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Analysis of Nature-Based Solutions Research Trends and Integrated Means of Implementation in Climate Change

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Abstract: Nature-based solutions (NbS) is an approach to solving climate change and social issues based on nature. Despite NbS being widely studied as an effective method to solve social problems, the trends in NbS research have hardly been analyzed. Therefore, this study examined change patterns in NbS-related research topics over time and analyzed the interactions of NbS research and relevant activities in various fields. After reviewing research papers based on the search term 'nature-based solutions' on Scopus, and collecting 1567 research papers, we conducted dynamic topic modeling (DTM) and network analysis. The papers were classified into 19 topics via DTM. Water, forest, and urban topics made up the greatest portion of NbS research, while NbS topics in the forest sector showed a steady increase over time. This study also found close connections between NbS studies on forests and other sectors and confirmed that the forest sector can become an integrated means of contributing to climate change responses and other resultant social issues. This study demonstrates that DTM and network analysis are useful tools for understanding the trends in NbS research and finding the linkages between various fields.

Keywords: dynamic topic modeling; nature-based solutions; research trend

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1. Introduction

The concept of nature-based solutions (NbS) began to appear in the scientific literature in the early 2000s [1], and the term NbS was first employed in 2002 [2]. NbS is not a new concept but an umbrella concept encompassing nature-based approaches (NbAs) such as ecosystem-based adaptation (EbA) and ecosystem-based mitigation (EbM) [2].

There is no globally agreed-upon definition of a NbS, but those of the International Union for Conservation of Nature (IUCN) and European Union (EU) are interchangeably used. According to the IUCN, the term is defined as follows: "Actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature" (https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions: accessed on 1 April 2022). The EU defines this term as follows: "Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits, and help build resilience" (https://portals.iucn.org/library/sites/library/files/documents/2016-036.pdf: accessed on 1 April 2022). As for the reinterpretation of the generally utilized definition of this term, the core idea of NbS is to provide "a wide range of benefits" by utilizing "solutions based on nature" to achieve "sustainability" to "solve social issues." In this sense, it is questionable as to what sorts of activities/sectors can be considered as solutions based on nature. NbS can be applied to a wide range of measures designed to improve the welfare of all humankind, biodiversity, and climate change responses, and can be readily integrated into diverse sectors, generating complex or multiple effects and, resultantly, can be widely applied to climate change adaption and damage reduction [3–5].

NbS is expected to provide synergy effects between technologies and environments, by breaking away from relying on technologies (engineering), and appropriately utilizing nature's resilience [6,7]. There have long been attempts to ensure environmental protection, but NbS has recently attracted a lot of attention because there is a rapid increase in evidence-based research findings [8] in which solutions based on nature's resilience or recovery ability can provide multiple benefits [9,10].

The NbS for Climate Manifesto, which was announced at the 2019 Climate Action Summit, indicated that NbS should be utilized as the key means to tackle climate change impacts and achieve biodiversity conservation, leading to higher political interest around the world. Since then, the 27th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC COP27) recommended that NbS should be considered in implementing climate change mitigation and adaptation through the Sharm el-Sheikh Implementation Plan [11]. In this regard, NbS has attracted attention as a means of reducing greenhouse gases (GHGs) [12,13].

Considering that nature has multiple functions, NbS in the forest sector provides not only a GHG emission reduction function, but also diverse benefits. NbS in the forest sector is closely connected to diverse sectors such as climate change mitigation, sustainable agriculture, and urban and peri-urban forests [14]. NbS has advantages in that one action can bring a large number of positive benefits due to the complexity and multiple functions of natural environments [15,16], and in particular, such benefits can be expected in the forest sector [17–19].

Despite NbS being extensively studied due to its wide applicability and efficiency, as noted above, the trends in NbS research have hardly been analyzed. We aimed to develop an answer to the questions considering all fields related to NbS research: What types of NbS research activities exist? Which sectors are paying attention to NbS? What proportion does each sector make up of NbS research activities? How have trends changed? And which sectors are connected with the forest sector and what kinds of synergy effects can be generated? Knowing the research trends of NbS can help us understand temporal shifts in perspective in NbS theory and find the direction we need to focus on in the near future.

2. Materials and Methods

This study aimed to investigate how NbS research trends have changed over time, and how they are structurally related. We used dynamic topic modeling (DTM) to identify the following: (1) how NbS research topics are classified and (2) how keywords within the main topics have changed over time. We also used network analysis to identify the kinds of relationships between those topics, by (3) analyzing the structural relationship between them.

After collecting research papers by searching for "nature-based solutions" in the database provided by Scopus, we created a dataset of 1581 research papers for a final analysis through a secondary review process to determine whether they were NbS-related research (Figure 1). Subsequently, we performed DTM after preprocessing for topic modeling and defined the extracted topics. Additionally, we identified interactions and relationships between each topic through network analysis based on the DTM results.

2.1. Data Analysis

We extracted a total of 15,017 research papers from 2003 to 2022 by using the search term "nature-based solutions" from the database provided by Scopus, Elsevier's global academic paper data platform. After that, we determined whether the extracted papers were based on NbS, and then, conducted a secondary review. As a result, we eventually selected 1581 research papers from 2012 to 2022 as the targets for analysis and organized the titles, abstracts, and index keywords.

