Malaysian Journal of Tropical Geography, 2026, 52(1): 1-22

CONCEPTUALIZING THE INFLUENCE OF URBANIZATION ON THE ECOLOGICAL ENVIRONMENT: A FRAMEWORK

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ABSTRACT

Ecological environment is crucial for human as it serves essential sustenance to live and the resource to develop human society. During the global trend of urbanization, which includes the process of population growth, social-economic activities, spatial land use changes, energy consumption. Researchers worldwide have explored its impact on the eco-environment. However, a lack of consensus exists regarding the specific aspects and driving factors that impact the ecological environment. In response to these gaps, we conducted a comprehensive analysis of empirical literature relating to the effects of urbanization on ecological environment, and generated a framework for summarizing. In all, 53 studies met the inclusion criteria. Key findings reveal substantial impacts on pollution, biodiversity, and overall quality: (1) Urbanization elements, singularly or combined, demonstrate negative correlations with water and soil contamination, the erosion of surface and groundwater, soil fertility decline, habitat fragmentation resulting in biodiversity loss, and a reduction in vegetation and species. These impacts seem irreversible; (2) Air quality, primarily driven by pollutant emissions, responds to urbanization rates, GDP growth, and energy efficiency. Improvements in air quality rely on higher urbanization rates, increased GDP, and enhanced energy efficiency; (3) Urbanization tends to exert a negative influence on overall eco-environmental quality, with specific driven factors in different urbanization contexts; (4) China's new urbanization, indicating a positive impact on eco-environmental quality, warrants further investigation.

Keywords: *Urbanization · Ecological environment · Framework · Review · Urban sustainable development.*

INTRODUCTION

Urbanization refers to the process of population concentration, industrial structural transformation, changes in urban spatial patterns, and shifts in social structures. By 2050, urbanization, fueled by both migration and local city growth, is expected to add 2.5 billion individuals globally, with 90% of this surge in Asia and Africa. Rapid urban expansion exceeds population growth rates, with urban land outpacing population growth and urban carbon emissions escalating faster than territorial expansion [1-2].

The ecological environment (eco-environment) encompasses the entirety of living and non-living elements within an ecosystem: plants, animals, microorganisms, soil, water, air, climate, and physical components. Its distinction from the broader term 'environment' lies in its emphasis on the interactions between living organisms and their surroundings, including factors like air and water quality, soil resources, and biological elements, crucial for human survival and development [3-4].

Throughout the urbanization process, the eco-environment faces threats from resource depletion, biodiversity decline, and environmental pollution. Examples like the rapid expansion of the 18th to 20th centuries, as urban populations burgeoned from 23.4% to 74.6%, which led to a dwindling per capita resource base, evidenced by soil fertility loss, reduced yields, and inadequate environmental sanitation. Additionally, it triggered deforestation, contributing to a reduction in biodiversity [5-6]. The Industrial Revolution also proved that urbanization significantly contributes to environmental challenges. Coal combustion emitted ash and carbon particles into the air, while industrial processes like metal melting resulted in dross, slag, and emitted waste gases containing sulfur. These pollutants transformed the once-pure air into a concoction of smoke, dust, and unpleasant odors, posing threats to human health. Additionally, heavy engineering activities discharged chemicals into water bodies [7]. Oil dominance production and the utilization of lower-level technologies to control pollutants have further damaged air and water resources.

Despite technological advancements and an increased emphasis on environmental protection in policies, the eco-environment continues to face substantial implications due to high population density and intense production activities in urban areas [8]. Consequently, challenges concerning the eco-environment persist, including diminishment of resources, decline in biodiversity driven by alterations in land use and the activities of urban residents, as well as environmental contamination from industrialized production and socioeconomic activities within the urbanization process. These challenges not only endure but also exhibit a rising trend, particularly in Asia and Africa.

Scholars are deeply concerned about eco-environmental issues linked to urbanization, given the pivotal role of a healthy eco-environment and the pursuit of sustainable development. These concerns manifest across several dimensions. Regarding resources, urbanization disrupts the natural water cycle by expanding impermeable areas like roofs and pavements, leading to fluctuations and deterioration in groundwater. Construction near rivers and the installation of engineering structures within them alter river dynamics, affecting sediment flow and hydraulic characteristics [9-10]. The expansion of urban areas consumes fertile soil, diminishing its quality, and leads to fragmented ecological landscapes [11]. Pollution stems primarily from automobiles, industrial enterprises, and utility companies in urban settings, affecting air, water, and soil quality [12-13]. Urban construction layouts mirror patterns of ecological degradation impacting biodiversity [14].

Current research focuses on two main aspects: direct eco-environmental problems like pollution and biodiversity loss resulting from urbanization, and comprehensive assessments of eco-environmental quality throughout the urban development process. Studies utilize diverse methodologies—ranging from qualitative and quantitative analyses to mixed methods—incorporating Remote Sensing (RS), Geographical Information Systems (GIS), and modeling to gauge changes or construct assessment indices.

Hence, this research reviews past literature concerning the impact of urbanization on the eco-environment, to illustrate the changing role of urbanization factors in the eco-environmental aspects such as pollution, biodiversity, and overall quality. Its goal is to construct a comprehensive framework summarizing the effects of urbanization on the eco-environment, which helps to understand these complex interactions by organizing them into a structured model and identify the primary drivers of environmental change, ultimately, to support sustainable development. The study aims to:

• Review previous literature on the impacts of urbanization for the eco-environment through an exhaustive search approach.

• Identify effect factors and build a structured framework.

METHODOLOGY

Systematic Review (SR) is a method used to investigate a well-defined question by employing systematic and explicit techniques to locate, choose, evaluate, and analyze pertinent research. The process involves gathering and scrutinizing data from selected studies included in the review, with the possibility of employing statistical methods for result analysis and summary [15]. Through this method, researchers can synthesize a vast array of information, providing a comprehensive understanding of the subject matter. By employing rigorous criteria and transparent process, identify gaps in current knowledge.

This review use SR to retrieve articles related to urbanization impact the eco-environment, 53 publications from the Web of Science and Scopus databases were finalized by the authors. These 53 articles Table 3 shows the details of each paper. Searching and organization process are given as below.

