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Article

Ecological city concept: Challenge and future research agenda in urban ecology perspective

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Abstract: Cities are no longer viewed as creatures with a linear-climax-established cycle but as ecosystems with dynamic and complicated processes, with people as the primary component. Thus, we must understand urban ecology's structure and function to create urban planning and appreciate the mechanisms, dynamics, and evolution that connect human and ecological processes. The ecological city (ecocity) is one of the city conceptions that has evolved with the perspective of urban ecology history. The concept of ecocity development within urban ecology systems pertains to recognizing cities as complex ecosystems primarily influenced by human activities. In this context, individuals actively engage in dynamic problem-solving approaches to address environmental challenges to ensure a sustainable and satisfactory quality of life for future generations. Therefore, it is necessary to study how ecocity has developed since it was initiated today and how it relates to the urban ecology perspective. This study aims to investigate the progression of scholarly publications on ecocity research from 1980 to 2023. Additionally, it intends to ascertain the trajectory of ecological city research trends, establish connections between scientific concepts, and construct an ecological city science network using keyword co-occurrence analysis from the urban ecology perspective. The present study used a descriptive bibliometric analysis and literature review methodology. The data was obtained by utilizing the Lens.org database, was conducted using the VOS (Visualization of Similarities) viewer software for data analysis. The urban ecology research area ecology of cities can be studied further from density visualization of ecosystem services and life cycle assessment. Finally, the challenges and future agenda of ecocity research include addressing humans by modeling functions or processes that connect humans with ecosystems (ecology of cities), urban design, ecological imperatives, integration research, and improving the contribution to environmental goals, spatial distribution, agriculture, natural resources, policy, economic development, and public health.

Keywords: ecological city; urban ecology; VOS viewer; bibliometric

1. Introduction

Urban development is not only in the physical sense of space as a centre of activity with various functions but also in line with shifts in urban environmental and ecological issues. The urban structure affects the environmental burden (Martine et al., 2012), and relates to spatially unique characters, differences in climate, and local culture. Therefore, comprehensive ecological approach is needed to overcome urban environmental problems (McClure and Bartuska, 2007), and continuous urban growth that cannot be avoided (perpetual growth) (Crowley, 2019). From a development

perspective of urban ecology, the city is no longer an organism with a linear cycle-climax-established but an ecosystem with a dynamic and complex cycle (Golubiewski, 2012). Thus, understanding the structure and function of urban ecological systems is very important. Understanding these processes can increase human resilience against ecological challenges in creating sustainable urban areas. The ecological city, often known as the ecocity, has emerged as a city idea in response to understanding urban ecological history and the intricate nature of urban environmental challenges. The history of the concept and implementation of ecocities showcases the diverse factors that influence their inception, including the timing of initiatives, technological advancements, emerging paradigms, developmental priorities, and the multitude of models employed. Highlights the absence of a universally applicable ecocity development model since each ecocity necessitates a unique approach (Joss et al., 2011; Joss et al., 2013; Rapoport, 2014). Various stages of transformation take place, involving new stakeholders from different sectors of society. The widespread adoption of ecocity implementation across the globe proves that the concept of ecocity has been promoted in multiple countries to attain sustainable urban development.

This article examines the evolution of the ecocity concept and its associated research publications from 1980 to 2023. The objective is to analyze the trajectory of ecological city research trends, ascertain the interconnections between scientific concepts, explore the ecological city science network through keyword co-occurrence analysis, and investigate its relationship with the urban ecology perspective.

2. Guiding literature

2.1. The development of the concept of ecocity

The concept of the ecological city, often known as the ecocity, has emerged in response to the evolving urban ecological landscape, historical context, and the intricate challenges posed by urban environmental issues. The concept of ecocity arose in response to the urban crisis to consider the significance of ecological principles in the redevelopment of urban spaces. This principle includes the evolution of cities in the form of an understanding of the relationship between extinction and evolution, the role of cities, and the evolution of urban civilization. In addition, the critical factors for urban evolution are density, diversity, form, and function of cities, and community awareness in rebuilding, rethinking, and understanding the city as a living organism. Richard Register (1987) defines an ecocity as a settlement modelled on the structure and function of natural ecosystems that are independent and sustainable (Register, 2006). This understanding concentrates on efforts to maintain the consumption and production balance of the ecosystem. The strategy for creating ecocity is a stable shift from motorized culture to human infrastructure. The strategy for Ecocity's success is to follow the existing urban development flow, starting with the foundation of land use and ecocity features. Furthermore, four ecological steps towards the economy, namely mapping the area, determining a list of activities in the form of technology and business as well as jobs to build an ecocity, determining incentives, and moving people to live and build ecocity.

According to Roseland (1997), the notion of ecocity is closely intertwined with the paradigm and movements of appropriate technology (AT), community economic

development (CED), social ecology, the green movement, bioregionalism, and sustainable development. Roseland argues that there is no single definition of ecocity, and aspects of sustainability must be defined from the perspective of the local community. The author additionally contends that an alternative method for delineating a "sustainable community" involves the establishment of requisite circumstances fora sustainable society, achieved through the implementation of efficient land utilization, diminished consumption, augmented livelihood opportunities, and sustainable governance. Along with its development, the application of this concept requires creative descent as an urban strategy related to new cultural stories (Crowley, 2019). Profound ecocity concept, this view must transform not in the sustainable phase (no destruction nature) but more to a regenerative position where participation processes and design as nature are carried out. However, the challenges faced are conflicts between the economic and planetary systems so that new system arrangements are needed that can accommodate green capital connected with local communities, community resilience to resources in the process of adaptation and resilience, clear communication in the process of resource intervention, power as well as trans-local movement. Nowadays, to meet the ecocity concept, one must fulfil the indicators set globally (Nozick, 1992). Ecocity Builders (International Ecocity Framework and Standards) is developing four fundamental components of the ecocities are urban design, bio-geophysical conditions, socio-cultural features, and ecological imperatives. These pillars are further reinforced by a comprehensive set of 18 standards, which assess and evaluate the extent to which ecocity conditions are being realized.

To gain a general understanding of how ecocity practice has developed globally (Joss et al., 2011; Joss et al., 2013; Rapoport, 2014; Tang, 2011), a literature study is conducted. In the study "Ecocities—A global survey 2009," Joss mapped 74 initiatives by looking at and seeking to identify ecocity types. Findings the ecocity concept is evolving more quickly, and its proponents highlight the striking differences between the various projects. The construction of ecocities might be brand-new cities, urban expansions, or "retrofitting" (upgrades) of existing cities. New technology is one area of attention for implementation, while other areas include urban planning and community empowerment. According to Joss (2010), ecocity is a large-scale development integrating several urban system sectors, and the solution is backed by policy and government. In 2011, the Joss mapping underwent an upgrade that included the same kind of study from 180 ecocity programs with access to more data.