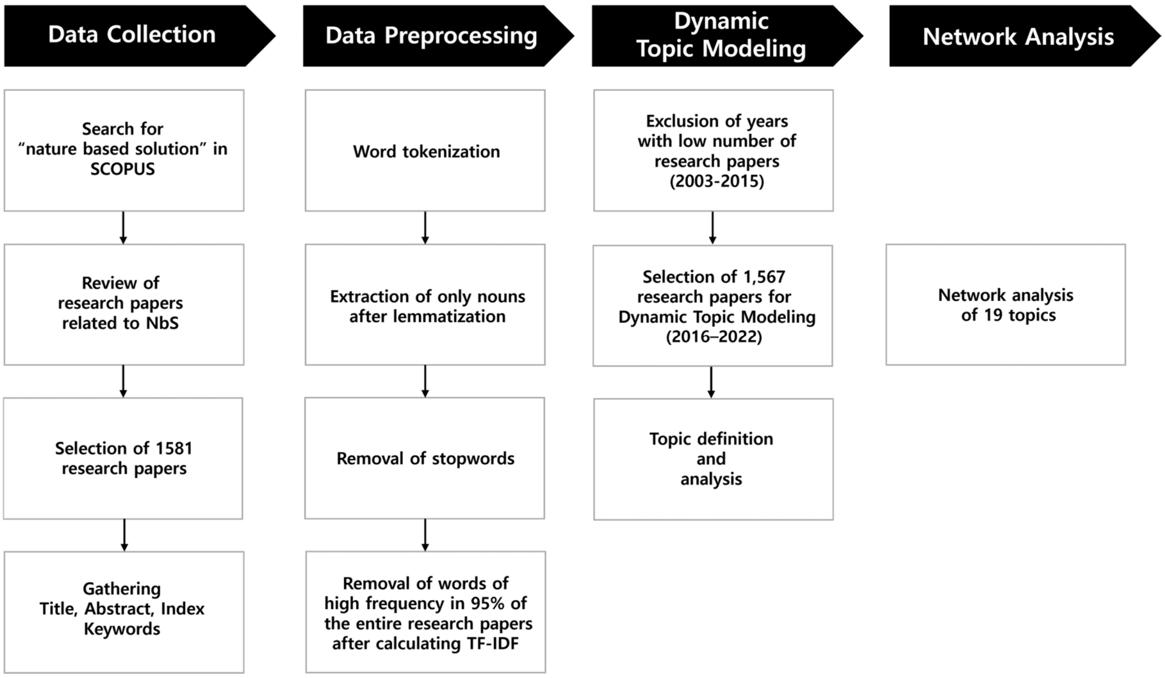

Figure 1. Procedures for data extraction and analysis.

Figure 2 and Table 1 show the number of finally collected NbS research papers per year. Research papers published from 2003 to 2015 were excluded in this study, because the number of papers was too low to analyze yearly trends, and DTM analysis was conducted for a total of 1567 papers published from 2016 to 2022.

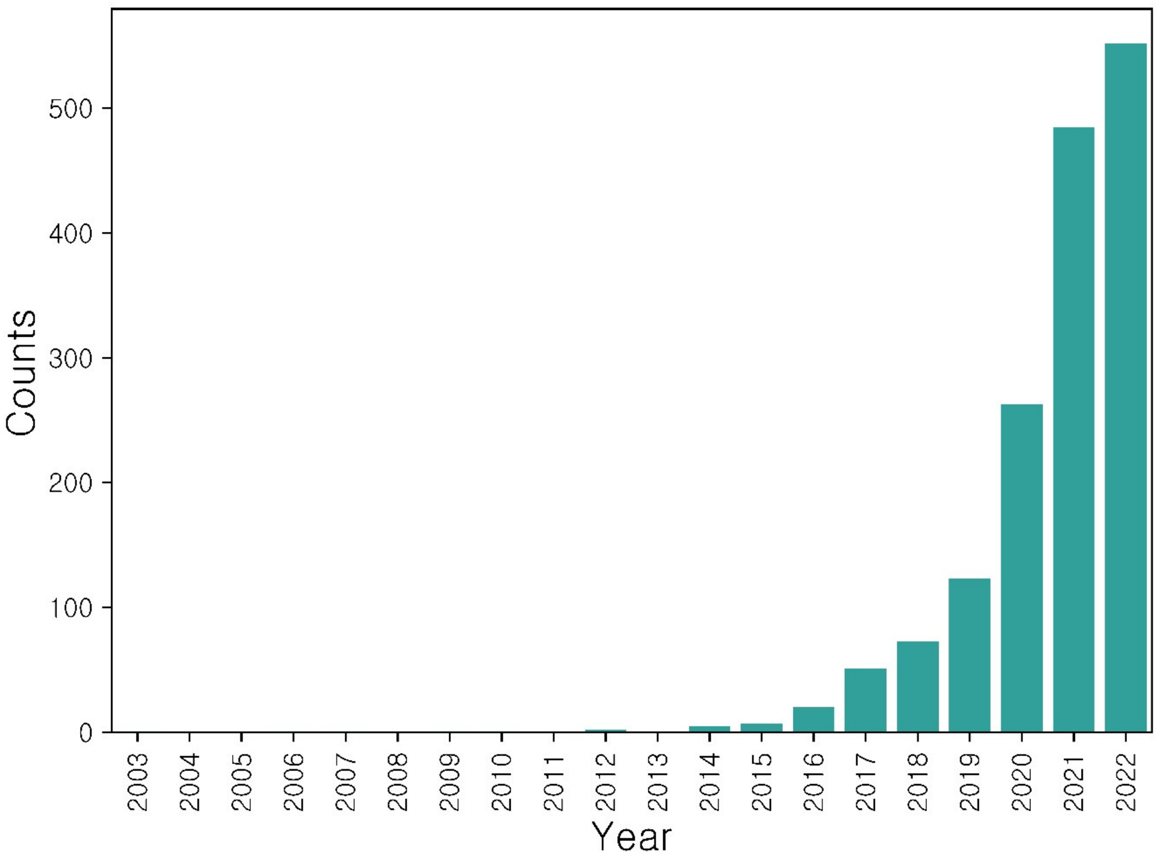

Figure 2. Number of nature-based solutions papers from 2003 to 2022.

Table 1. Number of research papers related to NbS by year.

