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Review Article

Remote Sensing-Based Urban Environmental Quality Indicators: A Review

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Abstract
Most of the global population lives in urban areas, which also serve as hubs of economy, industry, and government activities. Various factors that affect the quality of cities have been studied in different locations. This article reviews various papers that examine environmental quality indicators in urban areas that can be extracted from remote sensing data. The first aspect is vegetation cover, which is known from the vegetation index normalized difference vegetation index (NVDI), and the second aspect is surface temperature, which is known from land surface temperature (LST). In this work, urban environmental conditions in various countries are compared with urban conditions in Indonesia based on these indicators. It is found that NDVI and LST are indicators from remote sensing that are widely used to analyze urban environmental conditions. The vegetation index has a negative correlation with surface temperature. High surface temperature creates discomfort in urban quality of life and brings mental stress to residents living in those areas. Based on bibliometric analysis and network map, it is known that there are 30 most relevant words or terms to the keywords “urban remote sensing” and “remote sensing environment indicator” with the highest frequency of occurrence and relevance. This study can serve as input for the government as policymakers and urban planners to formulate spatial planning policies oriented towards sustainability and to research current topics related and relevant to remote sensing-based urban environmental quality indicators.

Keywords: comparative study, bibliometric analysis, urban remote sensing, normalized difference vegetation index, land surface temperature

1. INTRODUCTION

Urban areas globally are experiencing rapid population growth. Based on simulations, it is estimated that in 2030, the population in urban areas will be 60% of the world's population [1]. The need for land for settlements and industry in urban areas triggers a change in land cover from vegetation to built-up land [2]. Population growth is a phenomenon that occurs along with urbanization in various cities in the world, one of which is Addis Ababa [3]. In fact, in this city there has been unprecedented population growth, where from the 1950s to 2007 there was a 7-fold population growth from 392,000 people to 2.7 million people [3]. Apart from that, in this city there has also been significant land conversion where vegetation has changed into built-up land of 100.13 to 180.13 km^2 in 2011 [3]. Urban environmental issues have become a global concern that requires a holistic approach, emphasizing not only socio-economic aspects but also environmental sustainability [4]. This development concept has been globally accepted and is called sustainable development [4].

Cities in Indonesia are experiencing a significant increase in physical size and population [1]. Based on simulation, in 2035 it is estimated that the number of urban residents would increase by 80% for several regions such as Riau Islands Province, West Java, Special Region of Yogyakarta, Banten, and Bali [5]. The complete facilities available in urban areas coupled with high employment opportunities make villagers interested in moving and living in urban areas [1]. This population movement leads to high urban population density, which has an impact on the environment. Residents in urban areas also interact with the environment in which they live, using natural resources such as land, water, consuming food and fuel [1]. This population increase has an impact on the decline in urban environmental quality, which is characterized by reduced green open space, decreased air quality and increased waste [6].

Vegetation becomes an important aspect in environmental quality indicators because areas with high environment vulnerability index (EVI) are areas with less vegetation [7]. The relationship

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Table 1. The information about data used in the research.

Metrics	Result
Publication years	1993–2024
Citation years	31 (1993–2024)
Papers	200
Citations	10202
Cites/year	329.10
Cites/paper	51.01
h-index	49
g-index	89
hI,norm	49
hI,annual	1.58
hA-index	22
Document type	Journal
Papers with ACC ≥ 1,2,5,10,20	196,181,109,55,24
Keywords within title	"Urban remote sensing" and "remote sensing environment indicator"

between urban green space (UGS) and surface temperature has been studied in a city with hot climate, it is found that both have a negative correlation, where UGS provides a cooling effect on the city [8]. In another study, it is found that the proportion of vegetation combined with building shade can enhance urban cooling, which is beneficial for improving resident's well-being and thermal comfort [9]. From the findings of these studies, it can be concluded that urban greenery and surface temperature are interconnected and both contribute to the quality of the urban environment. Moreover, the type of vegetation present in urban areas also affects the cooling performance of vegetation in the city [10]. With the presence of green open spaces, thermal justice for city residents can be achieved [11].

Monitoring environmental quality is important considering its extensive impact on various aspects, including livestock production [12]. Some environmental conditions that can influence this are temperature, rainfall, and land cover [12]. One of the environmental conditions that can be detected with remote sensing is land cover, including vegetation cover. The normalized difference vegetation index (NDVI) is an indicator of the state of vegetation cover in a given area [13]. A review has previously been conducted to look at how to assess ecosystem services provided by urban vegetation using remote sensing [14]. In that study, vegetation index and LST are selected to show the environmental conditions of the study area.

Land Use Land Cover or LULC changes that contribute to environmental changes can be detected using remote sensing and geographic information systems [15]. Changes in land use patterns occurring in urban areas can trigger environmental degradation like surface temperature rise [16]. This research also shows the importance of conducting comparative studies on how these patterns occur in different places and what their impacts are, as seen in the comparison between Islamabad and Beijing [16]. Comparative studies of urbanization conditions and their environmental impacts are specifically important because each continent has its own characteristics [17]; thus, cross-continental comparative studies need to be conducted. For example, a study has been conducted showing that vegetation conditions in European cities tend to improve, while in African cities they tend to decline [17]. This is influenced by the intensity of development in each city.

In this study, several countries have been selected to review how the development of studies in their regions related to remote sensing-based urban environmental analysis. These countries include Ethiopia with the observed city of Addis Ababa, Indonesia with the observed city of Jakarta and its surroundings, Pakistan with the observed city of Islamabad, China with the observed city of Beijing, Bangladesh with the observed city of Dhaka and Malaysia with the observed city of Penang. These regions are selected in the case study on urban environmental analysis because they all have urban environmental problems mainly related to intensive urban physical development. Such regions also have high population density in urban areas and are experiencing urbanization processes in each region.

2. MATERIALS AND METHODS

2.1. Materials

The data used in this study are various literatures metadata that have been collected related to the research topic of environmental quality indicators in urban areas. The literature used includes research papers in the periods of 1997–2023 that examine this in selected study cases. The information about the literature used in the research is shown in Table 1. A map is utilised to plot all cities of the study, as shown in Figure 1.