Rapoport (2014), who chooses six ecocity efforts from Joss' list and describes and contrasts each of these initiatives' qualities, provides a second practical assessment. The findings indicate that the shared features focus on environmental sustainability goals—while briefly considering social and economic sustainability in the analysis—and the requirement for sustainable urban design and planning. The implementation emphasis and the stakeholders carrying out the program vary in practice. Government agencies, neighborhood activists, and private organizations are all taking action. In certain practices, new technologies are implemented to improve resource output, whereas, in others, resource consumption is the focus. Rarely are the functions of local government and people acknowledged in these initiatives. Society's definition is changing, and this transition should be considered a homogenizing society.

The transition in the concept of society evolved from viewing the city as a representation of change and diversity to perceiving it as a hub of business activities, leading to a more homogeneous society (Joss et al., 2013; Hu et al.,2016; Geddes, 2016).

The ecological city (ecocity), as a modern city idea in numerous nations, has led to the implementation of complex spatial linkages utilizing technology but is still modest in examining social issues. The original idea of ecocity saw the development of cities based on ecological principles to establish healthy human-nature interaction patterns where local populations may choose how to live following their natural surroundings. Human worth in terms of social features of the neighborhood is crucial in assessing the viability of their way of life.

2.2. Examining the concept of ecocity from an urban ecology perspective

On the development of city concept and practice, there is less discussion in detail about how the role of humans, individually and in groups, controls the dynamics and evolution of the development of the structure and function of complex urban ecosystems. In urban ecology, interactions occur between organisms, built structures, and the physical environment, where people are concentrated (McPhearson et al., 2016). In the development of cities, built structures are the key to urban ecology because they involve transforming human interaction as a dominant ecosystem component with complexity, resilience, non-linear system dynamics, adaptive management, and existence (Niemelä, 2011). Urban ecology integrated both primary (i.e., fundamental) and applied (i.e., problem-oriented) natural and social science research to explore and elucidate the multiple dimensions of urban ecosystems (Douglas, 2015). Urban ecology studies the structure and function of biotic and abiotic cities. The urban ecological structure is characterized by its components' number, size, composition, and nature and is composed of abiotic and biotic elements. The function is the adaptation or evolution of species in an urban environment. Urban ecology's development requires a discussion of the social relations theory that incorporates individual perceptions, requirements, values, knowledge of the sustainability planning process, and extensive stakeholder participation. From an ecological perspective, urban ecosystems differ because humans create distinctive ecological patterns through processes, disturbances, and subtle effects. In addition to the structures, functions, and processes that ecologists have traditionally studied in any ecosystem, urban systems also contain dominant components of social, cultural, and behavioural institutions and the built environment.

The concept of urban ecology pertains to the ecological dynamics within urban areas, encompassing the interconnected subsystems that collectively constitute the metabolic processes of the city as an ecosystem. Within this framework, the study of ecology in cities primarily centers on examining habitats within urban environments, with a particular emphasis on understanding the mechanisms by which the conditions in these locations influence and shape the structure and functioning of the ecological system (Pickett et al., 2016).

Another view states that urban ecology consists of four characteristics: the ecology of health in urban areas, Ecology in towns and cities, ecology of cities as a

whole, and Ecology for cities. In addition, Pickett (2016) state this characteristic a shift in the urban ecology paradigm between in, of, and for ecology. This paradigm shift as a continuum of complexity exists with an increase in the types of interactions and with more opportunities for the involvement of human motivations and actions.

The different characteristics of urban ecology are the ecology of health in urban areas and ecology in towns and cities, including their habitat and conditions. Meanwhile, the ecology of cities as a whole and ecology for cities include ecosystems and their functional systems. The establishment and progression of eco-cities within urban ecological systems are intricately linked to the concept of cities as complex ecosystems, wherein human activities play a dominant role. These human actors exhibit dynamic behavior as they actively seek viable solutions to environmental challenges, aiming to ensure a sustainable and satisfactory quality of life for future generations (**Figure 1**).

Furthermore, the characteristics of the urban ecology and the pillars of ecocity show that urban design and bio-geo-physical features describe the city's habitat conditions or structure of the city. Meanwhile, the pillars of socio-cultural and ecological imperatives are descriptions of ecosystems and their functions.

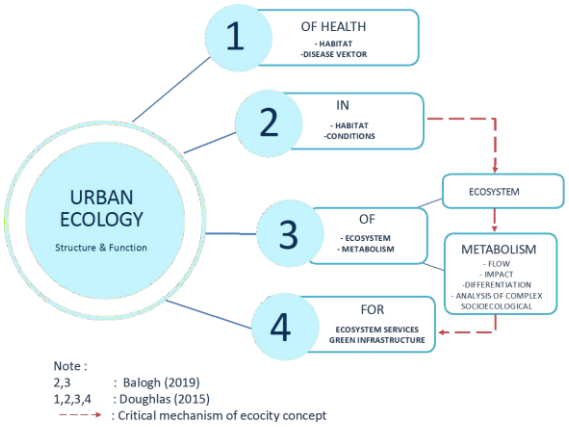

Figure 1. Ecocity in urban ecology concept, modified from (Hall and Balogh, 2019; Douglas, 2015).

3. Methods

The objective of this study is to examine the progression of research publications on eco-cities from 1980 to 2023, ascertain the trajectory of ecological city research patterns, establish the interconnections among scientific concepts, and delineate the ecological city science network through keyword co-occurrence analysis with a specific focus on its relationship to urban ecology. The method used in this study is descriptive bibliometric analysis using published data on ecological cities, and a literature review about the development of urban ecology and ecological cities for comparative analysis of the result of bibliometric analysis. The analytical framework is shown in **Figure 2**.

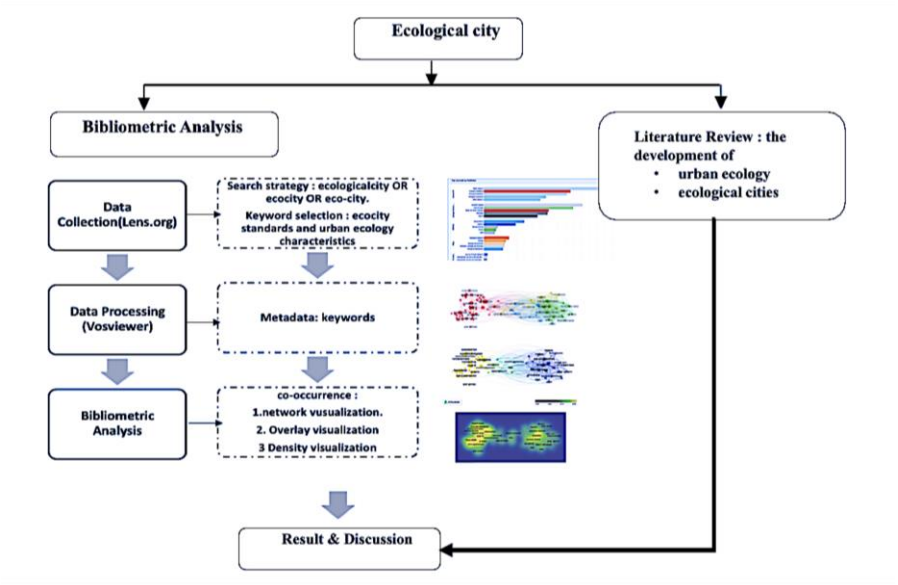

Figure 2. Framework for reviewing ecological city literature.