Year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
No. of research papers	1	0	0	1	1	0	1	1	0	2
Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
No. of research papers	0	5	7	20	51	73	123	263	485	552

Based on the data of the collected papers, basic preprocessing for modeling was performed. First, after removing numbers and special characters, tokenization was conducted to separate the data into tokens, which are the smallest units of words. After the lemmatization process, we extracted only nouns, except for other parts of speech. Additionally, based on the stop words provided by the Python nltk package, and following discussions among researchers, words that were assumed to have no value as keywords were treated as stop words. Finally, the TF-IDF (Term Frequency–Inverse Document Frequency), a weight indicating how important a particular word is within a document, was considered. The higher the frequency of words appearing within one document, the lower the frequency of those words among all documents, so words that appear frequently in most documents can be elected and only characteristic words can be filtered [20]. By calculating the TF-IDF value of each word, we removed words found in 95% of the papers.

2.2. Dynamic Topic Modeling

This study employed dynamic topic modeling (DTM), one of the topic modeling techniques, based on the data of the final selection of research papers. DTM is a topic modeling technique in which time series variables are added based on the latent Dirichlet allocation (LDA) calculation algorithm, which is commonly applied in topic modeling [21]. Since LDA can extract latent topics and topic rates within the document, it is possible to obtain static results [22]. DTM has advantages in that it can complement these limitations of LDA, assume trends over time, and resultantly, identify change patterns in topics and keywords corresponding to the topics [23].

Figure 3 is a reconstructed figure of the DTM algorithm process based on the DTM algorithm presented by Blei and Lafferty, 2006 [21]. First, as for the algorithm process of LDA, Figure 3 shows the process of extracting the entire topic from the document set and analyzing how each document contains the topic. ω refers to the word, which is the observable variable, and α refers to the topic distribution per document, which means the value of the Dirichlet distribution for the distribution of topics for each document. B refers to the word distribution per topic, which means a value of the Dirichlet distribution for the word distribution of each topic. So, α is the density between documents and topics, and the larger the value, the larger the set of documents consisting of a larger number of topics. β is the density between topics and words, and a larger value indicates that topics consist of more words [24]. Here, it is possible to estimate Z, the topic indicator; θ, the mixture proportions; and φ_k, the probability distribution of words per topic through α and β. In addition, ω, the word, can be determined via the estimated φ_k, and resultantly, k, the topic, can be decided as well [25,26]. Here, under DTM, based on the LDA generation process, the topic k at the time t evolves into the topic k at the time $t + 1$.

In this study, we analyzed the DTM research trends by using Python's 'ldaseqmodel' library. Here, the coherence score was calculated via the Gibbs sampling method to estimate the parameters necessary for calculating the optimal number of topics. The coherence score is a quantitative indicator of how consistently topics and keywords of topics are classified [27]. In the context of topic modeling, a higher coherence score indicates more effective topic classification. As a result of modeling learning several times, we finally selected 19 topics with the highest coherence score as the optimal number of topics. In addition, the co-authors named these topics based on the top 20 keywords and papers assigned to each of the 19 topics.

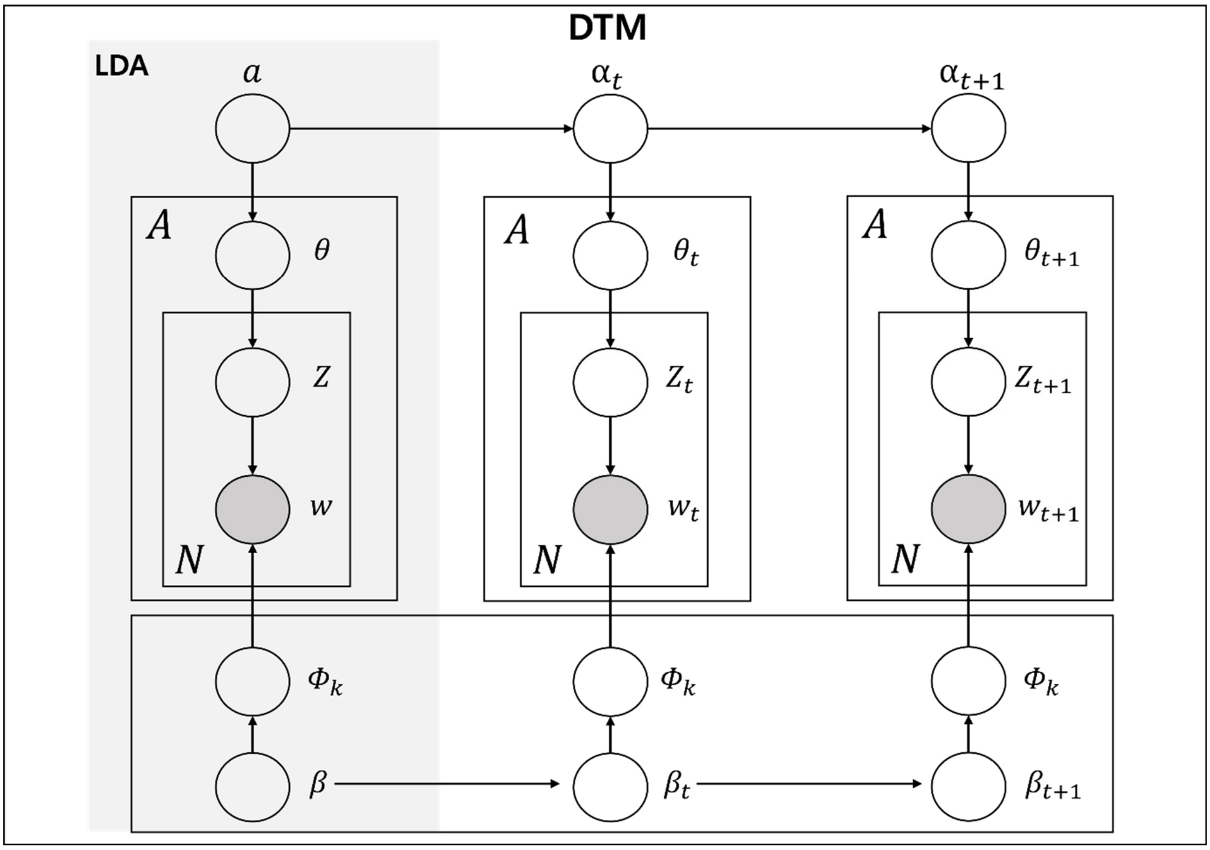

Figure 3. Process of dynamic topic modeling (DTM) and latent Dirichlet allocation (LDA).