Based on Table 1, it can be seen that the papers used in this bibliometric analysis were obtained from the Scopus database within the range of 1993 to 2024. The total citation years of the selected papers span 31 years from 1993 to 2024. Next, the number of papers analyzed in this study was 200 papers with a total of 10,202 citations. The average number of citations per year is 329.10 citations per year, and the number of citations per paper is approximately 51.01 citations per paper. Furthermore, the h-index of the selected papers is 49 and the g-index reaches 89. The keywords inputted into the search when selecting papers were "urban remote sensing" and "Remote sensing environment indicator." In this research, all papers were of the journal type.

2.2. Methods

2.2.1. Bibliometric Data Processing

This research was conducted using VosViewer software version 1.6.20. This software is an open source that is currently used for the creation and visualization of bibliometric networks widely. As the flowchart in Figure 2, this research was carried out starting with collecting the literature that became the main material for this research. The literature database was provided by Scopus and can be downloaded via the Application Programming Interface (API).

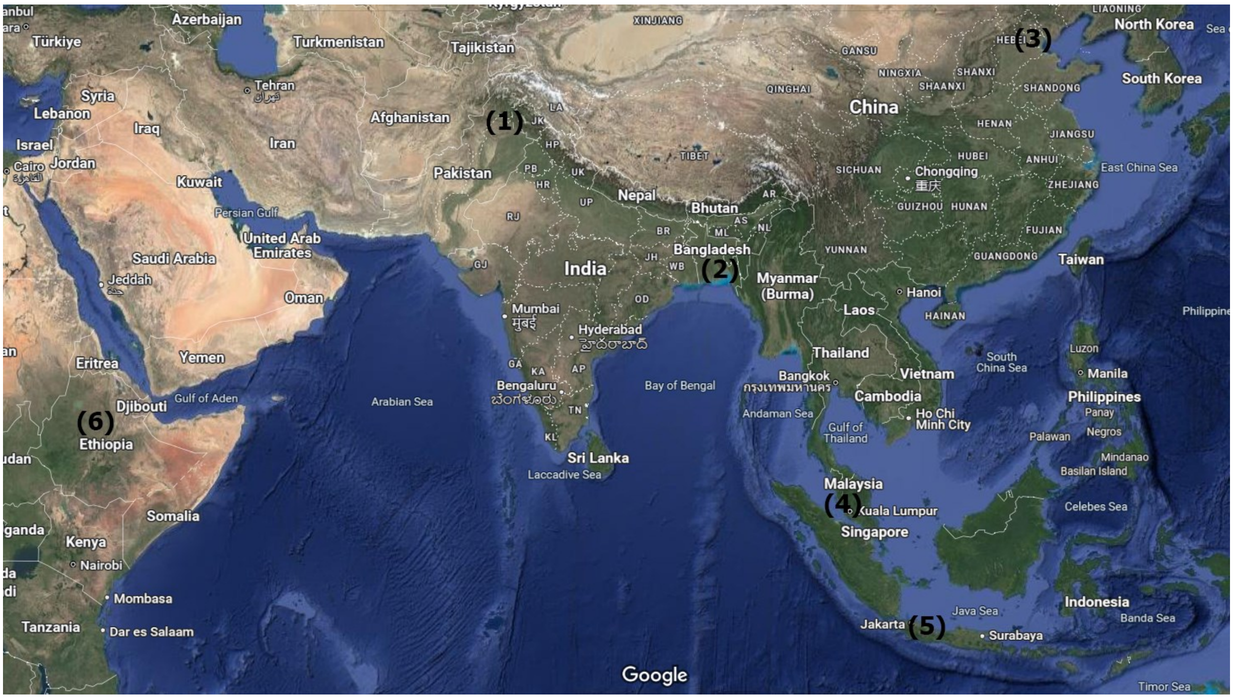

Figure 1. Study area in selected cities (1) Islamabad, Pakistan; (2) Dhaka, Bangladesh; (3) Beijing, China; (4) Penang, Malaysia; (5) Jakarta, Indonesia; (6) Addis Ababa, Ethiopia (Source: google.com/maps).

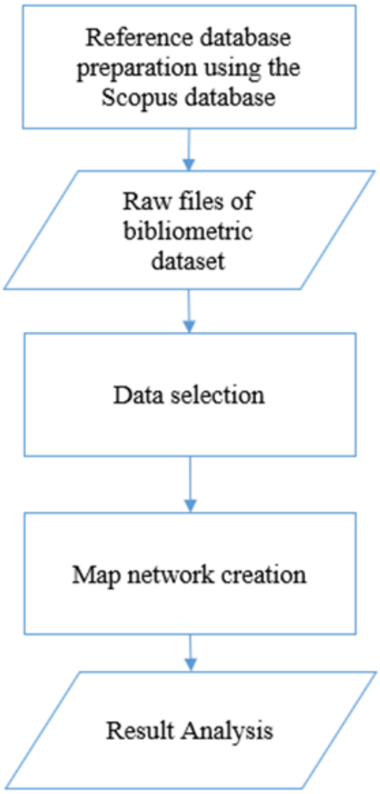

Figure 2. Flowchart of a comparative study of remote sensing-based urban environmental quality indicators.

Through the process of database collection, raw data from the bibliometric dataset was generated and then exported in *.csv format. The research was continued with the creation of a bibliometric network map. The process resulted in a network map showing relevant terms. The analysis was then conducted using comparative analysis on remote sensing-based urban environmental quality indicators in Indonesia and other selected countries.

3. RESULTS AND DISCUSSIONS

This part demonstrates (a) the use of remote sensing and environmental quality assessment in urban studies; (b) urban environmental conditions of different countries based on vegetation index NDVI and LST; (c) urban environmental conditions in Indonesia based on vegetation index and LST; (d) the impact of changes in vegetation conditions and urban surface temperature on the mental health or psychological condition of residents; and (e) environmental quality indicators in urban areas based on bibliometric analysis.

3.1. The Use of Remote Sensing and Environmental Quality Assessment in Urban Studies

Using multitemporal Landsat remote sensing data, a study has been conducted in Semarang, Indonesia to examine the relationship between the spatial dynamics of carbon emissions and surface temperature [18]. From this study, it is also found that the intensive urbanization occurring in Semarang contributes to the increase and dynamics of LST and carbon emissions [18]. Remote sensing-based environmental monitoring for carbon emission detection according to land use has been conducted in the Shandong Peninsula, using LULC classification methods and additional fossil fuel consumption data [19]. In another urban carbon emission monitoring research, carbon emissions are simulated using nighttime light (NTL) remote sensing data and public perception [20].