Data Source

This systematic review sourced its data from two comprehensive databases: Web of Science and Scopus. Web of Science, developed by Clarivate Analytics, covers a broad spectrum of scholarly literature spanning 256 disciplines, including social sciences, environmental studies, urban issues, and sustainable development. With over 33,000 journals in its repository, it offers researchers advanced search features, citation analysis tools, and the capability to monitor citation metrics. Scopus, developed by Elsevier, is another widely used multidisciplinary bibliographic database that incorporates over 22,800 journals across various subject areas. Both platforms provide an Advanced Search Tool, streamlining the process of finding relevant information efficiently.

The data related to the study's themes was systematically collected and retrieved from these databases through the e-library system. Following this, the retrieved information was reviewed using EndNote software to identify and remove any duplicate entries, ensuring the accuracy of the dataset. Literature searching and selection process are based on PRISMA 2020 software [16], which can generate flow diagrams facilitate rapid comprehension of basic review methodology with transparency.

Searching Strategy

In this systematic review, the impact of urbanization on the eco-environment is explored. To locate pertinent literature, specific retrieval queries were formulated. The relevant literature was gathered by employing the keywords listed in Table 1.

Table 1. Searching queries

Databases	Keywords
Web of Science	TS = (('urban development' OR 'urbanization' OR 'urban growth' OR 'urban expansion' OR 'urban sprawl') AND (('ecolog*' AND 'environment*') AND ('quality' OR 'effect' OR 'result' OR 'impact' OR 'consequence')))
Scopus	(TITLE-ABS-KEY("urbanization" OR "urban development" OR "urban growth" OR "urban expansion" OR "urban sprawl") AND TITLE-ABS-KEY("ecology" OR "environment") AND TITLE-ABS-KEY("impact" OR "effect" OR "consequence" OR "result" OR "outcome"))

Eligibility Criteria

Considering the large number of articles resulting from searching, specific inclusion and exclusion criteria were established. Empirical data-driven articles were exclusively chosen, which excluded review articles, book series, books, book chapters, and conference proceedings. Additionally, to ensure clarity and avoid translation challenges, only English-published articles were included. Moreover, for the purpose of focusing on the most recent and pertinent studies, a 20-year timeline (2004 to 2023) was set, then a total of 967 articles were identified (Table 2).

Following this initial selection, after review the titles and abstracts, if they are (1) not precisely focused on the eco-environment (e.g., eco-efficiency, ecological security, ecological corridors) accounted for 224 exclusions. (2) not fulfil the research objective, like urban ecological management, article number is 121. (3) not concentrate specifically on urbanization's relationship with the eco-environment, discussing topics like ecological landscape change or environmental changes unrelated to urbanization, amounted to 49 exclusions. After this process, 390 articles remained for further evaluation.

After detailed review of the entire text, articles lacking full access (65) were deleted from the list, and those discussing only singular aspects of urbanization related to the eco-environment, such as isolated discussions on land use change or economic impacts, resulted in 151 exclusions. Also, studies focusing on the coupling coordination between urbanization and the eco-environment were excluded, as this review specifically concentrates on the effects of urbanization on the eco-environment, leading to the exclusion of 128 articles. Finally, through examination of existing studies' references and citations, 7 articles were added, culminating in a final count of 53 articles (Fig.1.).

Table 2. Searching criteria

Criterion	**Eligibility**	**Exclusion**
Databases	Web of Science (WoS), Scopus	Other databases
Literature type	Journals, research articles	Review articles, book series, books, book chapters, conference proceedings
Language	English	Non-English
Timeline	Between 2004 to 2023	<2004

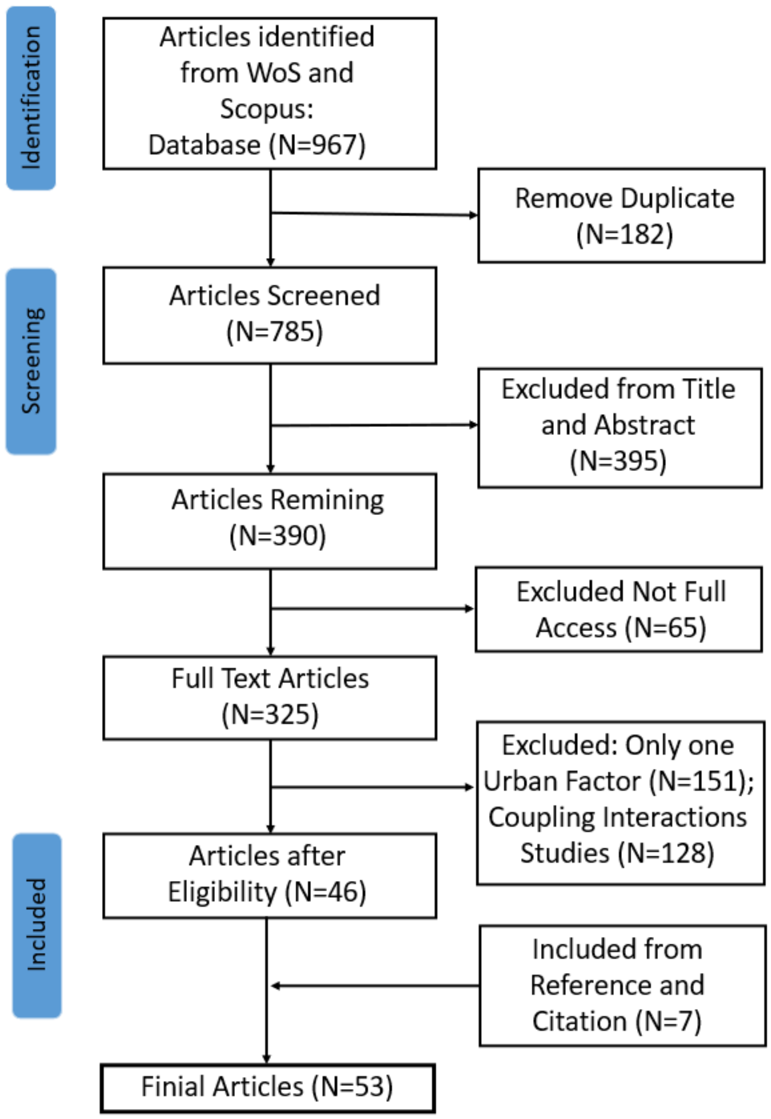

Figure 1. Literature selection process

RESULTS

The final set of 53 articles was imported into Endnote 20.6 software for comprehensive organization and review in January 2024. Through this process, themes and sub-themes were identified, which categorized these articles into three main themes and eight sub-themes, including pollutions (air, water, soil, solid), biodiversity (habitat, vegetation), the whole eco-environment (effects, quality). The details of extracted articles are shown as Appendix. we analyzed our resulting set of studies within the geographic area of interest of each article. Then classified methods that these articles used, tracking their finding and constructed the effect framework.