2.3. Network Analysis

Network analysis is a method of quantitatively analyzing the network structure created by the interaction and relationship between each node. Through the analysis, it is possible to visualize the interrelationships between nodes and to identify the structural features of the entire network via quantitative indicators. It is also possible to figure out relationships between nodes via network centrality analysis and measure the features of nodes within networks through centrality indicators. Among the indicators, degree centrality and betweenness centrality are representative. Degree centrality is the centrality indicator of the extent to which a particular node is directly connected to other nodes; the more connected the nodes are, the greater the centrality is [28]. Additionally, betweenness centrality is the indicator showing how many specific nodes exist on the shortest path between pairs of nodes existing within the network [29], indicating to what extent a topic is commonly connected to other topics. Methods for community detection are being utilized in large-scale networks. Typically, the Louvain algorithm clusters tightly connected communities within the network structure into clusters [30]. In this study, we created a keyword matrix based on TF-IDF while targeting the top 10 keywords representing each topic to conduct the network analysis. Furthermore, we performed the network analysis by calculating the similarity between topics. Based on the results, clustering between 19 topics was performed using the Louvain algorithm.

3. Results

3.1. Topic Analysis

As a result of analyzing NbS topics via DTM, we finally selected a total of 19 topics with the highest similarity indices (Table 2). During the period from 2016 to 2022, which is the analysis period via DTM, we determined the top 20 keywords by adding the probability values of keywords appearing according to each topic every year. In this manner, the names of 19 topics were clarified based on the top 20 keywords per topic. Topic 1 is coastal restoration, Topic 2 is forest carbon sequestration, Topic 3 is urban ecosystem, Topic 4 is water and ecology, Topic 5 is urban microclimate management, Topic 6 is water management, Topic 7 is ecosystem-based adaptation (EbA), Topic 8 is biodiversity conservation, Topic 9 is sustainable agriculture, Topic 10 is water conservation and restoration, Topic 11 is soil carbon sequestration, Topic 12 is water disaster management, Topic 13 is green therapy, Topic 14 is forest landscape restoration (FLR), Topic 15 is water purification technology, Topic 16 is natural pollination, Topic 17 is land degradation neutrality, Topic 18 is urban greening, and Topic 19 is infrastructure.

As mentioned earlier, although NbS has strengths as it is comprehensive, applicable to various fields, and able to have complex/multiple effects, such a feature makes it obscure to what extent it can be regarded as an NbS activity.

We attempted to classify the defined topics based on the following criteria: what kinds of social issues can be solved, and which fields those topics are related to. When the six defined topics were categorized per sector, the largest number of topics was classified into the "water" sector: Topics 4 (water and ecology), 6 (water management), 10 (water conservation and restoration), 12 (water disaster management), 15 (water purification technology), and 19 (infrastructure). A total of four topics (i.e., Topics 2, 11, 14, and 17) belong to the "forest" sector, and Topics 3, 5, and 18 correspond to the 'urban' sector.

Table 2. Results of dynamic topic modeling.

	Topic 1	**Topic 2**	**Topic 3**	**Topic 4**	**Topic 5**
	Coastal Restoration	**Forest Carbon Sequestration**	**Urban Ecosystem**	**Water and Ecology**	**Urban Microclimate Management**
1	sea	carbon	city	vegetation	air
2	wave	climate	tourism	water	heat
3	erosion	emission	tree	ecosystem	city
4	protection	sequestration	group	design	temperature
5	risk	ecosystem	land	structure	pollution
6	storm	gas	policy	landscape	island
7	sediment	soil	demand	living	climate
8	shoreline	storage	problem	risk	infrastructure
9	dune	mitigation	trading	pollution	vegetation
10	flood	greenhouse	ecosystem	concentration	space
11	engineering	forest	supply	assessment	surface
12	rise	nitrogen	Francis	condition	environment
13	transport	dioxide	Taylor	site	mitigation
14	beach	stock	community	lab	concentration
15	marsh	biomass	space	road	tree
16	cost	rate	regulation	cover	park
17	condition	flux	people	reservoir	urbanization
18	coast	seagrass	activity	grass	scenario
19	restoration	reforestation	risk	activity	reduction
20	reduction	sink	UK	stability	cooling