Monitoring of vegetation and temperature conditions has been conducted using vegetation index NDVI and LST, including study in the Himalayan Valley region [21]. It is found that there is a negative relationship between NDVI and LST in almost all land covers. In another research, urban environmental quality has been measured by the integration of remote sensing and GIS [22]. The data used in the study involved physical aspects of the environment such as green space and surface temperature, building quality aspects such as normalized difference built-up index (NDBI) and socio-economic aspects including population density and literacy [22]. In another study, machine learning models such as gradient boosting regression tree (GBRT), random forest (RF), and support vector machine (SVM) are developed for extracting surface temperature data based on urban green space (UGS) information from GaoFen-2 data [23]. Additionally, in research conducted in Beijing, surface urban heat island (SUHI) modeling is carried out using Landsat 8 and Sentinel-2 data, where the method has the potential to be applied in various regions of intensive urbanization to observe its impact on the environmental aspects of thermal environment [24]. In another urbanization area, namely the Pearl River Delta and the Yangtze River Delta, research has been conducted to examine the impact of urbanization on ecosystem dynamics, which is then compared with the spatial patterns of urban environmental conditions in developed countries such as the USA and Europe [25]. In this research, an improved neural network method based on remote sensing data has been applied [25]. Using remote sensing and the most recent indicator, the urban thermal field variance indicator (UTFVI), it has also been possible to identify the effects of Southern Iran's rapid urbanization on the spatial patterns of the thermal environment [26]. According to this study, the urban surface temperature has increased as a result of the decrease in vegetative area driven by urbanization [26].

The establishment of NDVI thresholds for optimal detection of urban green spaces has been developed [27]. NDVI for detecting urban green space is also used for assessing environmental justice [28]. Another urban environmental monitoring research is conducted in Iran, related to spatial modeling of air pollution from remote sensing data using the Google Earth Engine (GEE) platform, which is capable of observing the distribution of pollutants in the atmosphere due to emissions from anthropogenic activities and the impact of the COVID-19 pandemic lockdown to the air pollution [29].

3.2. Urban Environmental Conditions of Different Countries Based on Vegetation Index NDVI and LST

The dense population resulting from urbanization in China's megacities, including Beijing, poses a challenge for the government to maintain urban sustainability through improved urban governance [30]. Over the past few decades, China has experienced significant changes in land use/land cover, which have altered the country's natural conditions [2]. In this study, the vegetation index NDVI is used to see the vegetation condition and LST is used to see the surface temperature in the study area. In the study, it is found that land cover change in East China has caused surface temperature to rise by 3.4 ^{o}C in new urban areas that have decreased the amount of vegetation. In a study in downtown Beijing, China, an analysis is conducted on the relationship between LST and surrounding urban environmental factors, one of which is NDVI [31]. In this study, it is found that a strong negative correlation between LST and NDVI occurs in autumn, spring, and summer, and a weak positive correlation occurs in winter [31].

A study on the vegetation and surface temperature in the urban environments of Beijing and Islamabad has been carried out [16]. The study compares the surface temperature from LST to the vegetation state from NDVI. Regression analysis is used in this work to look at the link between the two environmental variables, NDVI and LST. From the analysis, it is found that the relationship between the two is negative. It is also found that NDVI, which indicates vegetation conditions, can affect surface temperature represented by LST, where the more vegetation present, the lower the surface temperature [16]. The urbanization occurring in Islamabad, Pakistan is intensive, causing the city to experience a significant increase in built-up areas, a rise in surface temperatures, and a reduction in the extent of vegetation [32]. Through this research, a negative correlation between LST and NDVI is also found in Islamabad [32]. A study of land cover change in Islamabad over four decades has been conducted using multitemporal Landsat satellite imagery [33]. The results of the study indicate an expansion of urban areas due to migration [33]. On the other hand, there has been a 41.7% increase in built-up land and

Table 2. Terms selected from the literature.

Term	Occurrences	Relevance
Beijing	3	2.10
Ecological environment	3	2.02
Capacity	3	1.80
Thermal environment	3	1.70
Water quality	4	1.49
GIS	3	1.35
Influence	5	1.28
Relationship	10	1.26
Application	7	1.22
Monitoring	6	1.13
Evaluation	5	1.13
Comparison	4	1.10
Landsat imagery	4	1.10
Urban green space	3	1.03
Land surface temperature	8	1.01
Guangzhou	5	0.90
Factor	7	0.89
Urban environment	4	0.77
Impervious surface	7	0.75
Indicator	15	0.69
India	4	0.68
Effect	10	0.63
Method	9	0.55
Case	7	0.53
Environment	8	0.51
Urban heat island effect	7	0.51
Remote sensing	17	0.50
Approach	9	0.44
Urban heat island	5	0.39
Impact	14	0.37

a 9.03% decrease in forest green areas [33]. Changes in LULC in Islamabad also frequently occur from green fields to dry land [34]. From this research, a negative relationship between NDVI and LST is also found, where surface temperature decreases as vegetation increases [34].

Urban heat island (UHI) occurrence in Penang, Malaysia, is known to be influenced by urbanization that leads to decreased plant cover and elevated carbon emissions [35]. In another study in Penang, it is found that there has been a trend of urban area expansion observed from Landsat satellite imagery using the Google Earth Engine platform [36]. Urbanization in Penang is growing at around 5%, which necessitates special attention to maintain environmental carrying capacity in this area [36]. Land conversion in the Penang region, including water bodies into buildings, has also been found in other research [37]. From various studies, it is known that the conversion of vegetation cover or water body into buildings contributes to the increase in surface temperature and the occurrence of UHI.

Addis Ababa is the capital of Ethiopia and one of the metropolitan cities on the African continent, with an urban population that continues to grow every year [38]. Urbanization that converts vegetation into built-up land is happening in Addis Ababa, Ethiopia [3]. During the observation period of 1985 to 2015, it is known that the built-up land increased from 18.23% to 33.86%, while the surface temperature increased by 3–8 °C [3]. This needs to be a concern to tackle urban heat stress. In a study integrating remote sensing and GIS, it is found that the impact of urbanization in Ethiopia's capital city is the decline of green space in the region from 1986 to 2015 [39]. Using medium-resolution Landsat remote sensing data, an analysis is conducted to observe land cover changes and their implications for the urban heat island [38]. From the research, it is found that there has been a landcover change in the form of a decrease in vegetation area from 217.66 km² in 1987 to 157.8 km² in 2019 [38]. Based on the research findings, it is known that urban warming occurs in the city center with a dominance of built-up land, indicating a negative relationship between vegetation and surface temperature [38].