Bibliometric analysis data was collected through publication searches using Lens.org metadata. The Lens platform aggregates and standardizes a vast collection of more than 200 million academic records. These records are sourced from prominent databases such as Microsoft Academic, PubMed, and Crossref. Additionally, the platform enriches the dataset by incorporating open-access information from OpenAlex and UnPaywall and establishing connections to ORCID profiles. The scholarly citation graph is provided for the first time as an open public resource. So, the author considers lens.org a comprehensive platform for evaluating and analyzing scholarly research publications. The data can be searched using keyword analysis, which uses various publications. The data contains a wide range of publications and can be searched using keyword analysis, which employs Boolean operators (AND, OR or NOT) to include and exclude relevant keywords (Ryan, 2023). The time range covered by the select review was from 1980 to 2023 (September), with the terms ecological city OR ecocity OR eco-city. As a result, we found 46,735 articles, and a preliminary screening found 1198 relevant articles.

4. Results

Development map of ecological city research publications based on keywords (co-occurrence) using Lens.org metadata, using the keywords ecological city OR eco-city OR ecocity found 46,735 articles. Then, it selected based on keywords by removing antibacterial, silver nanoparticles, PAHs, apoptosis, antibiotic resistance, microplastics, antibiotics, bacterial community, biochar. Based on documents from 1980 to 2023, 1198 documents have been produced. The increase in publications occurred after 2013. The highest growth in publications on ecological cities occurred in 2022, reaching 257 publications (22.73%). In comparison, the lowest publications occurred in 1998, 2002, 2006, 2008, 2009, 2011 and 2012 with no publications (**Figure 3**). The timeframe 2020–2023 accounts for 66.96% of publications. This condition shows that ecological city research in quantity is a topic of interest and

continues to grow. Furthermore, the Lens.org dataset was analysed using the VOS viewer application version 1.6.19 by selecting the data option 'create a map based on bibliographic data to create a mapping of co-authorship, keyword co-occurrence, citation, bibliographic coupling or co-citation based on bibliographic data.

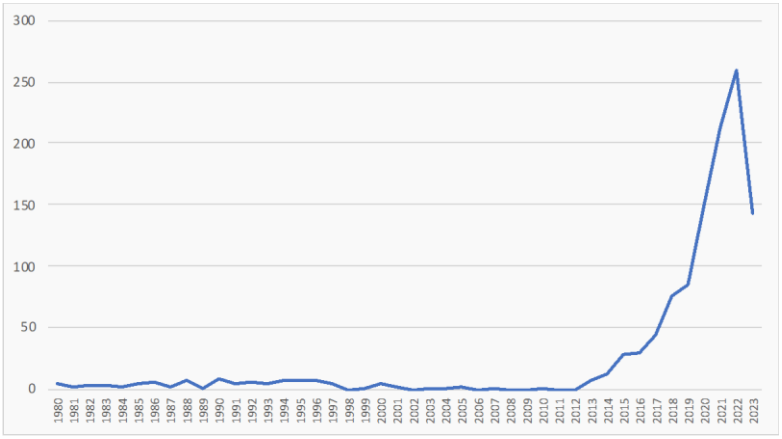

Figure 3. Ecocity's publication in 1980–2023 (Sept).

The top of the field shows the dominance of the research area is environmental science, followed by ecology, biology, economics and geography (**Figure 4**).

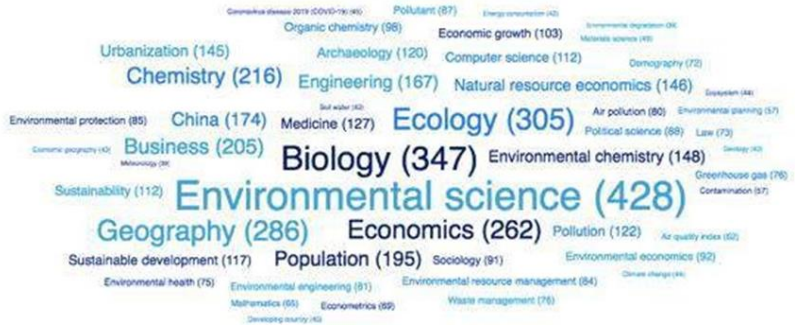

Figure 4. Top of field of ecocity's publication in 1980–2023 (June).

The type of analysis performed is co-occurrence with the unit of analysis keywords. The calculation method used is full counting. The minimum number of occurrences of a term is 10 out of 4211 keywords resulting in 91 meeting the threshold. For each of these 91 keywords, the total strength of the co-occurrence link with other keywords will be calculated. Keywords with the strength of the link will be selected from the 91 keywords and then selected by removing the keywords that contain the name of the country (14) because it is difficult to categorize concerning the ecological city and urban ecology perspective.

Bibliometric analysis involves the utilization of visual representations such as networks, overlays, and densities to ascertain the bibliometric connections among articles or online publications based on downloaded metadata. The bibliometric network comprises nodes, represented by either circular shapes or circles, that serve as visual representations of terms. On the contrary, the network's edges or nodes symbolize the connections between pairs of nodes. The utilization of VOS viewer software in bibliometric analysis encompasses mapping and clustering techniques,

which are mutually reinforcing and synergistic. Utilizing this mapping technique facilitates the acquisition of a comprehensive depiction of the composition of a bibliometric network. Furthermore, clustering provides a thorough understanding and analysis of bibliometric grouping.

A. Network visualization

The picture shows a network visualization of co-occurrence, which explains the network or relationship of one term with other terms in research in the ecological city (ecocity) field from 1980–2023 (**Figure 5**). Of the 1198 documents, 91 keywords that meet the threshold and 77 keywords selected can be grouped into 4 clusters, which can be identified through the colors of red, green, blue, and yellow.

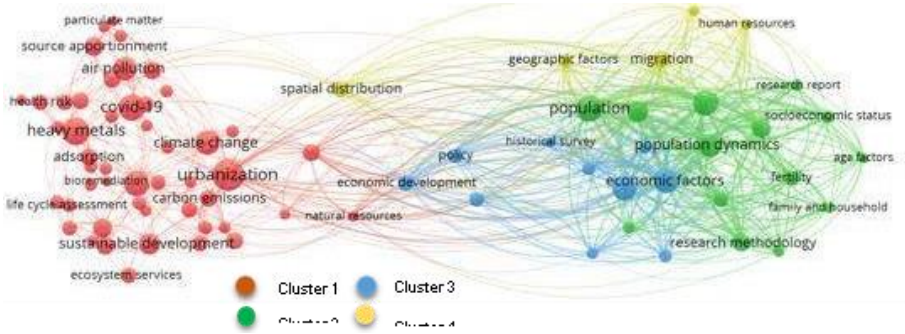

Figure 5. Network visualization keywords of ecological city.