Table 2. *Cont.*

	Topic 6	Topic 7	Topic 8	Topic 9	Topic 10
	Water Management	**Ecosystem-based Adaptation (EbA)**	**Biodiversity Conservation**	**Sustainable Agriculture**	**Water Conservation and Restoration**
1	wetland	climate	biodiversity	energy	water
2	water	policy	specie	food	river
3	wastewater	adaptation	conservation	technology	canopy
4	plant	ecosystem	ecosystem	cost	condition
5	efficiency	city	diversity	life	season
6	nitrogen	governance	habitat	agriculture	tree
7	oxygen	risk	forest	resource	performance
8	flow	resilience	tree	cycle	pollution
9	demand	decision	reef	economy	stormwater
10	nutrient	practice	protection	water	climate
11	phosphorus	design	restoration	sustainability	groundwater
12	waste	stakeholder	resource	city	cover
13	concentration	disaster	loss	assessment	patch
14	effluent	sustainability	land	production	habitat
15	rate	action	community	performance	site
16	performance	role	composition	environment	concentration
17	lake	landscape	convention	building	farm
18	biomass	community	landscape	farmer	phase
19	cost	measure	function	security	drought
20	greywater	actor	taxon	region	biofilters
	Topic 11	**Topic 12**	**Topic 13**	**Topic 14**	**Topic 15**
	Soil Carbon Sequestration	**Water Disaster Management**	**Green Therapy**	**Forest Landscape Restoration (FLR)**	**Water Purification Technology**
1	soil	water	health	restoration	metal
2	density	flood	community	ecosystem	plant
3	surface	runoff	environment	land	sediment
4	tree	roof	garden	climate	water
5	biochar	catchment	disease	landscape	pollution
6	time	river	water	community	leaf
7	property	risk	space	resource	specie
8	carbon	scenario	population	protection	pollutant
9	temperature	flow	human	river	vegetation
10	vegetation	event	intervention	function	delta
11	concentration	land	exposure	conservation	bay
12	material	climate	factor	biodiversity	condition
13	amendment	stormwater	specie	forest	bioretention
14	size	rainfall	risk	country	ecosystem
15	plant	surface	degradation	policy	wetland

Table 2. *Cont.*

16	space	control	cost	growth	remediation
17	chemical	drainage	oil	region	phytoremediation
18	compost	reduction	group	degradation	velocity
19	water	storm	engineering	risk	attenuation
20	cover	performance	therapy	support	bioremediation
	Topic 16	**Topic 17**	**Topic 18**	**Topic 19**	
	Natural Pollination	**Land Degradation Neutrality (LDN)**	**Urban Greening**	**Infrastructure**	
1	plant	soil	city	water	
2	specie	water	ecosystem	sustainability	
3	stream	erosion	infrastructure	resource	
4	meadow	measure	space	city	
5	pollinator	reduction	climate	innovation	
6	matter	land	indicator	ecosystem	
7	seed	cover	decision	infrastructure	
8	production	agriculture	stakeholder	barrier	
9	crop	loss	assessment	sector	
10	noise	plantation	design	forest	
11	pollination	acceptance	park	supply	
12	lawn	forest	resilience	factor	
13	biomass	redd	information	decision	
14	space	plot	land	irrigation	
15	perception	engineering	greenspace	resilience	
16	pollution	control	performance	condition	
17	field	plant	provision	investment	
18	home	pond	evaluation	action	
19	vegetation	catchment	map	practice	
20	seagrass	vegetation	condition	union	

A large number of topics were found to be related to the water sector. Topic 4 (water and ecology) focuses on ecological restoration in consideration of blue-green networks such as green spaces and landscapes, and highlights management at the level of ecosystems and landscapes. Topic 10 (water conservation and restoration) focuses on the management of water resources via ecology-based technologies. Topic 6 (water management) and Topic 15 (water purification technology) belong to 'water safety.' Topic 15 is characterized by research on environmental purification technologies using plants and microorganisms (bio). For instance, an eco-friendly technique using the features of *Epipremnum aureum* and plant purification abilities such as nutrients and growth can be applied to the process of wastewater treatment [31]. Additionally, there has been NbS research that demonstrates that water quality can be improved via plant purification and microorganisms after installing a floating wetland island (FWI) in a port [32]. Topic 12 (water disaster management), and Topic 19 (infrastructure) are related to water resource systems. Words such as supply systems, infrastructure, and sustainable water supply in cities were frequently found.

The forest sector, which is the focus of this study, can be clearly found in Topics 2 (forest carbon sequestration), 11 (soil carbon sequestration), 14 (forest landscape restoration), and 17 (land degradation neutrality). Regarding Topic 2, carbon, GHG emission reduction, climate change, mitigation, and reforestation were found, which were predictable outcomes in accordance with the definition of forest carbon sequestration. Topic 11 plays a pivotal role in climate change responses, and biochar is highlighted in this topic. Wang et al. (2020) studied GHGs emission reductions in acid soil by improving and utilizing biochar [33]. Peñalver-Alcalá et al. (2021), in addition, proved that the combination of composted urban solid refuse (USR) and biochar improved soil pollution driven by mining metal waste [34]. Furthermore, studies have shown that green infrastructure can provide an alternative to addressing aspects of climate change, including reducing GHGs, improving soil health, and enhancing biodiversity, particularly when applied to diverse agricultural systems [35].

Regarding Topic 14 and Topic 17, there have been numerous studies on NbS activities in the forest sector [36]. The four topics related to the forest sector can be assumed to be related to activities for GHG emission reduction and for achieving carbon neutrality in response to climate change. This finding was found to be consistent with that of previous studies whereby NbS activities related to the forest sector are noticeable in climate change responses, in particular, in the mitigation sector [2,37,38].

Topics 3 (urban ecosystems), 5 (urban microclimate management), and 18 (urban greening) are clearly related to cities. Topic 3 handles overall urban ecosystems and Topic 5 deals with urban heat islands, higher energy consumption for temperature management, and air pollution due to thermal power generation. In terms of solutions for urban social issues, there have been numerous studies on the creation of urban spaces for climate change adaptation to manage the urban microclimate by expanding areas of natural cover such as urban forests and green roofs, and to enhance environmental values, such as mitigating GHGs emissions and global warming. There have been several studies of urban heat island mitigation via green spaces through spatial resolution modeling of the cooling island effect using land cover [39]. It has also been demonstrated that NbS in the form of green infrastructure can mitigate urban heat islands by lowering atmospheric and surface temperatures [40]. A wind-based architectural design method has been proposed in consideration of interactions between wind and the built environment [41]. Topic 18 is about urban greening: urban parks and green spaces are interpreted via the green infrastructure concept, along with a focus on establishing plans at the spatial level. For example, Mexia et al. (2018) demonstrated that vegetation types in urban parks can influence effects such as carbon sequestration, and air and water quality purification [42]; green infrastructure facilities can positively affect urban local ecosystem services. Another study also suggested an NbS using bioenergy and biomass, by replacing lawns in city parks with energy crop plantations [43].

