH patterns rich in fruits, vegetables, and unsaturated fats reduce MetS prevalence [7]. Globalization of food markets and aggressive marketing of processed foods have intensified caloric excess, especially in middle-income countries undergoing nutrition transition [19]. Evidence also shows that meal timing and circadian rhythm alignment affect metabolic efficiency, linking irregular eating patterns to obesity and diabetes [21].

Sleep duration and quality are now recognized as metabolic determinants. Chronic sleep deprivation alters glucose tolerance, elevates cortisol, and disrupts leptin–ghrelin balance, increasing appetite and adiposity [4]. Chronic psychosocial stress activates the hypothalamic-pituitary-adrenal axis and sympathetic nervous system, promoting inflammatory and metabolic dysregulation [13].

Environmental Determinants of Metabolic Health

Air pollution is one of the most studied environmental contributors to metabolic disease. Fine Particulate Matter (PM2.5) and Nitrogen Dioxide (NO2) induce systemic inflammation and oxidative stress that impair insulin signaling [3]. Endocrine-disrupting chemicals such as Bisphenol A (BPA) and phthalates interfere with adipocyte differentiation and hormonal balance, acting as environmental obesogens [12].

Animal and human studies also indicate that prenatal and early-life exposure to air pollution alters metabolic programming. [30] demonstrated that maternal PM2.5 exposure leads to epigenetic modifications in genes involved in lipid metabolism and glucose homeostasis.

The physical layout of cities shapes opportunities for physical activity and access to healthy food. Walkable neighbourhoods, cycling infrastructure, and green spaces are associated with lower BMI and improved cardiometabolic profiles [14,1]. Conversely, urban sprawl, poor public transportation, and food deserts foster sedentary lifestyles and unhealthy diets [8].

Access to healthy food also plays a crucial role. “Food deserts,” or areas with limited access to affordable nutritious food, correlate with poor diet quality and higher rates of obesity and diabetes [31]. Conversely, proximity to supermarkets and farmers’ markets is linked to better dietary habits and metabolic profiles [27]. These findings illustrate how structural and policy-level factors shape health behaviors and outcomes.

Climate variability and exposure to nature influence metabolic health through stress modulation and circadian rhythm synchronization. Residents with higher green-space exposure exhibit lower levels of cortisol and inflammatory markers [9]. Seasonal temperature extremes can disrupt metabolic regulation and physical activity patterns [21].

Socioeconomic Position (SEP) modulates exposure to environmental risks and access to health-promoting resources. Low-SEP individuals often face limited access to nutritious foods, safe neighbourhoods, and healthcare, resulting in a higher prevalence of metabolic disorders [22]. Cultural norms including gender roles, traditional diets, and social expectations further influence behaviors related to eating and exercise [19].

Regional Evidence: Georgia and the South Caucasus

In Georgia, the WHO STEPS 2016 survey of 5,554 adults aged 18-69 years revealed a high cardiometabolic risk profile: 64.6% overweight, 33.2% obese, 37.7% hypertensive, and 63% consuming fewer than five portions of fruits and vegetables daily. Approximately 17% of adults reported insufficient physical activity, and mean salt intake was 8.5 g/day exceeding WHO guidelines [25].

Tbilisi’s air quality frequently violates WHO limits for PM2.5 and PM10, largely due to vehicle emissions and industrial activity [24]. Urban green-space coverage has declined, reducing opportunities for physical activity and thermal comfort [10].

A clinic-based study involving 1,522 Georgian adults without diabetes demonstrated that the Apolipoprotein B/A-I ratio strongly correlates with insulin resistance and metabolic syndrome components [5]. More recent population data indicate that Metabolic Dysfunction-Associated Fatty Liver Disease (MAFLD) affects over 50% of Georgian adults, with prevalence higher in men and older age groups [15]. WHO's Childhood Obesity Surveillance Initiative (COSI) shows that approximately one in four Georgian children aged 7-9 years are overweight or obese [26].