Table 1. Cluster of ecological city keywords.

Cluster 1			**Cluster 2**	**Cluster 3**	**Cluster 4**
a. Adsorption	y.	Environmental quality	a. Age factor	a. Economic development	a. Geographic factors
b. Agriculture	z.	Environmental sustainability	b. Behaviour	b. Economic factors	b. Human resources
c. Air pollution	aa.	Green synthesis	c. Demographic factors	c. Health	c. Labor force
d. Air quality	bb.	Health risk	d. Family and household	d. Historical survey	d. Migration
e. Antioxidant	cc.	Heavy metal	e. Family planning	e. Macroeconomic factors	e. Spatial distribution
f. Biodiversity	dd.	Heavy metals	f. Fertility	f. Organization and administration	
g. Bioremediation	ee.	Municipal solid waste	g. Population	g. Policy	
h. Cadmium	ff.	Natural resources	h. Population characteristic	h. Political factors	
i. Carbon emission	gg.	Particulate matter	i. Populaton dynamics	i. Public health	
j. Carbon emissions	hh.	PM (2.5)	j. Research methodology		
k. Chemical Composition	ii.	PM 2.5	k. Research report		
l. Circular economy	jj.	Pollution	l. Socioeconomic factors		
m. Climate change	kk.	Polycyclic aromatic hydrocarbon	m. Socioeconomic status		
n. CO_2 emissions	ll.	Renewable energy	n. Studies		
o. COVID-19	mm.	Risk assessment			
p. Data envelopment analysis	nn.	Soil			
q. Eco-efficiency	oo.	Source apportionment			
r. Ecological footprint	pp.	Sustainability			

Table 1. (*Continued*).

Cluster 1		Cluster 2	Cluster 3	Cluster 4
s. Ecological risk	qq.	Sustainable development		
t. Economic growth	rr.	Urbanization		
u. Ecosystem services	ss.	Waste management		
v. Energy consumption	tt.	Wastewater		
w. Environment	uu.	Wastewater treatment		
x. Environmental pollution	vv.	Water quality		

Cluster 1 with a red symbol contains 49 keywords (**Table 1**). In cluster 1, keywords are dominated by urbanization (127 total link strength), heavy metal (37 total link strength), sustainability (33 total link strength), and COVID-19 (28 total link strength) (**Figure 6**).

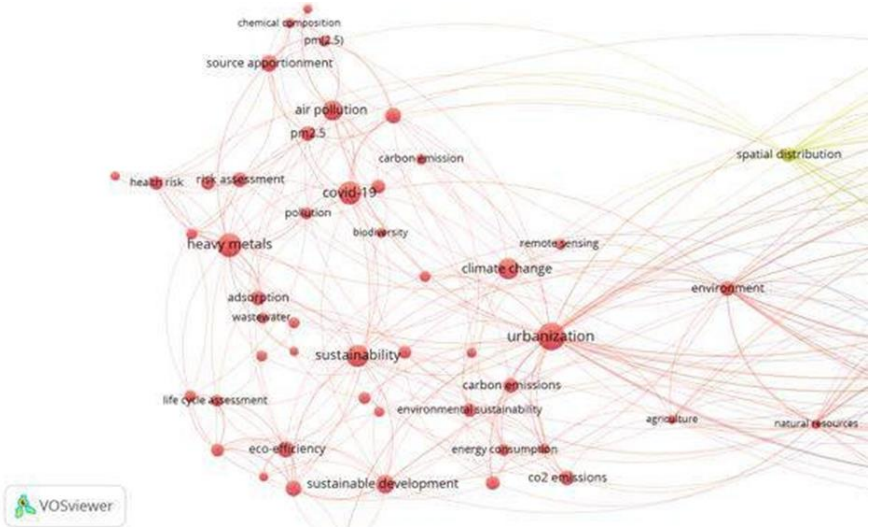

Figure 6. Cluster 1 of ecological city keywords.

Cluster 2 with green symbol contains 14 keywords (**Table 1**). Cluster 2 has several keywords with the largest total link strength among all ecological city keywords. Population (641 total link strength), demographic factors (616 total link strength), population dynamics (531 total link strength), socioeconomic factors (404 total link strength), and population characteristics (369 total link strength) (**Figure 7**).

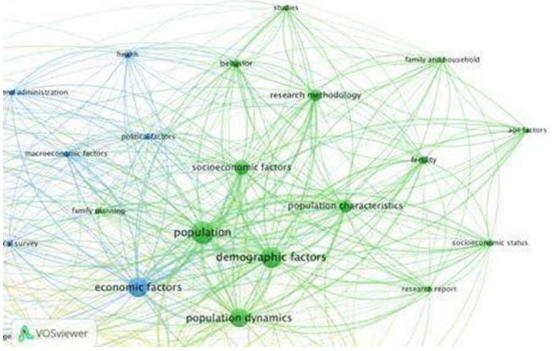

Figure 7. Cluster 2 of ecological city keywords.

Cluster 3, with a blue symbol, contains nine keywords (**Table 1**). In cluster 3, economic keywords dominate (560 total link strength). Other keywords have contiguous total link strengths such as macroeconomic factors (145 total link strength), economic development (116 total link strength), organization and administration (112 total link strength), policy (111 total link strength), health (110 total link strength), political factors (103 total link strength), historical survey (102 total link strength), and family planning (99 total link strength) (**Figure 8**).

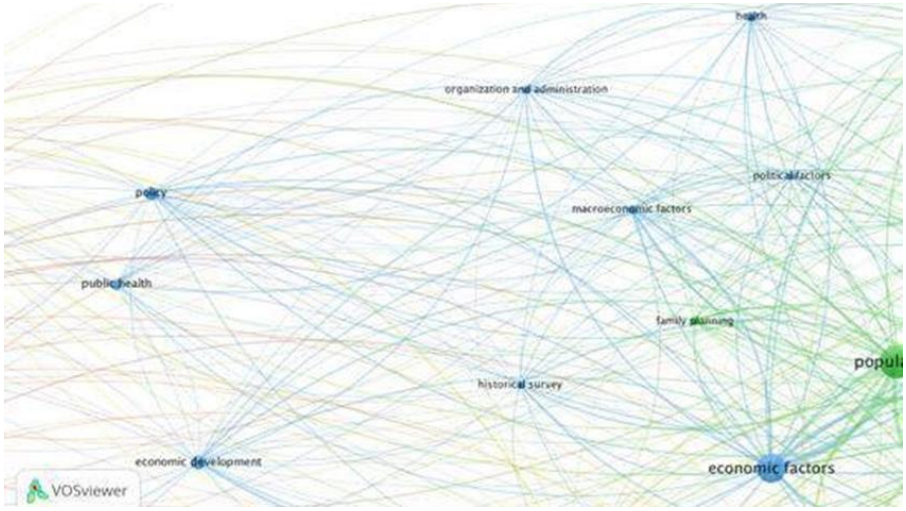

Figure 8. Cluster 3 of ecological city keywords.