Study Areas

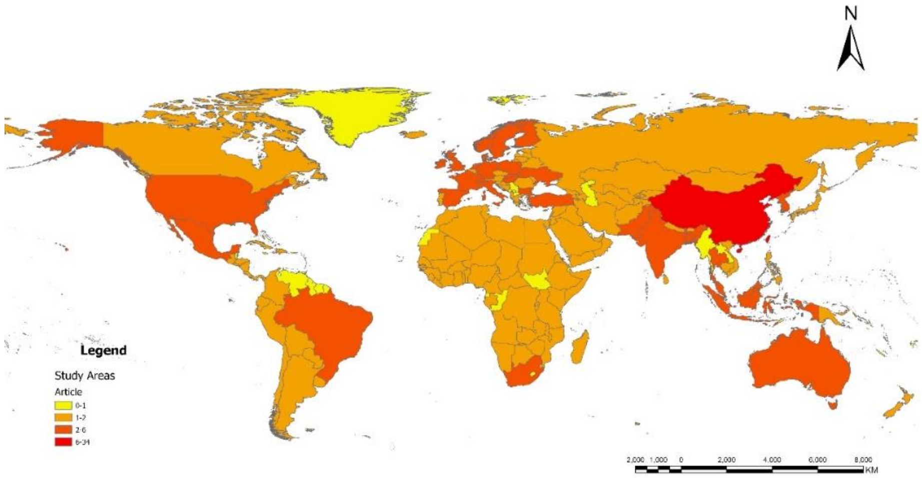

Figure 2. Spatial distribution of literature study areas

Figure 2. depicts the distribution of study area locations in the reviewed articles. Notably, the number of study areas does not match the total reviewed articles, due to some literature examining multiple regions [17-22]. The review indicates a global coverage of study areas, mirroring the widespread nature of urbanization worldwide. Studies in China emerge prominently in the reviewed articles, with 34 articles spanning from 2014 to 2023. These studies vary from single cities to regional and nationwide assessments, showing a significant attention to China's urbanization and eco-environmental issues in the research field.

Other studies covered Asia, Europe, Africa and Americas: In Asia, four articles belong to India, Indonesia, and Bangladesh. Three from Korea, Pakistan, Philippines, and Thailand. Two articles each on Japan, Kazakhstan, Malaysia, Nepal, Singapore, Sri Lanka, Vietnam, and Yemen. One of each study belongs to Afghanistan, Arab, Armenia, Azerbaijan, Bhutan, Cambodia, Jordan, Kyrgyzstan, Lebanon, Mongolia, Tajikistan, Turkmenistan, and Uzbekistan.

Europe's studies comprised four articles each for Finland, Germany, and Hungary. three articles concerning Bulgaria, Denmark, France, Ireland, Netherlands, Norway, Poland, Slovakia, Spain, Sweden, Turkey, Ukraine, and the UK. Two articles for Austria, Belgium, Croatia, Cyprus, Czechia, Estonia, Greece, Italy, Latvia, Lithuania, Portugal, Romania, Russia, Slovenia, and Switzerland. One article for Albania, Belarus, Bosnia and Herzegovina, Kosovo, Luxembourg, Malta, Moldova, Montenegro, North Macedonia, and Serbia.

In Africa, three articles belong to South Africa and Nigeria, two from Egypt, Kenya, and Morocco. One of each study belongs to Angola, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Comoros, Congo, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Ivory Coast, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Rwanda, Senegal, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.

The Americas had six articles on the USA, four each on Brazil, Canada, and Mexico, two from Argentina, Colombia, Panama, Peru, and Venezuela. And one of each study on Bolivia, Chile, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Paraguay, Puerto Rico, and Uruguay.

Relevant Research Methods

In the data collection methods employed, 93% of studies opt for secondary data drawn from sources like books, reports, articles, and datasets, sourcing information on population, economics, pollutant emissions, land use changes, and vegetation coverage. About 6% of studies rely on primary data gathered through surveys and observations to ascertain pollution statistics, while only 1% resort to experimental collection methods for similar pollutant data. Satellite data is frequently utilized to track urban expansion, including spatial composition, land use, and vegetation coverage. Datasets are typically employed to gather information on population, economics, energy consumption, infrastructure, and species data. Commonly utilized datasets include those from institutions such as the World Bank, government monitoring stations, and academic organizations like the Geospatial Data Cloud from the Chinese Academy of Sciences, as well as the Corine Land Cover and Land Cover Change Database for Europe.

As for data analysis, studies commonly employ correlation analysis to illustrate the relationships between changes in urban variables and corresponding shifts in eco-environmental factors. For instance, researchers frequently utilize linear regression models or spatial regression models to quantify these changes and assess their quantitative effects. Alternatively, some studies choose specialized environmental models, including the STIRPAT model, InVEST model, RSEI model, and their modified versions. Several researchers have innovatively combined these models with other methodologies. Examples such as Dong et al [23] merged the STIRPAT model with the GTWR model, Tang et al [24] integrated the InVEST model with the FLUS model, and J Wang et al [25] used the RSEI model with the linear regression method. Fewer studies focus on the dynamic simulation of urbanization effects on eco-environment, Li et al [26] simulated SO_2 concentration with urban developing through CFD model. Akiner [27] build an ANN model to simulate water pollution under urbanization (Fig. 3.).

Certain studies rely on indices as a methodological tool. Researchers select and assess indicators to form indices reflecting both urbanization and eco-environmental aspects. Weighting methods like entropy or PCA assign significance to these indicators. Mathematical equations interconnect and compute these indicators, transforming them into representative values. Established indices such as RSEI or ecological indices (EI) are used in conjunction with other methodologies, including the widely used pressure-state-response (PSR) method, to directly evaluate the effects.