Furthermore, we defined "coastal restoration (Topic 1)," "ecosystem-based adaptation (Topic 7)," "biodiversity conservation (Topic 8)," "sustainable agriculture (Topic 9)," and "natural pollination (Topic 16)." It has been recognized that topics such as coastal restoration, biodiversity conservation and promotion [44], and sustainable agriculture are closely related to the active utilization of NbS, as shown in a large number of reports. In terms of coastal restoration, NbS is widely utilized to respond to climate change, and the findings of the topic modeling in this study also indicate the approach to managing disaster risks. For instance, there is research on NbS alternatives that can effectively and simultaneously manage disaster risks (e.g., floods and coastal erosion), and the restoration of marine ecosystems by restoring coral reefs and utilizing hybrid artificial reefs [45]. Ecosystem-based adaptation (EbA) is a representative type of NbS approach and includes adaptation strategies in consideration of a diversity of social, economic, and cultural benefits for local communities [46]. The IUCN has set human welfare and "biodiversity conservation" as the final goal to achieve through NbS activities [2].

3.2. NbS Research Trends by Year

As for the annual NbS research trends, during the period from 2003 to 2015, there were only 19 NbS-related research papers, which accounts for 1.8% of the total number of papers. During the period from 2016 to 2022, which is the target period in this study, a total of 1567 NbS-related studies were published, with a noticeable increase in 2014, followed by a sharp increase, and the number of studies reached 552 papers in 2022.

This trend is in line with the international community's advancement of NbS through various activities since the 2010s. In 2009, the IUCN submitted a position paper at the 15th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC COP15), suggesting NbS as a solution to climate change responses. The NbS for Climate Manifesto, which was announced at the 2019 Climate Action Summit, emphasized NbS as a necessary tool to respond to climate change; the United Kingdom, which was the chair country at the 26th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC COP26) in 2021, emphasized NbS as one of the catalysts for its 'Race to Zero' campaign. Through these discussions, NbS has been recognized as a means of solving social and environmental issues, and NbS-related research trends are in line with this trend. We examined patterns of trends in research on the water, forest, and urban sectors, which account for a relatively large share of the entire NbS-related research, to identify the NbS research trends by sector (Table 3). Research related to sub-topics in each sector showed an increasing trend. The annually averaged rate of increase was as follows in each sector: 1.02% for water, 0.97% for forests, and 0.64% for cities. The average shares of NbS research compared to the total number of NbS research papers from 2016 to 2022 found in each sector were as follows: approximately 29.6% for water, 15.6% for forest, and 21.1% for cities. As for the ratio of the annual publications in each field to the total number of research papers by year, the urban sector showed a decreasing tendency, whereas the water sector accounted for a relatively large proportion compared to NbS research in the forest and urban sectors. However, it is noteworthy that the proportion of research papers in the forest sector among total research papers has been steadily increasing since 2020.

Table 3. Number of articles related to each sector on a yearly basis determined via dynamic topic modeling.

	Water NbS							Forest NbS					Urban NbS			
Topic No./Year	4	6	10	12	15	19	Sub-total	2	11	14	17	Sub-total	3	5	18	Sub-total
2016	1	0	0	0	0	2	1	0	0	2	0	2	0	1	4	5
2017	1	1	2	2	0	8	6	1	2	2	3	8	2	4	5	11
2018	2	3	2	15	1	3	23	3	4	5	0	12	1	5	5	11
2019	6	5	2	13	3	6	29	3	4	8	4	19	3	6	26	35
2020	7	17	7	28	5	18	64	9	2	16	7	34	8	17	26	51
2021	16	35	14	40	13	40	118	17	15	41	14	87	12	20	49	81
2022	20	45	20	48	16	55	204	24	18	56	19	117	17	28	53	98
total (rank)	53 (8)	106 (5)	47 (9)	146 (2)	38 (13)	132 (3)	522	57 (7)	45 (11)	130 (4)	47 (9)	279	43 (12)	81 (6)	168 (1)	292

Figure 4 indicates the year-over-year annually averaged rate of increase by sector. Compared to 2016, when NbS studies began to appear in earnest, the year-over-year annually averaged rate of increase in 2017, when NbS research began to emerge in earnest, was quite large, and that in 2018 dropped significantly. The number of NbS-related papers in the water sector showed a year-over-year decline, but the number of NbS-related papers in the forest sector showed a steady increase from 2018, and the year-over-year increase in 2021 was the largest. The number of NbS-related papers in the urban sector showed the largest year-over-year increase in 2019, but following that increase, the year-over-year growth rate showed a continuously decreasing trend. The forestry sector presented the largest year-over-year increase in 2022.

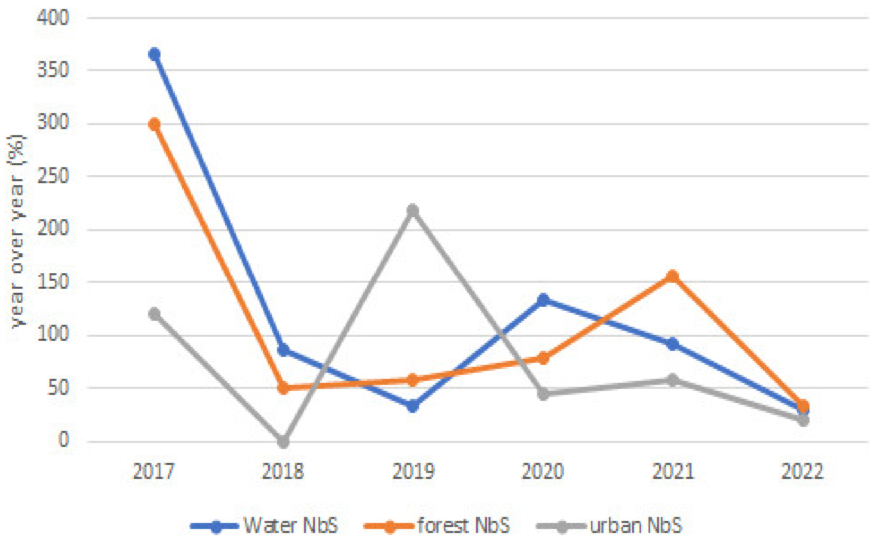

Figure 4. Year-over-year annually averaged rate of increase by sector.