On the other side of the world in South Asia, a study in Dhaka, the capital of Bangladesh, shows that urbanization in this area has occurred without proper planning [40]. Various impacts such as air pollution, increased health risks, waste management issues, and slum settlements have emerged in the region [40]. Dhaka has become one of the most interesting cities in urban environmental studies considering it is one of the densest megacities in the world that has experienced rapid urbanization in the last 20 years [41]. In a study of land cover changes using multitemporal Landsat data, it is found that there has been a 29% decrease in vegetation area and a 27% increase in built-up land [41]. The increase in the built-up area accompanied by the reduction of vegetation in Dhaka has caused a rise in LST by 25.33% from 2001 to 2017 [42]. An average temperature increase of 3 °C can trigger UHI, which poses a risk to public health [42].

Based on the use of RapidEye imagery for the study of land use change and air pollution in Dhaka, it is known that there has been a decrease in vegetation area by 5.3% [43]. The next result is a decrease in $PM_{2.5}$ along with the increase in vegetation area [43]. Related to land conversion, multitemporal vegetation cover monitoring has also been conducted in Dhaka, Bangladesh. In the study, the NDVI vegetation index is used to observe changes in vegetation conditions in the urban environment of Dhaka [44]. Historically, it can be seen that there has been a decrease in the amount of vegetation cover from 1989–2020 in Dhaka, which indicates a mismatch in realizing a healthy urban environment [44].

From all the cases discussed regarding urban environmental conditions from NDVI and LST, it can be seen that the common thread of all of them is that all the research locations that serve as case study areas are areas with intensive urbanization. Furthermore, the characteristics between each case is that the increase in surface temperature varies depending on the degree of land change and the condition of vegetation in the area to provide thermal comfort. Another difference is the value of the correlation that exists between NDVI and LST in each region, although it is generally recognized that the correlation is negative.

3.3. Urban Environmental Conditions in Indonesia Based on Vegetation Index and LST

Various studies have been conducted to see how monitoring of urban environmental conditions can be done with remote sensing data extraction. Based on a study conducted in Jakarta and the surrounding area, four geobiophysical indices are used to generate urban comfort classes. These indices are brightness index, greenness index, wetness index and surface temperature. Based on the research results, it is known that densely populated residential areas with little vegetation fall into the uncomfortable category [45]. This is in line with another research that areas with dense vegetation and few buildings have comfortable class environmental conditions; otherwise, if an area has sparse vegetation and dense buildings, it has uncomfortable class conditions [10].

In another research for Jakarta area, a simulation of building growth has been conducted using various multitemporal satellite image data [46]. It is found that the amount of vegetated area has

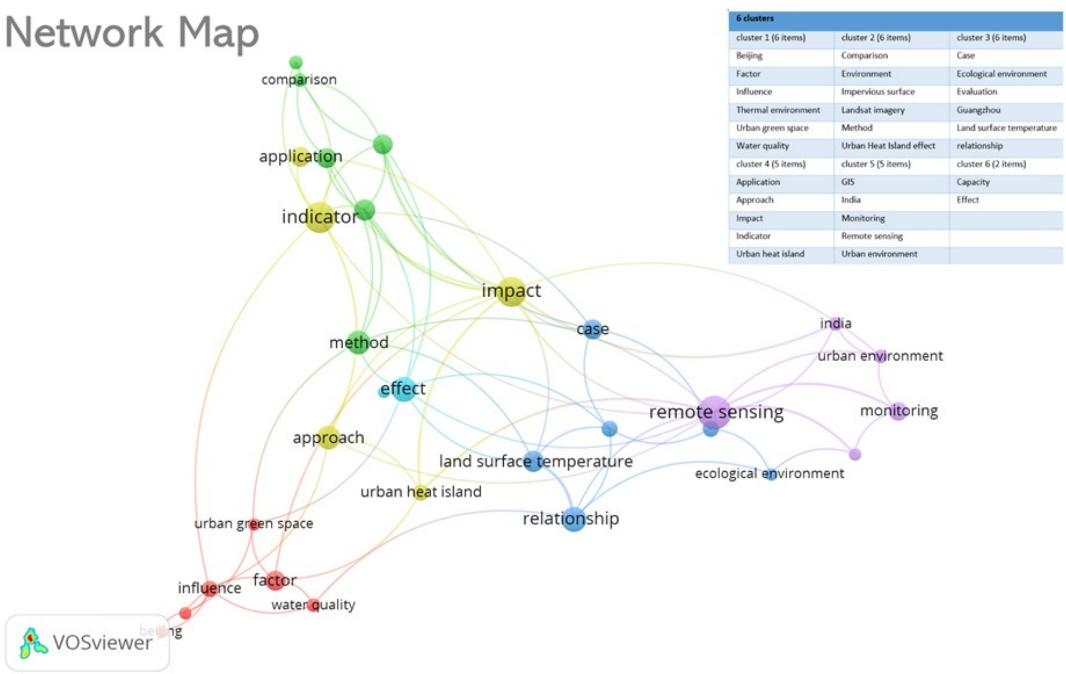

Figure 3. Keywords map of remote sensing-based urban environmental quality indicators.

decreased from 1972 to 2011, indicating urbanization [46]. The urban heat island phenomenon was found to have occurred in Jakarta based on the results of remote sensing data processing with NDVI and NDBI [47]. Correlation tests of both NDVI and LST indices have been performed for the study areas of Jakarta, Bandung and Surabaya and found that they are negatively correlated in all study areas [48]. This finding is consistent with research in another tropical city where it is known that there is a strong negative relationship between LST and NDVI [49].

3.4. The Impact of Changes in Vegetation Conditions and Urban Surface Temperature on The Mental Health or Psychological Condition of Residents

In one of the literature reviews on the role of green spaces for human health and well-being, it is found that green spaces have a role in this regard [50]. People who live around public green spaces will have a more fit body condition, avoid stress, reduce anxiety and depression, be satisfied in life and support the realization of a comfortable place to live for its citizens [50]. The benefits of green spaces in Indonesia in particular, have been studied and are known to have a positive impact on reducing depressive disorders in residents who live around them [51].