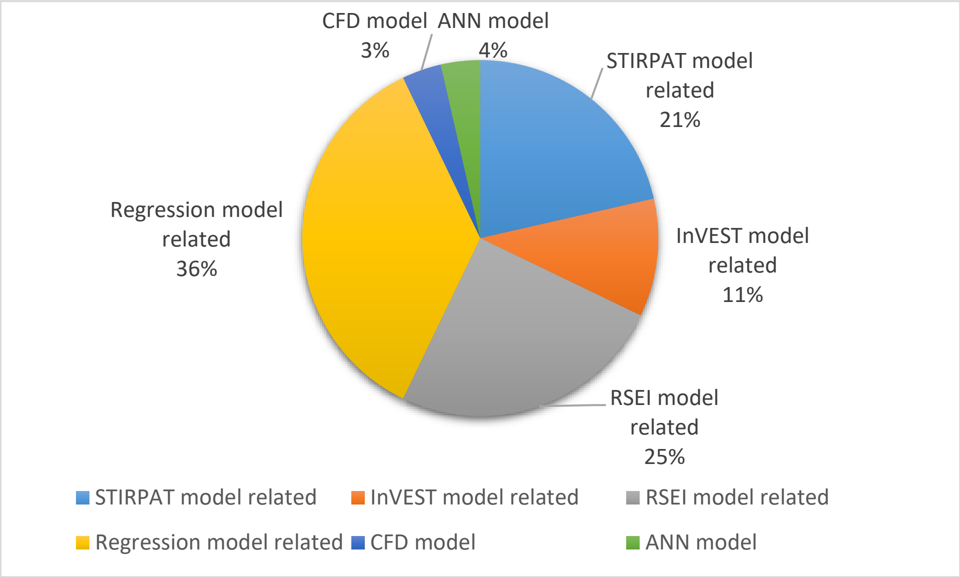

Figure 3. Utilization of Data Analysis Methods

Framework of Affecting Factors

From the literature review, a conceptual framework illustrating the impact of urbanization factors on the eco-environment was developed (Fig. 4.). This framework delineates three primary aspects of these effects: pollution, biodiversity, and overall environmental quality. Pollution encompasses various forms such as air, water, soil, and solid pollution. Air pollution, for instance, arises from emissions of CO_2 and SO_2, primarily sourced from vehicular traffic and industrial activities within urban areas. Additionally, population growth, rising incomes, and increased energy intensity also contribute to air pollution, as do construction activities related to urban development. Water pollution is predominantly caused by industrial discharges and domestic sewage, leading to the contamination of water systems with pollutants like mercury and excess phosphorus and nitrogen. Soil pollution, including contaminants like lead, often originates from construction activities. Solid pollution, attributed to factors like population growth and economic development, is characterized by the accumulation of waste products such as plastic and other non-biodegradable materials.

The impact of urbanization on vegetation and species biodiversity is profound. Human activities associated with urbanization, such as rapid population growth and the scale of development, exert significant pressure on species diversity. Moreover, the fragmentation of urban land resulting from extensive construction activities exacerbates this effect. The decline in vegetation is primarily attributed to the expansion of impervious surfaces, which is driven by population growth and GDP expansion. Furthermore, urban size and density, as well as social structure, also play crucial roles in shaping variations in vegetation across urban areas.

The overall environmental quality is significantly influenced by various factors, including transportation, population density, and socioeconomic activities, which are fundamentally linked to population growth. Industries and infrastructure play substantial roles in shaping environmental quality through their emissions and resource utilization. Additionally, land use change, expansion, and real estate development contribute to alterations in environmental conditions. These factors collectively interact to shape the overall quality of the environment, highlighting the complex interplay between human activities and ecological systems.