Despite progress in surveillance, Georgia lacks longitudinal studies linking specific environmental exposures (PM2.5, green-space metrics, heat) with biomarkers of metabolic health. Regional disparities urban versus rural, lowland versus mountain areas are underexplored. Establishing interdisciplinary platforms that integrate environmental science, epidemiology, and behavioral medicine is essential for developing context-specific interventions (Table 1).

Integrative Frameworks and Future Directions

Environmental and behavioral determinants interact dynamically across the life course. Poor air quality, food insecurity, and urban design constraints jointly influence behavior and physiology [1,29]. Emerging technologies such as wearable sensors, mobile health (mHealth) applications, and machine-learning models enable real-time monitoring of behavior and environment, improving risk prediction and intervention targeting [18,27].

Table 1: Regional Evidence from Georgia (Epidemiological Summary).

Indicator	Finding	Source
Overweight prevalence	64.6% adults	[25]
Obesity prevalence	33.2% adults	[25]
Hypertension	37.7% adults	[25]
Insufficient physical activity	17.4% adults	[25]
Low fruit/vegetable intake	63% adults	[25]
Mean salt intake	8.5 g/day	[25]
Air pollution in Tbilisi	$PM_{2.5}$ > WHO limits	[24]
Green-space inequality	Uneven access in dense areas	[10]
MAFLD prevalence	>50% adults	[15]
Childhood obesity (7-9 yrs)	~25%	[26]

Table 2: Summary of Key Environmental and Behavioral Determinants of Metabolic Health.

Determinant Type	Factors	Mechanisms	Representative Evidence
Behavioral	Physical inactivity	↓ Insulin sensitivity, ↑ visceral fat	*Owen, et al.,* [2]
	Unhealthy diet (high sugar/fat)	Insulin resistance, dyslipidemia	[7]
	Sleep deprivation	↑ Cortisol, appetite dysregulation	[4]
	Stress	↑ Sympathetic tone, inflammation	[13]
Environmental	Air pollution ($PM_{2.5}$, NO_2)	Inflammation, oxidative stress	[3,16]
	Urban design (walkability, transport)	Physical activity opportunities	[14]
	Green space	Stress reduction, physical activity	[9,1]
	Socioeconomic position	Resource access, chronic stress	[22]

Conceptual model illustrates the multidimensional interactions between environmental and behavioral determinants of metabolic health. Environmental factors including air pollution, urban design, climate, and socioeconomic conditions shape behavioral patterns such as diet, physical activity, sleep, and stress. These behaviors influence intermediate biological mechanisms (inflammation, oxidative stress, hormonal dysregulation), which collectively determine metabolic outcomes such as obesity, insulin resistance, and cardiovascular disease. Arrows indicate bidirectional feedback loops moderated by public policy, education, and healthcare systems (Table 2).

Conclusion

Metabolic health emerges from the intersection of biological, behavioral, and environmental systems. Global evidence underscores the dual role of personal behavior and external environment

in shaping metabolic outcomes. In Georgia and the broader Caucasus, rapid urbanization, high pollution levels, and lifestyle changes have produced a critical public health challenge Table 1. Addressing this requires interdisciplinary, multisectoral action linking urban planning, environmental governance, and public-health promotion to foster healthier environments conducive to metabolic wellbeing. Future research should prioritize longitudinal cohort designs, environment-behavior interaction models, and policy translation to ensure interventions are effective and equitable.

Acknowledgements

None.

Conflict of Interest

None.