3.3. Topic Network Analysis Results

As a result of network analysis, when arranging topics based on degree centrality and betweenness centrality indices, Topics 4, 12, 1, and 15 were all found to be related to water resources (Table 4). The NbS research trend showed that most topics in the water resource sector had high degree centrality and many directly connected links. Additionally, Topics 15, 4, and 12 showed high betweenness centralities and were located on the shortest path between other topics, indicating their mediating role in NbS research topics.

Table 4. Ranking of degree centrality and betweenness centrality of topics.

Topic	Degree Centrality	Topic	Betweenness Centrality
4	0.3333	15	0.2317
8	0.3333	8	0.1521
12	0.3333	4	0.122
1	0.2777	12	0.1132
15	0.2777	2	0.0987
7	0.2222	17	0.0981
11	0.2222	1	0.0751
13	0.2222	7	0.0551
14	0.2222	14	0.0499
18	0.2222	13	0.0484
2	0.1666	18	0.0366
3	0.1666	3	0.0294
6	0.1666	11	0.0202
9	0.1111	6	0.0007
10	0.1111	5	0
17	0.1111	9	0
5	0.0555	10	0
16	0.0555	16	0
19	0.0555	19	0

As for NbS-related topics in the forest sector, except for Topics 4, 8, 12, and 15, which commonly ranked at the top in degree centrality and betweenness centrality, Topic 11 (soil carbon sequestration) and Topic 14 (forest landscape restoration) showed high degree centrality, confirming that they were directly related to other topics. Topic 2 (forest carbon sequestration) and Topic 17 (land degradation neutrality) also showed high betweenness centrality, indicating that the corresponding research topics served a role in connecting NbS research in other fields.

We clustered the 19 topics derived from the topic modeling results into five groups and analyzed each topic through the network between the groups. As a result, we classified a total of five groups via clustering, as shown in Figure 5. Nodes indicate the degree centrality of each topic and links indicate the similarity between topics. The size of a node increases as the degree centrality of each topic increases. And the length of a link becomes shorter as the similarity of between topics increases. Topics with the same color of nodes were classified into the same group by the Louvain algorithm. Group 1 encompasses Topics 5 (urban microclimate management) and 7 (ecosystem-based adaptation). Group 2 includes a total of seven topics: Topics 1 (coastal restoration), 6 (water management), 15 (water purification technology), 16 (natural pollination), 17 (land degradation neutrality), 18 (urban greening), and 19 (infrastructure). Group 3 encompasses a total of five topics: Topics 2 (forest carbon sequestration), 8 (biodiversity conservation), 11 (soil carbon sequestration), 12 (water disaster management), and 14 (forest landscape restoration). Group 4 has a total of three topics: Topics 3 (urban ecosystems), 4 (water and ecology), and 10 (water conservation and restoration). Group 5 covers Topics 9 (sustainable agriculture) and 13 (green therapy).

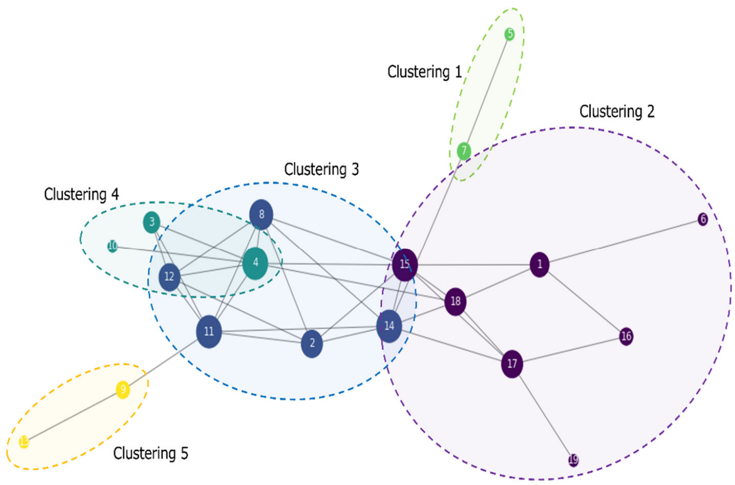

Figure 5. Clustering of networks of 19 topics in the NbS sector.

Figure 5 indicates that Group 3, with the most forest-related topics among the five groups, is somewhat closer to Group 2's Topic 15 (water purification technology) and Group 4's Topic 4 (water and ecology) than other topics and has short links. This implies that NbS research in the forest sector, such as forest carbon sequestration, soil carbon sequestration, and forest landscape restoration, is related to biodiversity conservation and NbS research in the water sector, such as water purification technology, and water and ecology.

4. Discussion

In this study, we applied DTM and network analysis to the text data of titles and abstracts of research papers searched using the term "nature-based solutions" in the database provided by Scopus to examine NbS research trends. We analyzed the resulting 1567 research papers from 2016 to 2022, which are the targets for the DTM analysis.

First, based on the results of DTM, we quantitatively analyzed all the time periods for research related to NbS. It is significant that we could define the scope of the NbS activities using the results obtained upon classifying them into 19 topics.