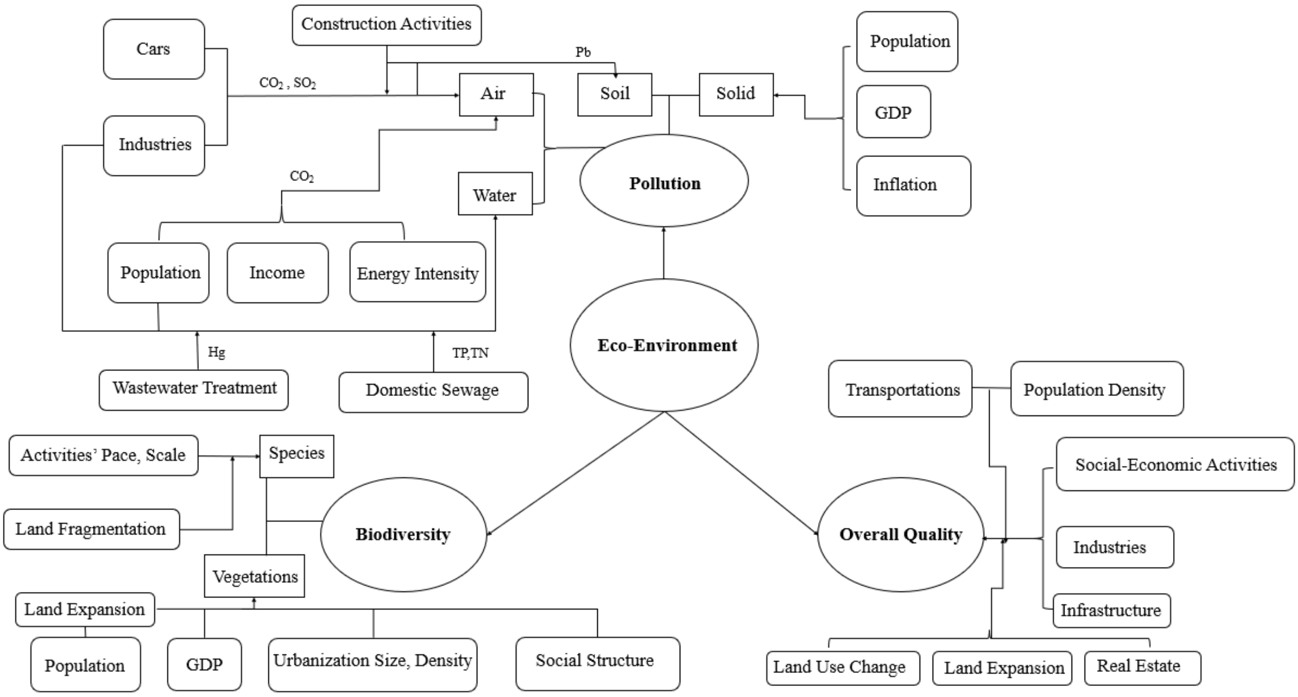

Figure 4. Framework of urbanization effects on eco-environment

Pollution Impact

Urbanization processes contribute to pollution in various forms, including air, water, soil, and solid waste pollution. In air pollution articles, CO_2 and SO_2 are identified as the main pollutants in urban air quality compared to other emissions. The direct sources of them are from industrial, transportation, and construction activities. Factors like economic GDP and population growth, energy intensity also contribute to these emissions. Besides, Ahmed et al [28] used the Modified STIRPAT Model in Indonesia and revealed a non-linear relationship between urbanization and CO_2 emissions—a finding of an inverted U-shape. This relationship, which initially sees an increase in CO_2 due to urbanization but later mitigates emissions after reaching a certain threshold, is supported by Chikaraishi et al [18]. Their study on 140 countries indicated that highly urbanized nations tend to bolster GDP in a more environmentally friendly manner, emphasizing higher energy efficiency.

Urbanization stands out as the primary source of water pollution in the reviewed studies. Construction activities associated with urban expansion contribute to decreased water flow and quality. Pollutants like phosphorus (P) and nitrogen (N) charge from industrial and domestic sewage, while high Hg concentration is founded in a Mexican lake because of urban wastewater production, treatment, and final disposal, which high concentrations of mercury (Hg) in a Mexican lake result from untreated urban wastewater disposal, particularly in densely populated and production-centric areas [9, 29-30]. Moreover, urbanization's impact on groundwater is significant—the transformation of natural ground surfaces into impervious ones disrupts water infiltration and surface runoff, leading to fluctuations and deterioration of groundwater quality due to increased water extraction resulting from population growth [10].

Studies also uncovered the influence of urbanization on both soil quality and the generation of solid waste. Parvez [13] identified heavy metal pollution in the soil of Rampal city, Bangladesh. Using inductive spectrometry and pollution indexes, the investigation pointed out that Pb contamination in anthropogenic regions, primarily source from metal-based industries, landfills, and waste dumps. Another aspect of impact on soil is consumption, the expansion of urban areas due to population growth and economic development consumes fertile soil for construction, reducing the available soil per inhabitant and leading to soil degradation

[11]. Additionally, solid pollution's major influencing factors, as highlighted by Chu et al [31] using multifactor regression analysis, include urban population, the rate of harmless treatment, and the quantity of waste collection vehicles.

Biodiversity Impact

Biodiversity is a valuable natural resource including an array of plants, animals, microorganisms, and their genetic diversity, reflecting the richness of ecosystems [32]. However, the ongoing urban development poses threats to biodiversity through habitat quality declining, diminishing vegetation, and species' diversity. The deterioration and loss of natural habitats are the primary indicators of declining habitat quality. L. M. Bai, Xiu, Feng, and Liu [33] utilized the InVEST model to quantitatively analyze habitat loss. The findings revealed a clear degradation trend in Changchun city attributed to unregulated urban construction land expansion and the impact of tourism development. Through combination the InVEST model with the FLUS model, habitat degradation value is found highly associated with urban densely populated areas and transportation land where human activity is intensest, which has led to a strong degradation of habitats [24].

Urbanization directly leads to vegetation loss by converting forest and grasslands into artificial construction land. This link is often established by correlating urban land use changes with vegetation coverage. In the Greater Bay Area of China, a 30-year analysis revealed an increase of 6638.7 square kilometers in impervious surfaces, resulting in the decline of 569 square kilometers of forest and grasslands. This spatial shift caused fragmentation and separation of vegetation, evident even in urban surrounding areas. Moreover, this rise in impervious surfaces lifted land surface temperatures, particularly in summer, further reducing vegetation coverage [34-36]. Besides, Clement et al [37] highlighted the differential contributions of population size, density, and growth pattern to deforestation by spatially correlating population data with forest coverage across the USA. Similar findings emerged in Greater Dhaka, Bangladesh, where increasing population significantly reduced vegetation coverage and coherence through indices analysis [38]. Research in Debrecen, Hungary, noted fewer plant species in the city center compared to vacant lots and peri-urban grasslands, which underscores how urbanization not only diminishes vegetation coverage and coherence but also impacts vegetation species diversity [39].

In contrast, Li et al [40] claimed that urbanization might not uniformly degrade vegetation across China. Their study, analyzing NDVI trends and correlation coefficients of urban intensity, indicated instances where urbanization positively correlated with improved urban vegetation. They suggested that urbanization could indirectly foster vegetation growth by creating more favorable growing conditions. Another study in China, led by Chen et al [41], highlighted GDP as a significant factor influencing vegetation. Their findings revealed a threshold effect: when urbanization is under 77.59%, vegetation coverage increases with GDP growth. At the 77.59% urbanization mark, vegetation remains stable. However, when urbanization exceeds 77.59%, vegetation coverage starts declining with rising GDP.

Urbanization in both the USA, Switzerland and China has resulted in a significant reduction in species richness. which is linked to the decrease in habitat area, as smaller habitats tend to support fewer species. Moreover, the removal of mature trees during urban development, serving as vital feeding sites for various species, has contributed to this reduction. Additionally, habitat fragmentation caused by urban construction has severed habitat connectivity, further impacting species richness negatively [14, 37, 42]. A study of Schmidt [43] discovered another aspect of urbanization's impact—a decline in genetic diversity. Through regression models, they assessed the genetic composition of mammals and birds concerning urbanization factors. Result in that higher human population density emerged as the primary cause behind this reduction in genetic diversity.