Other research reinforces the finding that a landscape with more trees and fewer buildings will be able to boost resident's morale and reduce stress [52]. Another social benefit provided by urban green spaces is the improvement in residents' quality of life; however, urban green spaces face issues of inequality in quality, distribution, and access. In ensuring the equitable distribution of UGS, precise planning and continuous monitoring are required [53]. Urban green spaces as public spaces function as places for fostering community interactions [54]. The presence of green spaces and their accessibility have been found to have a positive correlation with the social, mental, and physical health of urban residents [55]. Considering the role of green open space in comfortable environmental conditions and its benefits for residents' health, the government is committed to providing green spaces to maintain their function. One form of this commitment is the Jakarta spatial planning masterplan that provides integrated green spaces with roads and water bodies [56].

3.5. Environmental Quality Indicators in Urban Areas Based on Bibliometric Analysis

Bibliometric analysis for urban environmental quality has previously been studied using remote sensing-based ecological indexes [57]. In that study, bibliometric analysis of remote sensing-based urban environmental quality studies was conducted. This is the continuation of research that identifies the most relevant terms and their frequency of occurrence based on the entered keywords. Data is processed from recent curated literature.

Data processing in this research was conducted using the VosViewer software. From the research results displayed in Table 2 and Figure 3, it is known that there are 30 words or terms most relevant to the keywords "Urban remote sensing" and "remote sensing environment indicator" with the highest frequency of occurrence and relevance as shown in Table 2. The terms are divided into 6 clusters according to Figure 2. The first cluster consists of 6 words, namely Beijing, Factor, Influence, Thermal environment, Urban green space and Water quality. The second cluster consists of 6 words, namely Comparison, Environment, Impervious surface, Landsat imagery, Method and Urban heat island effect. The third cluster consists of 6 words, namely Case, ecological environment, evaluation, Guangzhou, Land surface temperature and relationship. The fourth cluster consists of 5 words, namely Application, Approach, Impact, Indicator and Urban heat island. The sixth cluster consists of 2 words namely Capacity and Effect. Not all selected words appear in the keywords map, as they are adjusted to the scale of the network map. As for the aspects that have not been extensively studied, they are evident from the words that are still not visible on the network map, such as the relationship with the environmental impact of air pollution, carbon stock and emissions, as well as the development of remote sensing methods using multisensors, OBIA, machine learning, and the use of very high-resolution imagery.

From the results, it can be seen that these words often appear in remote sensing-based urban environmental quality indicators studies in Indonesia and various countries from 1993 to 2024. Terms with large circles indicate frequent occurrences, namely remote sensing, impact, indicator, relationship, effect, and approach. These terms are related to remote sensing as the core topic of journals on remote sensing and specific fields that are heavily researched in relation to remote sensing-based urban environmental quality indicators studies. From the network map, it is known that the focus of the field on studies of relationships, effects, and impacts has become the most widely researched topic. If we also look at the network map, it shows that these relationships, effects, and impacts are related to terms such as urban heat island, land surface temperature, urban green space, and water quality.

Regarding the limitations of the NDVI and LST vegetation indices as indicators of environmental quality from remote sensing data, a paper has discussed this, especially due to the close relationship with the important role of satellite data for environmental justice [58]. Several points need to be highlighted regarding the limitations of NDVI and LST derived from satellite data, such as the potential for gaps both spatially and temporally due to various reasons, including light influence, atmospheric effect, cloud cover, certain types of vegetation, and surface reflectance [58][59]. Specifically for NDVI, further limitations include the inability to detect invasive plants and fully identify the quality of vegetation [58]. NDVI is also found to be less sensitive for application in high vegetation density areas because the red band is difficult to measure accurately, as well as other issues such as the angle of the sun and shadows that cause bias [60].

Meanwhile, for LST, the obtained LST values are actually not sufficiently relevant for applications related to human health impacts considering that LST does not represent exposure at heights greater than 1 meter, thus the potential for bias is quite significant [58]. Urban LST measurements often yield excessively high values [58]. On the other hand, LST and SAT (surface air temperature) have a weak correlation during the rainy season months, so the accuracy for measuring annual local heat risk could also be lower [61].

Environmentalism has now developed as a response to the environmental crisis. Considering the environmental impacts that arise in the urban environment, green attitudes and behaviors are needed in urban areas. Green behavior coupled with environmental ethics can foster awareness to jointly protect the environment, including by using environmentally friendly products and doing other environmentally friendly habits [62]. The practice of environmental philosophy is expected to help the realization of sustainability [63]. Hope in environmental philosophy is also influential in fostering enthusiasm for achieving the goal of realizing a sustainable environment [64]. By using a philosophical view on environmental issues, the handling of environmental issues can be carried out more thoroughly and comprehensively, because it is done by looking at the root of the problem and involving all interested parties.

4. CONCLUSIONS

In general, we found that NDVI and LST are indicators from remote sensing that are widely used to analyze urban environmental quality. The vegetation index NDVI has a negative correlation with land surface temperature. High surface temperature creates discomfort in urban quality of life and it brings about mental stress on residents living in those areas. Based on bibliometric analysis and network map, it is known that there are 30 most relevant words or terms to the keywords “urban remote sensing” and “remote sensing environment indicator” with the highest frequency of occurrence and relevance. The aspects that have not been extensively studied are evident from the words that are still not visible on the network map, where these topics become research gaps and can still be developed in further research, such as the relationship with the environmental impact of air pollution, carbon stock and emissions, as well as the development of remote sensing methods using multisensors, OBIA, machine learning, or the use of very high-resolution imagery. This study can serve as input for the government as policymakers and urban planners to formulate spatial planning policies oriented towards sustainability and to research current topics related and relevant to remote sensing-based urban environmental quality indicators.

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Conflicts of Interest

The authors declare no conflict of interest.

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REFERENCES

[1] N. S. Darmanto, A. C. G. Varquez, N. Kawano, and M. Kanda. (2019). "Future urban climate projection in a tropical megacity based on global climate change and local urbanization scenarios". *Urban Climate.* **29**. 10.1016/j.uclim.2019.100482.

[2] Y. Wang, J. Wang, H. Zhang, N. Janechek, Y. Wang, M. Zhou, P. Shen, J. Tan, Q. He, T. Cheng, and C. Huang. (2023). "Impact of land use change on the urban-rural

temperature disparity in Eastern China". *Atmospheric Environment*. **308**. 10.1016/j.atmosenv.2023.119850.