Cluster 4, with a yellow symbol, contains five keywords (**Table 1**), such as migration (282 total link strength), geographic factors (170 total link strength), human resources (139 total link strength), labor force (119 total link strength), and spatial distribution (97 total link strength) (**Figure 9**).

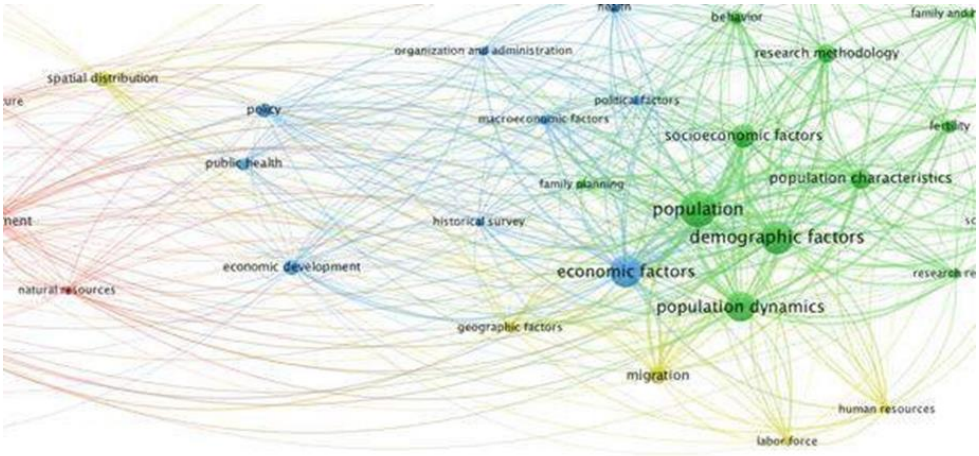

Figure 9. Cluster 4 of ecological city keywords.

The analysis of the generated clusters reveals that the categorization of the ecological city keyword grouping is as follows:

a) Cluster 1 pertains to examining the provision of an ecological city, focusing on the bio- geo physical features and ecological imperative elements.

b) Cluster 2 examines ecological cities through social dynamics and demographic

considerations.

c) Cluster 3 explores the multifaceted dimensions of ecological cities, encompassing economic factors, health considerations, policy, and political elements.

d) Cluster 4 explores the concept of ecological cities, focusing specifically on their spatial dimensions.

B. Overlay visualization

After identifying the mapping and clustering of ecological cities using network visualization, the next step is to map and cluster ecological city research trends based on historical traces or years of research publication. The information obtained from the Overlay visualization results can be used as a reference for identifying and detecting the state of the art of research in the field of ecological cities that can be carried out (**Figure 10**).

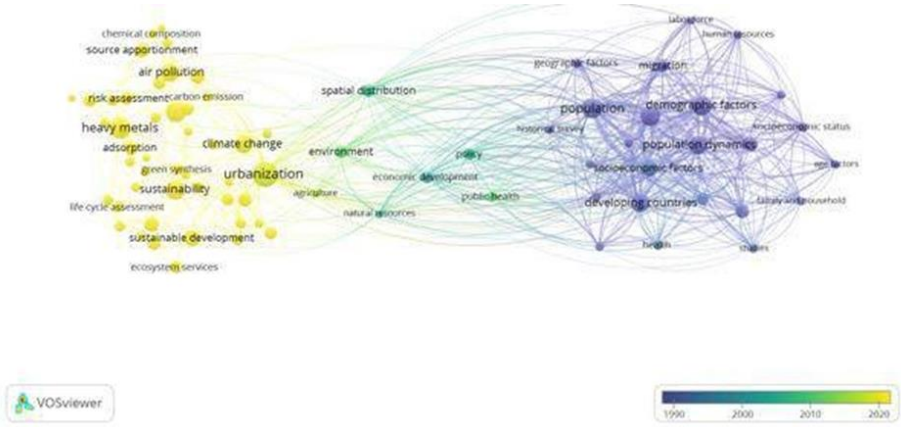

Figure 10. Overlay visualization keywords of ecological city.

Based on the overlay visualization mapping, it shows that towards 1990 until 2000, the research contained more keywords related to clusters 2 and 4, which were dominated by social aspects of population and socio-economic, and shifted to 2010 towards economic development, spatial distribution, and policies. After 2010 it shifted to the environment, public health, natural resources and agriculture. Towards 2020 until now, the keywords in cluster 1 are dominated by urbanization, sustainability, climate change, air pollution, COVID-19, sustainable development, renewable energy, eco-efficiency, energy consumption, ecosystem services, carbon emission, water quality, heavy metals and life cycle assessment, risk assessment and other keywords.

The study initially explored the ecological city from multiple angles, encompassing social, population, and spatial dimensions. Following that, there was a shift in concentration towards economic development and spatial dispersion. As 2020 approaches, there is an increasing scholarly discussion on ecological cities. This debate mostly centres around analysing their bio-geo-physical characteristics and the ecological imperatives.

C. Density visualization

The next step is bibliometric analysis using density visualization or density visualization. From the visualization results, it can be identified that there are dense areas with high density at one node with other nodes. The saturation level identified

in the number of keywords marked in yellow means that the area is a topic that has been widely researched; for example, the keywords population, population dynamics, economic factors, urbanization, COVID-19, heavy metals, sustainable development, climate change, sustainability, air pollution, ecological footprint, CO_2 emission and others.

The nodes marked with dark colours indicate that these topics have not been extensively researched, which can increase the opportunity to do research or research on these topics. Bibliometric analysis on density visualization, which shows the presence of strain and low intensity, indicates that research on the topic of the ecological city is related to the development of research keywords showing low intensity, namely ecosystem services, environment, spatial distribution, agricultural, natural resources, policy, public health, life cycle assessment are keywords ecological city that has the opportunity to be studied further (**Figure 11**). Even though the social and economic aspects were discussed more at the beginning of development, it is interesting to study related to the process of keywords with low intensity as an opportunity to conduct research or research on these topics.