Overall quality Impact

Urbanization factors, including population, economic growth, energy intensity are strongly associated with the eco-environmental quality, Pham [20] explored this relationship across European countries using the STIRPAT model and EKC framework. Their findings suggested a complex dynamic: while these factors initially contributed to short-term environmental improvements, long-term implications surfaced, especially with energy intensity exerting the most significant negative impact on the eco-environment. The increasing intensity of urbanization has amplified the reliance on ecological resources, evident in the escalating stresses on the eco-environment, as highlighted in Chinese studies by Liu et al; Wang et al; Yao et al [44-46]. This dependence on the environment for urban development has intensified resource consumption and pollutant emissions over the years. In a Chilean study by Romero and Ordenes [47], 40% of the land converted into urban impervious surfaces caused the loss of 17667 hectares of highly productive vegetation, areas with abundant soil moisture, and rich biomass. Similarly, a doubling of industrial spaces encroaching upon ecological lands. Expansion in service facilities and transport corridors also contributed to ecological degradation [48]. Additionally, excessive dependence on industry or services leads to increased pollutant emissions, negatively impacting the eco-environmental quality, whereas urban greening initiatives could potentially enhance it [21, 49].

The assessment of eco-environmental quality in the Samara Region, Russia, identifies urban socioeconomic activities as primary indicators [50]. However, regression analysis in China and India presents contrasting findings, attributing factors such as population urbanization or high population density as key drivers [51-52]. Additionally, studies by Han et al [53] and Wang et al [25] emphasize the predominance of population growth in China. The contribution of a single factor is significantly outweighed by the interaction effects of multiple factors, with population growth emerging as the primary driver in vegetation loss and PM2.5 concentration. As vegetation plays a crucial role in shaping eco-environmental quality, population stands out as the key indicator of eco-environmental quality.

On the other hand, the overall ecological state of China's coastal zones exhibits improvement, even though there exists spatial heterogeneity, with southern regions showing better conditions due to richer forest resources [54]. The introduction of the new urbanization concept in China in 2012, emphasizing urbanization quality and sustainable development, has been assessed by Yu [55] using indices and the DSPM model. The findings indicate an encouraging trend in eco-environmental quality, marked by reduced pollution and enhanced energy efficiency. Also S. Yang and Su [56] have uncovered a fluctuating relationship between eco-environmental quality and urbanization in Xi’an city, China. Initially declining from 2000 to 2010, it rebounded after 2015 to 2020. Factors such as transportation, land use change, GDP, and population have been identified as pivotal influences. This demonstrates a positive association between China's new urbanization strategies and the restoration of eco-environmental quality.

DISCUSSION

After reviewing the 53 studies, it's evident that the urbanization process significantly impacts the eco-environment, a crucial consideration for sustainable urban development to mitigate adverse effects. Across the globe, rapid urbanization has been linked to population growth, altering land use, and socio-economic activities, all of which contribute negatively to the eco-environment. Diverse studies have illustrated urbanization's impact through emissions of pollutants, loss of biodiversity, and degradation of eco-environmental quality. While specific urban factors driving these effects vary by location, these studies consistently highlight several key points: (1) Socio-economic activities intensify transportation, energy consumption, industrial production, and urban construction, resulting in emissions of CO_2, SO_2, PM2.5, and other pollutants that contaminate air, water, and soil; (2) Urban expansion due to population growth leads to the conversion of natural habitats into impermeable surfaces, causing loss of vegetation, species, and habitat fragmentation; (3) Enhanced GDP and energy-efficient strategies, including the development of urban green infrastructure, offer potential avenues to restore and improve eco-environmental quality.

In discussions surrounding pollution, a positive viewpoint emerges suggesting that air pollutants emission will naturally decrease because it has a ‘U’ shaped relationship with urbanization level, which means highly urbanized countries normally consider more sustainable way to develop. However, this positive outlook contrasts sharply when considering water and soil quality. The overconsumption of resources, coupled with inadequate waste management practices, contributes to elevated pollutant concentrations. This, in turn, leads to the deterioration of both surface and ground water quality, a loss of fertile soil due to urban expansion, and solid pollution concerns. These damages, unlike the potential decline in air pollutants, seem to be irreversible and pose significant challenges to eco-environmental sustainability.

The effects on biodiversity include habitat degradation, vegetation loss, and a decline in species diversity. Various studies employing indicators, regression models, and tools like the InVEST model have revealed distinct impacts of urbanization on habitats, largely propelled by human activities. Construction expansion has led to habitat fragmentation and subsequent vegetation loss. There's a negative correlation between urbanization levels and species diversity, indicating that more urbanized areas exhibit lower species richness. Moreover, the rate of urbanization influences the relationship between GDP growth and vegetation coverage: in areas with lower urbanization rates, vegetation thrives alongside GDP growth, while in highly urbanized regions, vegetation shows a decline with GDP growth.

The perspectives on eco-environmental quality diverge across studies. Various quantitative methods like indexes, regression analyses, and models such as STIRPAT and PSR frameworks have been utilized to pinpoint the primary drivers of urbanization affecting this quality. Findings showcase diverse factors dominating different regions: while land expansion to impervious surfaces takes precedence in Chile, social-economic activities take the lead in Russia. Meanwhile, China and India point to population increase as the primary driving force. These variations could be attributed to distinct urbanization scenarios in different countries. Also, studies in European countries suggest that urbanization may have detrimental long-term effects on eco-environmental quality due to over-reliance on resources. Conversely, China's new type urbanization approach exhibits a positive impact, significantly enhancing eco-environmental quality. This suggests that the effects on eco-environmental quality are contingent upon various factors inherent to specific urbanization contexts.

CONCLUSIONS AND FUTURE DIRECTIONS

This systematic review provides an overview perspective on the impact of urbanization on the eco-environment. The studies collectively reveal substantial connections between urbanization factors (population, social-economy activities, industry, energy consumption, spatial land use change) and eco-environment (air, water, soil quality, biodiversity and overall eco-environment quality). These urbanization factors, whether singular or in combination, exhibit negative correlations with water and soil pollution, the degradation of surface and groundwater, soil fertility decline, biodiversity loss with habitat fragmentation, vegetation and species decline. These detrimental impacts appear to be largely irreversible, necessitating restorative efforts. Air quality, primarily influenced by pollutant emissions, is triggered by urbanization rates, GDP growth, and energy efficiency. The prospect of improvement in air quality depends on higher urbanization rates, increased GDP, and enhanced energy efficiency. On the broader scope of overall eco-environmental quality, the prevailing consensus is that urbanization tends to have a negative influence. However, this influence is subject to the specific contexts of individual urbanization scenarios with different main driven factor. Besides, China's perspective diverges, suggesting a positive attitude after the implementation of its new urbanization type, which indicates the potential for improved eco-environmental quality.