[3] G. Worku, E. Teferi, and A. Bantider. (2021). "Assessing the effects of vegetation change on urban land surface temperature using remote sensing data: The case of Addis Ababa city, Ethiopia". *Remote Sensing Applications: Society and Environment*. **22**. 10.1016/j.rsase.2021.100520.

[4] N. P. Hariram, K. B. Mekha, V. Suganthan, and K. Sudhakar. (2023). "Sustainalism: An Integrated Socio-Economic-Environmental Model to Address Sustainable Development and Sustainability". *Sustainability*. **15** (13). 10.3390/su151310682.

[5] R. Miranti. (2019). In: "Internal Migration, Urbanization and Poverty in Asia: Dynamics and Interrelationships, ch. Chapter 3". 47-76. 10.1007/978-981-13-1537-4_3.

[6] H. Herdiansyah, J. Rouli, R. Dyah Kusumastuti, and A. Sodri. (2020). "Decreasing urban environment quality and smart environment initiatives". *E3S Web of Conferences*. **211**. 10.1051/e3sconf/202021101025.

[7] R. Kurniawan, A. M. W. Saputra, A. W. Wijayanto, and W. Caesarendra. (2022). "Eco-environment vulnerability assessment using remote sensing approach in East Kalimantan, Indonesia". *Remote Sensing Applications: Society and Environment*. **27**. 10.1016/j.rsase.2022.100791.

[8] C. Munyati. (2024). "Detecting the air-cooling effect of urban green spaces in a hot climate town relative to land surface temperature on Landsat-9 thermal imagery". *Advances in Space Research*. **74** (10): 4598-4615. 10.1016/j.asr.2024.07.027.

[9] T. Sun, L. Chen, and R. Sun. (2024). "Cooling effects in urban communities: Parsing green spaces and building shadows". *Urban Forestry & Urban Greening*. **94**. 10.1016/j.ufug.2024.128264.

[10] D. R. Richards, T. K. Fung, R. N. Belcher, and P. J. Edwards. (2020). "Differential air temperature cooling performance of urban vegetation types in the tropics". *Urban Forestry & Urban Greening*. **50**. 10.1016/j.ufug.2020.126651.

[11] R. Ufaira, S. Amir, G. S. Indraprahasta, and A. Nastiti. (2023). "Living in a hot city: thermal justice through green open space provision". *Frontiers in Human Dynamics*. **5**. 10.3389/fhumd.2023.1237515.

[12] S. M. Mahdavian, F. Askari, H. Kioumarsi, R. Naseri Harsini, H. Dehghanzadeh, and B. Saboori. (2024). "Modeling the linkage between climate change, CH4 emissions, and land use with Iran's livestock production: A food security perspective". *Natural Resources Forum*. 10.1111/1477-8947.12532.

[13] Z. Davis, L. Nesbitt, M. Guhn, and M. van den Bosch. (2023). "Assessing changes in urban vegetation using Normalised Difference Vegetation Index (NDVI) for epidemiological studies". *Urban Forestry & Urban Greening*. **88**. 10.1016/j.ufug.2023.128080.

[14] K. A. García-Pardo, D. Moreno-Rangel, S. Domínguez-Amarillo, and J. R. García-Chávez. (2022). "Remote sensing for the assessment of ecosystem services provided by urban vegetation: A review of the methods applied". *Urban Forestry & Urban Greening*. **74**. 10.1016/j.ufug.2022.127636.

[15] V. T. Phuong and B. B. Thien. (2024). "Land Use Change Mapping and Analysis Using Remote Sensing and GIS: A Case Study in Tam Ky City, Quang Nam Province, Vietnam". *Journal of Multidisciplinary Applied Natural Science*. **4** (2): 210-224. 10.47352/jmans.2774-3047.208.

[16] M. S. Khan and Y. Li. (2024). "Comparative study and effects of urban green scape on the land surface temperature of a large metropolis and green city". *Heliyon*. **10** (3): e24912. 10.1016/j.heliyon.2024.e24912.

[17] Q. Zhong and Z. Li. (2024). "Long-term trends of vegetation greenness under different urban development intensities in 889 global cities". *Sustainable Cities and Society*. **106**. 10.1016/j.scs.2024.105406.

[18] D. D. Dewa and I. Buchori. (2023). "Impacts of rapid urbanization on spatial dynamics of land use-based carbon emission and surface

temperature changes in the Semarang Metropolitan Region, Indonesia". *Environmental Monitoring and Assessment.* **195** (2): 259. 10.1007/s10661-022-10839-6.

[19] L. Zhao, C.-h. Yang, Y.-c. Zhao, Q. Wang, and Q.-p. Zhang. (2023). "Spatial Correlations of Land Use Carbon Emissions in Shandong Peninsula Urban Agglomeration: A Perspective from City Level Using Remote Sensing Data". *Remote Sensing.* **15** (6). 10.3390/rs15061488.

[20] F. Gao, J. Wu, J. Xiao, X. Li, S. Liao, and W. Chen. (2023). "Spatially explicit carbon emissions by remote sensing and social sensing". *Environmental Research.* **221** : 115257. 10.1016/j.envres.2023.115257.

[21] W. Ullah, K. Ahmad, S. Ullah, A. A. Tahir, M. F. Javed, A. Nazir, A. M. Abbasi, M. Aziz, and A. Mohamed. (2023). "Analysis of the relationship among land surface temperature (LST), land use land cover (LULC), and normalized difference vegetation index (NDVI) with topographic elements in the lower Himalayan region". *Heliyon.* **9** (2): e13322. 10.1016/j.heliyon.2023.e13322.

[22] S. Roy, A. Bose, S. Majumder, I. Roy Chowdhury, H. G. Abdo, H. Almohamad, and A. Abdullah Al Dughairi. (2022). "Evaluating urban environment quality (UEQ) for Class-I Indian city: an integrated RS-GIS based exploratory spatial analysis". *Geocarto International.* **38** (1). 10.1080/10106049.2022.2153932.

[23] D. Chen, W. Sun, J. Shi, B. A. Johnson, M. L. Tan, Q. Pan, W. Li, X. Yang, and F. Zhang. (2024). "Utilizing GaoFen-2 derived urban green space information to predict local surface temperature". *Urban Forestry & Urban Greening.* **99**. 10.1016/j.ufug.2024.128463.