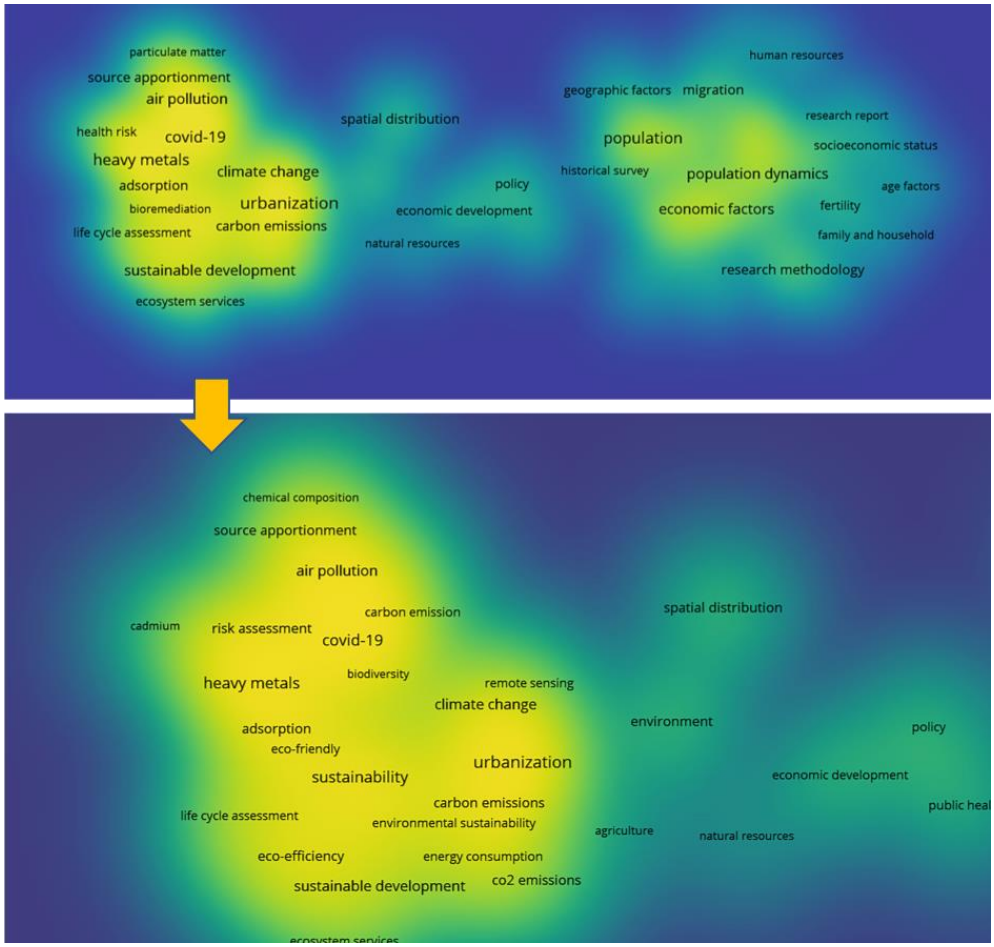

Figure 11. Density visualization keywords of ecological city.

The keywords are population, demographic factors, economic factors, population dynamics, socioeconomic factors, population characteristics, and migration, as viewed from the strength of the ten highest relationships. The identified keywords indicate that research on ecological cities predominantly focuses on socio-economic and

demographic issues. Ecosystem services and life cycle assessment are two areas that have garnered relatively less scholarly attention but present significant opportunities for further inquiry in contemporary research.

5. Discussion: Challenge and future research agenda

The existing body of research on creating ecological cities (ecocity) suggests that the successful implementation of such cities is influenced by various factors, including political, economic, social, and spatial aspects. Upon closer examination of the created clusters, it becomes apparent that most research advancements mainly concentrate on the clusters of bio geo physical features and ecological imperatives. The heightened level of discourse within these domains evidences this. The primary emphasis of the discourse lies in the examination of bio-geo physical properties rather than the consideration of ecological imperatives. Other clusters also participate in social, demographic, economic, healthcare, policy, political, and spatial conversations. In the present era, to adhere to the ecocity paradigm, it is imperative to satisfy the internationally established indicators outlined by the Global Ecocity Standards (Builders,2017).The four fundamental components of the ecocities are urban design, bio-geophysical conditions, socio-cultural features, and ecological imperatives. These pillars are further reinforced by a comprehensive set of 18 standards, which assess and evaluate the extent to which ecocity conditions are being realized (**Table 2**).

Table 2. Ecocity standards.

Category and standards			
Urban design	**Bio geo physical features**	**Socio cultural features**	**Ecological imperatives**
Access by proximity: median distance between housing, work and daily services	Clean air: quality of indoor and quantity of greenhouse gas emissions	Healthy culture: elements include trust, sense of place, eco- literacy, inclusion, and identity	Healthy biodiversity: number of representative keystone species in bioregion where city is located and from where the city draws sustenance
Safe and affordable housing: percentage population living in safe and affordable housing afford	Clean and safe water: quantity and quality of available water supplies	Community capacity/governance: percentage of population that participates in decisions that affect them	Earth's carrying capacity: ecological footprint that measures demand on nature's services relative to global (and regional) available biocapacity
Green building performance of building stock, both residential	Healthy soil: elements include soil physical and chemical properties	Elements include soil physical and chemical properties	Ecological integrity: elements include capability to regenerate.
Environmentally friendly transportation: percentage mode split for walking, cycling and transit	Responsible resources/material: quantity of waste produced	lifelong education: percentage of literacy for men and women	
	Clean and renewable energy: percentage of total energy that is renewable	Well being/quality of life: percentage of population with access to means of self-sufficient living	
	Healthy and accessible food: percentage of diet that is plant-based		

Categorize keywords to the four pillars of an ecological city are urban design, bio-geophysical features, socio-cultural features, and ecological imperatives (**Table 3**) show there are no keywords in urban design features, 36.96% keywords in bio-geophysical features and 31.52% socio-cultural features, and 8.69% in ecological

imperatives. Some keywords (6.52%) show common classify, such as sustainability/sustainable development and research.

Table 3. Categorize keywords to the four pillars of an ecological city.

Bio geo physical features		**Socio cultural features**		**Ecological imperatives**	**General**
Adsorption	Green	Age factor	Fertility	Biodiversity	Sustainability
Geographic factors	Synthesis	Economic development	Population	Eco-efficiency	Sustainable development
Agriculture	Heavy metal	Circular economy	Population characteristic	Ecological footprint	Research methodology
Air quality	Heavy metals	COVID-19	Population dynamics	Ecological risk	Research report
Antioxidant	Municipal	Data envelopment analysis		Risk assessment	Studies
Bioremediation	Solid waste	Economic growth	Socioeconomic factors	Environmental Sustainability	Historical survey
Cadmium	Natural resources	Health risk	Socioeconomic status	Ecosystem services	
Carbon emission	Particulate matter	Urbanization	Political factors	Life cycle assessment	
Carbon emissions	PM (2.5)	Human resources	Macroeconomic factors		
Climate change	PM 2.5	Labor force	Organization and administration		
Chemical composition	Air pollution	Migration			
CO_2 emissions	Pollution polycyclic	Spatial distribution	Policy		
Energy consumption	Aromatic hydrocarbon	Economic factors	Public health		
Renewable energy	Soil source apportionment	Health			
Environment	Waste management	Behaviour			
Environmental pollution	Wastewater	Demographic factors			
Environmental quality	Wastewater treatment	Family and household			
	Water quality	Family planning			

The compiled keywords indicate research prospects in urban design, specifically about access by proximity, safe and affordable housing, green building, and environmentally friendly transportation. These keywords represent both obstacles and chances for further investigation and scholarly advancement.