According to the reviewed studies, this review identified several gaps for future directions: (1) Present studies predominantly focus on longitudinal comparisons of eco-environmental impacts across various countries, cities, or regions over time. To capture a more comprehensive understanding, future research should consider a horizontal comparison, examining the disparities in eco-environmental effects between countries driven by different urbanization factors; (2) Although current research primarily shows the negative impact of the urbanization process on eco-environmental quality, there exists a crucial oversight regarding the eco-environment's restorative capacity. Most studies focus on quantifying the overall effects without accounting for the eco-environment's ability to recover from these impacts. Therefore, there is a need to ascertain the net effects of the urbanization process on eco-environmental health; (3) The contrasting conclusion regarding China's new urbanization, indicating a positive impact on eco-environmental quality, warrants further investigation. Existing studies primarily focus on overall quality improvement and decreased pollutant emissions, necessitating additional research to comprehensively explore biodiversity-related influences and corroborate the observed positive effects. These gaps highlight the need for future studies to explore these aspects in greater depth, aiming to enhance our understanding of urbanization's impact on the eco-environment and thereby fostering sustainable urban development.

Acknowledgments. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
We express gratitude to the technic support from Universiti Malaya, which granted us free access to E-library resources.

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APPENDIX

No.	Author (Year)	Theme	Study area	Methods	Findings
1	(Melniichuk et al., 2022)	Pollution (Air)	Volyn region (Ukraine)	Air Pollution Index with Regression, Comparison.	Cars and industries are the main contributors to air pollution.
2	(Abdulqadir, 2023)	Pollution (Air)	Sub-Saharan African	Quantile Regression and Trade Models with CO_2 Emissions.	Urbanization tends to conditionally foster eco-environmental pollution through increased CO_2 emissions.
3	(Li et al., 2020)	Pollution (Air)	Shenyang (China)	Computational Fluid Dynamics (CFD Model)	SO_2 in the city is higher on the windward side and peaks at 30 meters above ground level.
4	(Sadorsky, 2014)	Pollution (Air)	16 countries in the world	STIRPAT model[1]	Income, population growth, higher energy intensity, increased CO_2 emissions over time.
5	(Chen et al., 2020)	Pollution (Air)	China	Moran's-I index, the Spatial (Durbin Model).	Population drives carbon emissions, while economic growth and energy intensity increase it.
6	(Ahmed et al., 2019)	Pollution (Air)	Indonesia	Modified STIRPAT Model	Urbanization and CO_2 emissions exhibit an inverted U-shape.
7	(Chikaraishi et al., 2015)	Pollution (Air)	140 countries in the world	The latent class STIRPAT model	Energy efficiency can reduce environmental impact.
8	(Dong et al., 2019)	Pollution (Air)	China	STIRPAT model combines Geographically and Temporally Weighted Regression (GTWR)	Industrial, transportation, and construction activities majorly contribute to air pollution.
9	(Jiao et al., 2021)	Pollution (Water)	Qingdao West-Coast Economic New Area (China)	A Water Benefit Based Ecological Index (WBEI)	Coastal environmental conditions decreased because of urbanization.
10	(Yar, 2020)	Pollution (Water)	Mardan City (Pakistan)	Interpolation (IDW), SMLC[2]	Urban expansion and population growth fluctuated and

					deteriorated groundwater.
11	(Wang et al., 2023)	Pollution (Water)	Chaohu Lake (China)	Pearson Correlation Analysis	Industrial and domestic sewage worsen water pollution, TP and TN[3] are pollution indicators.
12	(Hnativ et al., 2023)	Pollution (Water)	Carpathian region (Ukraine)	Survey, Observation, Experiment on Water Samples	Constructions reduced water flow and quality.
13	(Cohuo et al., 2023)	Pollution (Water)	Lake La Sabana (Mexican)	Multivariate Analysis, Water Quality Index-NSF	Urban wastewater treatment results in high Hg metal concentrations.
14	(Akiner & Akiner, 2021)	Pollution (Water)	Lake Sapanca (Turkey)	Artificial Neural Network, Multiple Linear Regression (MLR)	Rapid urbanization is Lake Sapanca's primary pollution source.
15	(Ricca & Guagliardi, 2023)	Pollution (Soil)	Southern Italy	Metrics Landscape Analysis; Patch Analyst	Soil consumption from urban leads to ecological degradation.
16	(Parvez et al., 2023)	Pollution (Soil)	Rampal (Bangladesh)	Experiment of Soil Samples, Multiple Indexes	Vehicle emissions and industries contaminated soil Pb.
17	(Chu et al., 2016)	Pollution (Solid)	China	MLR	Solid waste generation is mainly influenced by population, GDP, inflation.
18	(Sun et al., 2019)	Biodiversity	Beijing (China)	InVEST Model[4]	Ecological degradation followed urban construction and ring road patterns.
19	(Schmidt, 2020)	Biodiversity	North America	Linear Mixed Models	Land fragmentation low connectivity reduces mammal and genetic diversity.
20	(Sol et al., 2020)	Biodiversity	Africa, Australia, Europe, North America and South America	Quadratic Entropy and Linear Mixed Models	Highly urbanized environments reducing species richness and evenness.
21	(Concepción et al., 2015)	Biodiversity	Swiss Plateau (Switzerland)	Generalized Linear Models (GLMs)	Urbanization affects highly mobile specialist species.
22	(Buczkowski & Richmond, 2012)	Biodiversity	West Lafayette (USA)	A General Linear Model-ANCOVA	Urbanization sharply drops species richness.