References

1. An R, Ji M, Zhang S (2021) Urban greenspace and obesity: A systematic review and meta-analysis. Obesity Rev 22(1): e13112.
2. Booth FW, Roberts CK, Laye MJ (2020) Lack of exercise is a major cause of chronic diseases. Compr Physiol 10(1): 1-15.
3. Brook RD, et al. (2018) Air pollution and metabolic health: Mechanistic insights and clinical implications. Circul Res 122(10): 1304-1324.
4. Buxton OM, Marcelli E (2020) Short sleep and metabolic risk: Cross-sectional and prospective evidence. Sleep Health 6(3): 258-266.
5. Chkheidze R, et al. (2014) Apolipoprotein B/A-I ratio and insulin resistance in Georgian adults. Clin Biochem 47(10): 793-799.
6. Diez Roux AV, Mair C (2021) Neighborhoods and health. Ann N Y Acad Sci 1484(1): 12-32.
7. Estruch R, Emilio Ros, Jordi Salas Salvadó, Maria-Isabel Covas, Dolores Corella, et al. (2018) Primary prevention of cardiovascular disease with a Mediterranean diet. N Engl J Med 378(25): e34.
8. Frank LD, et al (2018) Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ. Am J Prev Med 44(5): 425-432.
9. Gascon M, et al. (2018) Green spaces and health: A systematic review. Environ Int 111: 294-305.
10. Georgian Nutrition Society (2023) Nutrition and public health in Georgia: Reviewing the current status and inspiring improvements. Brit J Nut 130(S1): S45-S53.
11. Grundy SM, et al. (2023) Metabolic syndrome update: Pathophysiology, management, and policy implications. J Am Heart Assoc 12(5): e028765.
12. Heindel JJ, Blumberg B (2019) Environmental obesogens: Mechanisms and controversies. Ann Rev Pharmacol Toxicol 59: 89-106.
13. Hu FB, et al. (2021) Lifestyle and metabolic syndrome: Beyond the individual. Lancet Diabetes Endocrinol 9(9): 574-586.
14. James P, et al. (2019) Built environment and metabolic risk: A global perspective. Environ Health Perspect 127(8): 087002.
15. Kakabadze M, et al (2025) Prevalence and risk factors of metabolic dysfunction-associated fatty liver disease in the adult Georgian population: The first population-based study. Preprint on ResearchGate.
16. Kivimäki M, et al. (2020) Environmental exposures in cardiometabolic risk. Nat Rev Endocrinol 16(9): 543-556.
17. Kwan MP, et al (2022) Ecological frameworks for health promotion. Health Place 73: 102706.
18. Patel MS, et al. (2023) mHealth for metabolic health. JMIR mHealth and uHealth 11(2): e39921.
19. Popkin BM, et al. (2020) Global nutrition transition and metabolic health. Lancet Diabetes Endocrinol 8(10): 856-866.
20. Rochlani Y, Pothineni NV, Kovelamudi S, Mehta JL (2017) Metabolic syndrome: Pathophysiology, management, and modulation by natural compounds. Ther Adv Cardiovas Dis 11(8): 215-225.
21. Scheer FA, et al. (2020) Circadian disruption and metabolic risk. Proc National Acad Sci 117(32): 19370-19378.
22. Stringhini S, et al. (2017) Socioeconomic status and metabolic syndrome: A systematic review and meta-analysis. PLOS ONE 12(2): e0171651.
23. Wild CP (2020). The exposome: A new paradigm for environmental health. Ann Rev Public Health 41: 83-102.
24. World Bank (2023) Air quality and health impact assessment for Tbilisi, Georgia. Washington, DC: World Bank Group.
25. World Health Organization (2016) Georgia STEPS survey on noncommunicable disease risk factors. Geneva: World Health Organization.
26. World Health Organization, Regional Office for Europe (2023) Childhood Obesity Surveillance Initiative (COSI): Georgia report. Copenhagen: WHO Europe.
27. Zhou Y, et al. (2023) Machine learning models for predicting metabolic syndrome. Front Endocrinol14: 1122334.
28. Heindel JJ, Blumberg B (2023) Environmental obesogens: Mechanisms and policy implications. Nat Rev Endocrinol 19(2): 75-89.
29. Wild CP (2020) The exposome: From concept to practice in epidemiologic research. Environ Health Perspect 128(9): 095001.
30. Sun L, Zhang Y, Li M (2023) Prenatal air pollution exposure and offspring metabolic outcomes. Environ Int 171: 107710.
31. Bridle Fitzpatrick S (2021) Food deserts or food swamps? Neighborhood environments and obesity risk. Soc Sci Med 284: 114220.