The classification of keywords, utilizing the overlay visualization mapping technique (**Figure 10**), demonstrates the existence of three separate time periods: the period prior to the 1990s until 2000, the period from 2000 to 2015, and the period from 2015 to the present. This demonstrates that:

1) From 1990 to 2000, the research focused mostly on clusters 2 and 4, which were characterized by a strong emphasis on the social elements of population and socio-economic issues. The current depiction of the timeline in the ecocity literature (**Figure 12**) showcases:
    a. The early phases of conceptualization and investigation of several facets of ecocity. These include elements such as ecological technology, social

interaction, power relations, and design nature and cognition.

b. The rise of urban ecology represents the progress of ecological research and the acknowledgement of urban environments as important objects of study, making valuable contributions to several domains of human understanding.

c. The notion of sustainability forms the fundamental basis for the green agenda. The existing amount of research on ecological cities mostly focuses on humans as the central ecosystem inside urban settings. In this instance, the study of ecological cities demonstrates the preliminary advancement in understanding the urban ecological framework pertaining to human populations. This includes issues such as population size, demographic features, population dynamics, as well as socioeconomic aspects. Additionally, this study encompasses research technique pertaining to several aspects of human behavior, including but not limited to family households, age demographics, fertility rates, socioeconomic status (cluster 2), as well as geographic characteristics, labor force dynamics, human resources, geographical distribution, and migratory patterns (cluster 4).

This period is commonly regarded as the formative period (Wang et al., 2020), during which urbane ecological management began to arise and flourish. During its embryonic stage, the concept of the eco-city underwent a process of diversification in terms of its meanings, which was influenced by advancements in several fields such as biology, sociology, and others. Subsequently, additional disciplines emerged to enhance urban governance, leading to the swift and extensive implementation of urban ecological management theory.

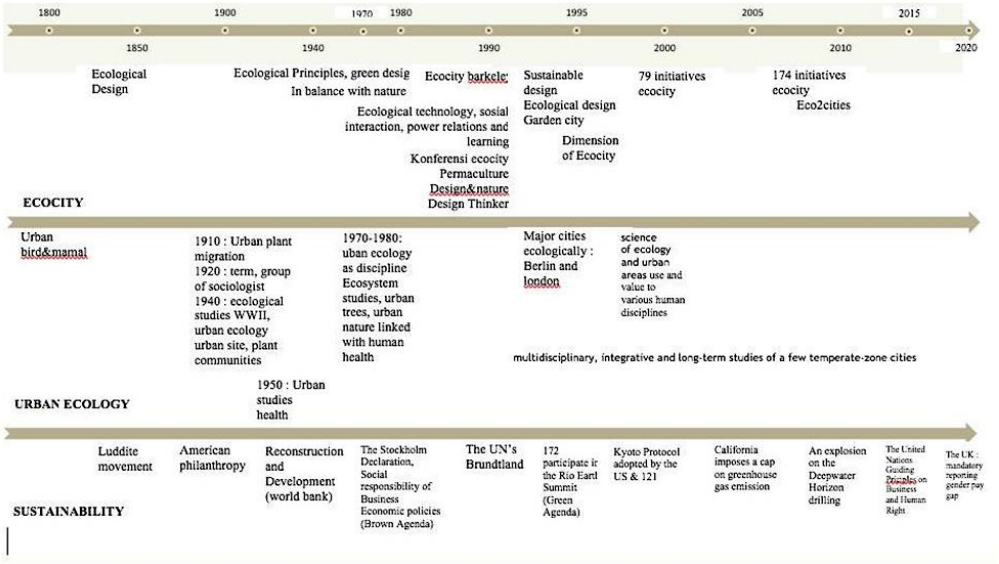

Figure 12. Timeline of development of ecocity, urban ecology, and sustainability concepts (Mayona, 2021).

2) Between 2000 and 2010, there was a notable focus on economic development, spatial distribution, and policies. During the specified period, there was a significant rise and progression of ecocity and eco2 cities initiatives. There is an emerging inclination towards advancing multidisciplinary research, integrative research, and investigations of extended duration. Urban ecological management

has had a significant advancement, including the time frame from 2000 to the present era. Since the year 2000, extensive research has been undertaken by specialists and researchers from diverse countries on the principles, key characteristics, fundamental meanings, planning concepts, index systems, and implementation processes of urban management, approached from numerous viewpoints (Stoltz et al., 2014).

3) Following 2010, there was a notable transition towards focusing on matters of the environment, public health, natural resources, and agriculture. During that particular era, the progression of sustainability was supported by the fundamental principles governing business practices and human rights. Furthermore, Stoltz and colleagues (2014) analyzed to identify ten specific target areas for evaluating Eco-city Projects across various global regions. Their study aimed to assess if these projects were being designed more fully compared to previous initiatives. A multitude of urban management approaches have surfaced on a global scale. The field of urban ecology has witnessed a transition in the focus of ecological cities from a people-centric approach to one that emphasizes economic issues associated with economic development, macroeconomic factors, policies, political factors, public health, organization, and administration (cluster 3).
4) In the year 2020, cluster 1 was primarily characterized by prevalent themes such as urbanization, sustainability, climate change, air pollution, COVID-19, sustainable development, renewable energy, eco-efficiency, energy consumption, ecosystem services, carbon emission, water quality, heavy metals, and risk assessment, among other notable keywords. During the period of prosperity (Wang et al., 2020), notable progress has been made in developing ideas, institutions, and applications for urban ecological management, resulting in a substantial expansion of its scope. The intersection of urban ecological management and support for sustainable development encompasses several aims, such as promoting low-carbon transformation, facilitating coordinated development, and the advancement of industrial upgrading. The concept of urban management has achieved global recognition to date. Research is presently being conducted to address the intricate nature of urban management. However, it has been observed that urban ecological building and management models have been effectively implemented and validated to varying extents in numerous countries and regions.

A bibliometric analysis was conducted to investigate the utilization of density visualization in the context of strain and low intensity. The results indicate a positive relationship between studies conducted on the concept of the ecological city and the subsequent appearance of research keywords associated with low-intensity research. In the framework of the ecological city, potential subjects for further inquiry include ecosystem services and life cycle assessment.

The keywords for population, demographic factors, economic factors, population dynamics, socioeconomic factors, population characteristics, and migration, when viewed from the strength of the ten highest relationships, are as follows: ecosystem services and life cycle assessment of ecological city have been highlighted as important topics worthy of scholarly investigation.