23	(Tang et al., 2023)	Biodiversity (Habitat)	The Yellow River Basin (China)	InVEST Model with FLUS Model	Land expansion declines habitat quality.
24	(Bai et al., 2019)	Biodiversity (Habitat)	Changchun (China)	InVEST Model	Urbanization pace and scale affect habitats through human activities.
25	(Gui et al., 2019)	Biodiversity (Vegetation)	Wuhan (China)	Urban Expansion Model, Landscape Metrics	Urbanization decreased vegetation cover, increased surface temperature.
26	(Zhang et al., 2022)	Biodiversity (Vegetation)	The Greater Bay Area (China)	Correlation Analysis	Urbanization fragments wood and grass lands.
27	(Chen et al., 2022)	Biodiversity (Vegetation)	China	NDVI, Econometric Models	NDVI relations to GDP and urbanization rate[5].
28	(Li et al., 2020)	Biodiversity (Vegetation)	China	NDVI, Theil–Sen Mean Trend Estimate	Urbanization may not lead to widespread vegetation degradation.
29	(Zhou et al., 2019)	Biodiversity (Vegetation)	Beijing–Tianjin–Hebei Region (China)	A Partial Derivative Model	Urbanization drives fractional vegetation changes in the expanded area.
30	(Yang et al., 2021)	Biodiversity (Vegetation)	China	NDVI, Spearman Correlation Coefficient	Urbanization intensity reduced vegetation cover.
31	(Huang et al., 2021)	Biodiversity (Vegetation)	48 coastal cities (China)	EVI[6], Linear Regression Models	Land changes lead to vegetation loss.
32	(Deák et al., 2016)	Biodiversity (Vegetation)	Debrecen (Hungary)	GLMs and Tukey-Tests	City center has fewer plant species, mostly weeds and disturbance-tolerant species.
33	(Clement et al., 2015)	Biodiversity (Vegetation)	USA	Spatial Regression Models	Urbanization size, density, and social structure directly drive deforestation.
34	(Byomkesh et al., 2012)	Biodiversity (Vegetation)	Greater Dhaka (Bangladesh)	Patch Indices, Spatial Metrics Analysis	Green space loss resulted from rural-to-urban migration, causing heightened landscape fragmentation.
35	(Liu et al., 2021)	Eco-environmental (effects)	Xinjiang (China)	Geodetector Method and PSR[4] Model	Transportation, population, economy and industry mainly raised resource use and

					pollution.
36	(Yao et al., 2022)	Eco-environmental (effects)	Hefei (China)	Entropy Weight Method, Eco-Environmental Index Model	Urban expansion caused ecological land degradation and pollutant emissions.
37	(Wang et al., 2016)	Eco-environmental (effects)	Bohai coastal area (China)	Dynamic Degree Method, Correlation Analysis	Urban activities increasingly relied on resources over time.
38	(Yu, 2021)	Eco-environmental (effects)	China	Dynamic Spatial Panel Model (DSPM)	China's new urbanization cuts pollution and boosts energy efficiency.
39	(Romero & Ordenes, 2004)	Eco-environmental (effects)	Chile	Multi-Temporal Ecological Landscape Analysis	Urbanization lowers vegetation productivity and soil moisture, elevating pollution.
40	(Zhu et al., 2021)	Eco-environmental (effects)	Wuhan (China)	Remote Sensing Ecological Index (RSEI) with Local Adaptability	Land use change damaged the eco-environment, while greening projects can improve it.
41	(Izakovicova et al., 2022)	Eco-environmental (effects)	Slovakia	Coefficient of Ecological Stability	Urbanization seizes and degrades ecological land, consuming top-quality soils for development.
42	(Zheng et al., 2020)	Eco-environmental (effects)	China's coastal zone	RSEI and Comprehensive Nighttime Light Index (CNLI)	China's eco-environment shows enhancements.
43	(Pham et al., 2020)	Eco-environmental (effects)	28 European countries	STIRPAT model	Population and economy increase environmental degradation.
44	(Li et al., 2023)	Eco-environmental (quality)	Luoyang (China)	RSEI, A Univariate Linear Regression Model	Population is the main factor for eco-environment quality.
45	(Yang & Su, 2023)	Eco-environmental (quality)	Xi'an (China)	RSEI, Spatial Autocorrelation Analysis, Geodetector Model	Eco-environment quality initially declines, then rebounds. Transportation, land use change, GDP, population are key factors.
46	(Wang et al., 2023)	Eco-environmental (quality)	Zhanjiang (China)	RSEI, MLR	Vegetation primarily shapes eco-environment

					quality.
47	(Wu et al., 2023)	Eco-environmental (quality)	China	Entropy Method, M-RSEQI[7]	Urbanization and industrial structure cause pollution and ecological harm.
48	(Han et al., 2021)	Eco-environmental (quality)	China	Population-Weighted PM2.5 &Vegetation Formula	Population growth reduces vegetation and elevates PM2.5 air pollution.
49	(Hang et al., 2020)	Eco-environmental (quality)	Nanjing (China)	RSEI, Pearson's Correlation Analysis	Infrastructure and real estate development limited eco-environment improvements.
50	(Li et al., 2021)	Eco-environmental (quality)	China	Panel Regression and Correlation Analysis	Industry affects resources, while pollution arises mostly from population and land use.
51	(Boori et al., 2021)	Eco-environmental (quality)	Samara (Russia)	RSEI, Ecological Index (EI), PSR method	High human socio-economic activity in urban areas, negatively affects ecological health.
52	(Arshed et al., 2021)	Eco-environmental (quality)	80 countries	STIRPAT, EKC[8], Dynamic Ordinary Least Square (DOLS)	Overreliance on industry leads to amplified harmful environmental effects.
53	(Krishnan & Firoz, 2020)	Eco-environmental (quality)	Kerala (India)	PCA, Regression Analysis	Population density and land surface temperature are mainly impact factors.

Note: 1 Stochastic Impacts by Regression on Population, Affluence and Technology Model; 2 Supervised Maximum Likelihood Classifier; 3 Total Phosphorus and Total Nitrogen; 4 Integrated Valuation of Ecosystem Services and Trade-Offs Model; 5 NDVI: rising with GDP increase (urbanization < 77.59%), stable (urbanization = 77.59%), declining with higher GDP (urbanization > 77.59%); 6 Enhanced Vegetation Index; 7 Modified Remote Sensing Eco-Environmental Quality Index; 8 Environmental Kuznets Curve.