[24] F. Guo, J. Sun, and D. Hu. (2024). "Surface energy balance-based surface urban heat island decomposition at high resolution". *Remote Sensing of Environment.* **315**. 10.1016/j.rse.2024.114447.

[25] H. Gu and Y. Wei. (2021). "Environmental monitoring and landscape design of green city based on remote sensing image and improved neural network". *Environmental Technology & Innovation.* **23**. 10.1016/j.eti.2021.101718.

[26] M. Mokarram, F. Taripanah, and T. M. Pham. (2024). "Spatial-temporal analysis of atmospheric environment in urban areas using remote sensing and neural networks". *Sustainable Computing: Informatics and Systems.* **42**. 10.1016/j.suscom.2024.100987.

[27] J. Aryal, C. Sitaula, and S. Aryal. (2022). "NDVI Threshold-Based Urban Green Space Mapping from Sentinel-2A at the Local Governmental Area (LGA) Level of Victoria, Australia". *Land.* **11** (3). 10.3390/land11030351.

[28] N. Moos, C. Juergens, and A. P. Redecker. (2022). "Combined Small- and Large-Scale Geo-Spatial Analysis of the Ruhr Area for an Environmental Justice Assessment". *Sustainability.* **14** (6). 10.3390/su14063447.

[29] N. M. Sari and M. N. S. Kuncoro. (2021). "Monitoring Of Co, No2 And So2 Levels During The Covid-19 Pandemic In Iran Using Remote Sensing Imagery". *Geography, Environment, Sustainability.* **14** (4): 183-191. 10.24057/2071-9388-2020-74.

[30] Y. Wang and F. Wiedmann. (2024). "Everyday urbanism in Beijing's edge cities: on spatial and experience patterns". *Journal of Urbanism: International Research on Placemaking and Urban Sustainability.* 1-21. 10.1080/17549175.2024.2383928.

[31] Q. Meng, W. Liu, L. Zhang, M. Allam, Y. Bi, X. Hu, J. Gao, D. Hu, and T. Jancsó. (2022). "Relationships between Land Surface Temperatures and Neighboring Environment in Highly Urbanized Areas: Seasonal and Scale Effects Analyses of Beijing, China". *Remote Sensing.* **14** (17). 10.3390/rs14174340.

[32] A. Aslam, I. A. Rana, and S. S. Bhatti. (2021). "The spatiotemporal dynamics of urbanisation and local climate: A case study of Islamabad, Pakistan". *Environmental Impact Assessment Review.* **91**. 10.1016/j.eiar.2021.106666.

[33] A. Shah, K. Ali, and S. M. Nizami. (2021). "Four decadal urban land degradation in Pakistan a case study of capital city

islamabad during 1979–2019". *Environmental and Sustainability Indicators.* **10**. 10.1016/j.indic.2021.100108.

[34] M. T. Sohail, Z. Manzoor, M. Ehsan, N. Al-Ansari, M. B. Khan, A. Shafi, J. Ullah, A. Hussain, D. Raza, U. Usman, S. Akbar, and A. Elbeltagi. (2023). "Impacts of urbanization, LULC, LST, and NDVI changes on the static water table with possible solutions and water policy discussions: A case from Islamabad, Pakistan". *Frontiers in Environmental Science.* **11**. 10.3389/fenvs.2023.1018500.

[35] Z. A. Rahaman, A. A. Kafy, M. Saha, A. A. Rahim, A. I. Almulhim, S. N. Rahaman, M. A. Fattah, M. T. Rahman, K. S, A.-A. Faisal, and A. Al Rakib. (2022). "Assessing the impacts of vegetation cover loss on surface temperature, urban heat island and carbon emission in Penang city, Malaysia". *Building and Environment.* **222**. 10.1016/j.buildenv.2022.109335.

[36] Y. L. Tew, M. L. Tan, N. Samat, and X. Yang. (2019). "Urban Expansion Analysis using Landsat Images in Penang, Malaysia". *Sains Malaysiana.* **48** (11): 2307-2315. 10.17576/jsm-2019-4811-02.

[37] I. Yin, L. T. Mou, D. S. Abang Mahmud, A. A. S. Muthuveeran, M. A. Hassan, and L. T. Yi. (2022). "Monitoring Major City Urban Expansion in Kuala Lumpur and Penang City Centre". *Planning Malaysia.* **20**. 10.21837/pm.v20i20.1079.

[38] A. Balew and F. Semaw. (2021). "Impacts of land-use and land-cover changes on surface urban heat islands in Addis Ababa city and its surrounding". *Environment, Development and Sustainability.* **24** (1): 832-866. 10.1007/s10668-021-01472-3.

[39] M. T. Abebe and T. L. Megento. (2017). "The City of Addis Ababa from ‘Forest City’ to ‘Urban Heat Island’: An Analysis of Urban Green Space Dynamics Using Remote Sensing and Geographic Information System". *Journal of Urban and Environmental Engineering.* **10** (2): 254-262. 10.4090/juee.2016.v10n2.254262.

[40] M. A. Rahaman, A. Kalam, and M. Al-Mamun. (2023). "Unplanned urbanization and health risks of Dhaka City in Bangladesh: uncovering the associations between urban environment and public health". *Frontiers in Public Health.* **11** : 1269362. 10.3389/fpubh.2023.1269362.

[41] M. H. Rahman. (2022). "A Study on Determining Land Use/Land Cover Changes in Dhaka over the Last 20 Years and Observing the Impact of Population Growth on Land Use/Land Cover Using Remote Sensing". *Malaysian Journal of Civil Engineering.* **34** (2): 1-9. 10.11113/mjce.v34.17812.

[42] A. S. M. S. Uddin, N. Khan, A. R. M. T. Islam, M. Kamruzzaman, and S. Shahid. (2021). "Changes in urbanization and urban heat island effect in Dhaka city". *Theoretical and Applied Climatology.* **147** (3-4): 891-907. 10.1007/s00704-021-03872-x.

[43] T. Zarin and M. Esraz-Ul-Zannat. (2023). "Assessing the potential impacts of LULC change on urban air quality in Dhaka city". *Ecological Indicators.* **154**. 10.1016/j.ecolind.2023.110746.