There are 24 themes of ecosystem services (Zhou et al., 2018; Aguilera et al.,

2020; Aryal et al., 2023; Gültekin, 2022; Ren and Li, 2022; Viezzer and Biondi, 2021; Xie et al., 2023; W. Wang et al., 2021; Gao et al., 2020; Calheiros and Stefanakis, 2021; R. Wang et al., 2022; Liu et al., 2023; Cai et al., 2021; F. Wang et al., 2022; Xiao and Xiao, 2018; Dee et al., 2017; Yan et al., 2023; Li and Zhou, 2015; Ma et al., 2022; Pan et al., 2022; Singhal et al., 2017; Rosini and Revelli, 2020; Du et al., 2023) dan 17 life cycle assessment (Zarea et al., 2019; Ng et al., 2014; Jirapornvaree et al., 2021; Tang et al., 2023; Ding et al., 2019; Rostami et al., 2019; Adeleke et al., 2021; Avarand et al., 2023; Ibáñez-Forés et al., 2021; Yadav and Samadder, 2017; de Sampaio Lopes et al., 2020; Y. Wang et al., 2016; Marzban et al., 2020; Bicer et al., 2017; Liu et al., 2021; Pokhrel et al., 2020; Gheibi et al., 2018). Within the framework of urban ecology, ecosystem services topics are characterized by the prevalence of specific keywords:

- Ecology in cities centres on the role of humans as habitats within urban environments, examining their capacity to alter or influence the structure and functioning of the 508 city's ecological system (Zhou et al., 2018; Ren and Li,2022; Xie et al., 2023; W. Wang et al., 2021; Calheiros and Stefanakis, 2021; Xiao and Xiao, 2018; Li and Zhou, 2015; Ma et al., 2022; Singhal et al., 2021).
- The ecology of health in urban areas examines the relationship between cities as human habitats and disease vectors and the impact of urban nature on human well-being (Viezzer and Biondi, 2021).
- Ecology for cities: to optimize the ecosystem services offered by urban green infrastructure to foster resilience to various forms of change, such as environmental shifts, enhance urban sustainability, and promote community cohesiveness (Calheiros and Stefanakis, 2021; Wang et al., 2022; Ma et al., 2022; Singhal et al., 2021; Rosini and Revelli, 2020).
- The ecology of cities as a whole, including examining the dynamics of energy, water, materials, and information entering and exiting urban areas and their corresponding impacts on internal and external environments (Aryal et al., 2023; Gültekin, 2022; Zarea et al., 2019; Ng et al., 2014; Jirapornvaree et al., 2021).

All life cycle assessment keywords are dominated by discussions regarding the optimization of ecosystem services in ecology for cities, municipal solid waste management (Zarea et al., 2019; Adeleke et al., 2021; Avarand et al., 2023; Yadav and Samadder, 2017; Liu et al., 2021; Pokhrel et al., 2020), wastewater and storm water (Ng et al., 2014; Tang et al., 2023; Rostami et al., 2019; Avarand et al., 2023; de Sampaio Lopes et al., 2020).

Keywords of the ecology of health in urban areas and the ecology of cities as a whole are views of urban ecology that can be developed because most ecological city themes are more in ecology in cities and ecology for cities. Furthermore, these keywords examine variations within urban areas, the rural-urban gradient, and the analysis of intricate socioecological systems within urban settings.

Urban ecology concerns the ecological interactions inside urban environments, embracing the interrelated subsystems that collectively represent the metabolic processes. The focus of ecological city research specifically emphasizes comprehending the mechanisms in these settings that impact and mold the structure and functionality of the ecological system (Pickett et al., 2016).

Here are some of the challenges and future agendas of ecocity research based on

the search results.

5.1. Challenges

1) There is a limited amount of detailed discussion regarding the influence of human individuals and groups on the dynamics and evolution of complex urban ecosystems in the context of city concept and practice. From the urban ecology perspective, this endeavor to explicitly represent an urban ecosystem by incorporating human elements biomodelling functions or processes that establish connections between humans and ecosystems (called the ecology of cities).

2) The discourse surrounding the concept of ecocities highlights a noticeable dearth of scholarly investigation into urban design and ecological imperatives in the context of worldwide standards and pillars. These circumstances imply potential avenues for additional advancement.

3) The concept of ecocities encompasses not only the achievement of the four ecocity standards but also highlights the importance of the human process involved in attaining these standards and the interconnectedness between each standard: urban design, bio-geophysical conditions, socio-cultural features, and ecological imperatives.

4) The study of urban ecology research area, specifically the ecology of cities, can be further explored by utilizing density visualization of ecological services and life cycle assessment, particularly in the context of ecological cities.

5) The cluster 1 keywords that have emerged and gained prominence from 2020 until now primarily revolve around urbanization, sustainability, climate change, air pollution, COVID-19, sustainable development, renewable energy, eco-efficiency, energy consumption, ecosystem services, carbon emissions, water quality, heavy metals, risk assessment, and other related terms. The present keyword is currently a subject of extensive discourse, presenting a promising avenue for further exploration in the context of human modelling of functions or processes on the ecology of cities. This connection between the keyword and such processes warrants further investigation and development.

5.2. The future agenda

Connecting ecocity knowledge needs with urban ecology solutions: The city research and innovation agenda is a pathway to transforming ambition into future action. In light of the abovementioned issues, it is necessary to outline potential avenues for future research agenda:

1) Formulating models of an urban ecosystem by reflecting human functions (metabolism) or processes that connect humans with ecosystems of ecocity in ecosystem services and lifecycle assessment: flow, impact, differentiation, analysis of complex socioecological
2) Exploring research prospects in urban design, specifically about access by proximity, safe and affordable housing, green building, and environmentally friendly transportation.
3) Exploring research prospect in ecological imperatives: healthy biodiversity, earth’s carrying capacity, ecological integrity.
4) Promoting Integration research of urbanization, sustainability, climate change,

air pollution, COVID-19, sustainable development, renewable energy, eco-efficiency, energy consumption, ecosystem services, carbon emission, water quality, heavy metals and risk assessment with human modelling functions or processes (ecology of cities).

5) Improving the contribution of ecocity to environmental goals, spatial distribution, agriculture, natural resources, policy, economic development and public health.

6. Conclusion

The ecological city, the ecocity, has emerged as a city idea in response to understanding urban ecological history and the intricate nature of urban environmental challenges. The history of the concept and implementation of ecocities (1980–2023) showcases the diverse factors influencing their perception, including political, economic, social, and spatial factors. This shift shows that the ecological city at the beginning of the research was studied from social, population, and spatial aspects. Then, it shifted towards economic development and spatial distribution. In the end, approaching 2020, ecological cities will be discussed from the aspects of bio geo physical features and ecological imperatives. The original idea of ecocity saw the development of cities based on ecological principles to establish healthy human-nature interaction patterns where local populations may choose how to live following their natural surroundings. Human-nature interaction can be illustrated by the ecology of cities as a whole in providing ecology for cities. However, in its development, it discusses ecology in cities dominated by humans, based on the development of keyword research shows. From the urban ecology approach standpoint, this attempt explicitly models an urban ecosystem by reflecting humans by modeling functions or processes that connect humans with ecosystems (ecology of cities).

Moreover, in terms of compliance with international ecocity standards, it still focuses on the pillars of bio-geophysical features, 38.16%, and socio-cultural features. One pillar of an ecological city is an ecological imperative that can be studied further as a part of human-nature interaction in the ecology of cities. If it is related to topics that are still minimally discussed, ecosystem service and life cycle assessment are keywords that allow a current topic to be discussed further. Finally, the challenges and future agenda of ecocity research include addressing humans by modeling functions or processes that connect humans with ecosystems (ecology of cities), urban design, ecological imperatives, integration research, and improving the contribution to environmental goals, spatial distribution, agriculture, natural resources, policy, economic development, and public health.

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