[44] N. Nawar, R. Sorker, F. J. Chowdhury, and M. Mostafizur Rahman. (2022). "Present status and historical changes of urban green space in Dhaka city, Bangladesh: A remote sensing driven approach". *Environmental Challenges.* **6**. 10.1016/j.envc.2021.100425.

[45] N. M. Sari, D. Kushardono, M. Mukhoriyah, K. Kustiyo, and M. D. M. Manessa. (2023). "Optimized Artificial Neural Network for the Classification of Urban Environment Comfort using Landsat-8 Remote Sensing Data in Greater Jakarta Area, Indonesia". *Journal of Applied Engineering and Technological Science (JAETS).* **4** (2): 743-755. 10.37385/jaets.v4i2.1760.

[46] A. A. Putra, C. E. Trisnawati, and P. W. Widayat. (2024). "The impact of urbanization on environmental degradation in Jakarta". *Journal of City: Branding and Authenticity.* **2** (1). 10.61511/jcbau.v2i1.2024.903.

[47] I. Prasasti, Suwarsono, and N. M. Sari. (2017). "The Effect of Environmental Condition Changes on Distribution of Urban Heat Island in Jakarta Based on Remote Sensing Data". *International Journal of*

Remote Sensing and Earth Sciences (IJReSES). **12** (1). 10.30536/j.ijreses.2015.v12.a2670.

[48] F. R. Fajary, H. S. Lee, T. Kubota, V. Bhanage, R. P. Pradana, H. Nimiya, and I. Putra. (2024). "Comprehensive spatiotemporal evaluation of urban growth, surface urban heat island, and urban thermal conditions on Java island of Indonesia and implications for urban planning". *Heliyon.* **10** (13): e33708. 10.1016/j.heliyon.2024.e33708.

[49] S. Guha and H. Govil. (2020). "Land surface temperature and normalized difference vegetation index relationship: a seasonal study on a tropical city". *SN Applied Sciences.* **2** (10). 10.1007/s42452-020-03458-8.

[50] M. Jabbar, M. M. Yusoff, and A. Shafie. (2022). "Assessing the role of urban green spaces for human well-being: a systematic review". *GeoJournal.* **87** (5): 4405-4423. 10.1007/s10708-021-10474-7.

[51] A. Kusumaning Asri, H.-Y. Lee, W.-C. Pan, H.-J. Tsai, H.-T. Chang, S.-C. Candice Lung, H.-J. Su, C.-P. Yu, J. S. Ji, C.-D. Wu, and J. D. Spengler. (2021). "Is green space exposure beneficial in a developing country?". *Landscape and Urban Planning.* **215**. 10.1016/j.landurbplan.2021.104226.

[52] A. Jahani and M. Saffariha. (2020). "Aesthetic preference and mental restoration prediction in urban parks: An application of environmental modeling approach". *Urban Forestry & Urban Greening.* **54**. 10.1016/j.ufug.2020.126775.

[53] P. I. Korah, M. A. Akaateba, and B. A. A. Akanbang. (2024). "Spatio-temporal patterns and accessibility of green spaces in Kumasi, Ghana". *Habitat International.* **144**. 10.1016/j.habitatint.2024.103010.

[54] G. Zhang, G. Qiao, and Z. Mao. (2024). "The order characteristics of daily life space in Chinese urban communities--a case of Ningbo Green Axis Sports Park". *Heliyon.* **10** (13): e33548. 10.1016/j.heliyon.2024.e33548.

[55] D. Lin, Y. Sun, Y. Yang, Y. Han, and C. Xu. (2023). "Urban park use and self-reported physical, mental, and social health during the COVID-19 pandemic: An on-site survey in Beijing, China". *Urban For Urban Green.* **79** : 127804. 10.1016/j.ufug.2022.127804.

[56] R. Setiowati, H. Hayati Sari, and T. S. K. Raldi Hendro. (2020). "Studi Komparasi Perencanaan Ruang Terbuka Hijau Perkotaan Antara Jakarta dan Singapura". *Jurnal Lanskap Indonesia.* **12** (2): 54-62. 10.29244/jli.v12i2.32409.

[57] N. M. Sari, D. Kushardono, M. D. M. Manessa, Kustiyo, Mukhoriyah, A. Indradjad, S. Arifin, and A. Maryanto. (2023). "A bibliometric analysis of urban environment quality studies based on satellite remote sensing data". The Machine Learning and Information Processing: Proceedings of Icmlip 2023. http://dx.doi.org/10.1063/5.0183687.

[58] T. K. Sayyed, U. Ovienmhada, M. Kashani, K. Vohra, G. H. Kerr, C. O'Donnell, M. H. Harris, L. Gladson, A. R. Titus, S. B. Adamo, K. C. Fong, E. M. Gargulinski, A. J. Soja, S. Anenberg, and Y. Kuwayama. (2024). "Satellite data for environmental justice: a scoping review of the literature in the United States". *Environmental Research Letters.* **19** (3). 10.1088/1748-9326/ad1fa4.

[59] J. Xue and B. Su. (2017). "Significant Remote Sensing Vegetation Indices: A Review of Developments and Applications". *Journal of Sensors.* **2017** : 1-17. 10.1155/2017/1353691.

[60] C. Knoble and D. Yu. (2023). "Bridging the Gap: Analyzing the Relationship between Environmental Justice Awareness on Twitter and Socio-Environmental Factors Using Remote Sensing and Big Data". *Remote Sensing.* **15** (23). 10.3390/rs15235510.

[61] A. Kenawy, N. Muse, A. Clement, and K. J. Mach. (2024). "Daytime land surface temperature and its limits as a proxy for surface air temperature in a subtropical, seasonally wet region". *PLOS Climate.* **3** (10). 10.1371/journal.pclm.0000278.

[62] M. N. Alam, O. Ogiemwonyi, I. E. Hago, N. A. Azizan, F. Hashim, and M. S. Hossain. (2023). "Understanding Consumer Environmental Ethics and the Willingness to

Use Green Products". *Sage Open.* **13** (1). 10.1177/21582440221149727.

[63] S. Sarkar. (2014). "Environmental philosophy: from theory to practice". *Studies in History and Philosophy of Biological and Biomedical Sciences.* **45** : 89-91. 10.1016/j.shpsc.2013.10.010.

[64] L. Kretz. (2012). "Hope in Environmental Philosophy". *Journal of Agricultural and Environmental Ethics.* **26** (5): 925-944. 10.1007/s10806-012-9425-8.