Second, we found that the major activities of NbS are water, forest, and urban. We first classified the defined topics based on the following criteria: what social issues they were designed to solve, and which fields they were related to.

Most topics were related to water: Topics 4 (water and ecology), 6 (water management), 10 (water conservation and restoration), 12 (water disaster management), 15 (water purification technology), and 19 (infrastructure). Water-related topics were grouped into the middle classification: water supply (Topics 4, 10, and 19), water management (Topics 6 and 15), and disaster reduction (Topic 12); the outcomes were found to be consistent with the classifications for existing water management and of NbS activities [47]. The purpose of water management was found to be water supply, water quality management, and disaster reduction, as mentioned earlier; NbS was utilized at the management level, in particular, for afforestation, forestry, restoration and protection, and wetland restoration. It was also possible to confirm the linkages between the water and forest sectors. Also noteworthy, regarding Topic 6 (water management), the purification and management of wastewater is not simply about supplying and managing sustainable water, but is related to achieving carbon neutrality [48,49]. There have been more attempts to find solutions for achieving carbon neutrality through eco-friendly energy from biotechnologies, and there have been numerous studies on producing biomass from wastewater [50–53]. This is the case based on NbS basic principles, in which nature is fully employed as a solution to issues faced by human beings.

There are four topics related to “forest”: Topics 2 (forest carbon sequestration), 11 (soil carbon sequestration), 14 (forest landscape restoration), and 17 (land degradation neutrality). The activities of the topics related to the forestry sector are all connected to climate change mitigation. In particular, it is necessary to note the reconfirmed relationship between Topic 11 (soil carbon sequestration) and biochar. Several previous studies already prove that there have been climate change mitigation effects from biochar [54,55]; biochar has attracted attention due to its potential to be utilized as a tool for NbS in terms of climate change responses in the land and green space sector. Many developing countries have plans to utilize mitigation outcomes through various removal activities for their Nationally Determined Contribution (NDC). However, they lack the technology and financial resources to execute the project on their own. Implementing cooperation projects with developed countries under Article 6 of the Paris Agreement is a practical alternative. Therefore, it is necessary to add not only afforestation and reforestation, which are approved activities by UNFCCC, but also various land-based NbS activities as removal activities.

Topics related to “urban” are more evident in Topics 3 (urban ecosystems), 5 (urban microclimate management), and 18 (urban greening). NbS activities related to cities clearly show the ultimate goal of improving human well-being. Various activities (e.g., the betterment urban thermal environment and air pollution, the lowering of energy demand, and the creation of green spaces and green infrastructure) are also closely related to NbS activities in the forest sector. The frequency of keywords extracted from each topic indicated that keywords related to forests (e.g., vegetation, forest, and trees) were at the top of the list. Despite this, it was possible to infer a close relationship between forests and cities [56–58].

Finally, as a result of conducting a network analysis to identify the connection between topics, we found that the topics in the field of water resources had an overall influence on NbS research and that the forest-related NbS topics also had complementary relationships with research topics in other fields. NbS has strong relationship with climate change mitigation because of the activities of afforestation and reforestation [9,36,59–61]. However, we found that NbS is readily integrated into other sectors, generates complex effects, and is applied to various fields for climate change adaptation and risk/disaster reduction.

After clustering the networks of the 19 topics separately, they were clustered into five groups, of which Group 3, with the most forest sector-related topics, tended to be closer to the water-related topics in the other groups, especially Topic 15 (water purification technology) in Group 2 and Topic 4 (water and ecology) in Group 3. This implies that NbS research in the forest sector, such as forest carbon sequestration, soil carbon sequestration, and forest landscape restoration, is related to water purification and ecological issues among water-related NbS research [10,62].

Additionally, as for NbS-related topics in the forest sector, except for Topics 4, 8, 12, and 15, which commonly ranked at the top in degree centrality and betweenness centrality, the topics that are highly ranked in degree centrality were Topics 11 (soil carbon sequestration) and 14 (forest landscape restoration). This indicates that NbS research in soil carbon sequestration and forest landscape restoration is directly linked to topics related to water resources, and topics in other sectors.

Moreover, Topics 2 (forest carbon sequestration) and 17 (land degradation neutrality) ranked high in betweenness centrality, because these topics serve a mediating role between NbS studies due to their common connections between other research fields. In other words, it can be found that forest carbon sequestration and land degradation neutrality play an important role in mediating research fields since they are related to other fields.

Despite NbS being widely studied, quantitative analyses of NbS research have hardly been done. This study analyzed the temporal change in global NbS research via DTM and network analysis. We found that regarding the types of NbS research activities that exist across the 19 topics, the major activities of NbS are water, forest, and urban, and there are patterns of connections between topics. It is generally accepted that NbS is readily integrated into other sectors and has complex/multiple effects [63–68], which was demonstrated through DTM and network analysis.

Topic modeling has the advantage of being able to identify research trends through the efficient analysis of a large number of documents. However, it has a limitation in that it is difficult to completely exclude the subjectivity of researchers, because the process of inferring topics from a combination of words, topic labeling, and detailed interpretation depends on the researchers' background knowledge. There is another limitation of over-reliance on words of high frequency. In the future, it would be possible to provide more useful NbS research trend analysis results if there is sufficient analysis of details by field and topic.

5. Conclusions

In this study, we analyzed NbS-related research trends and interconnections between fields via DTM and network analysis. Despite the limitation that the researchers' subjective interpretation cannot be completely excluded, DTM analyzed a large amount of data and produced significant results. As a result of DTM, we found a total of 19 topics. These topics can be mainly classified into water, forest, and urban. It was also possible to confirm close interconnections between water, forest, and urban based on the frequency of keywords by topic, which was re-confirmed by the network analysis. NbS is a nature-based activity and a means to contribute to solving social issues. In this sense, it was possible to find evidence that is consistent with the findings of previous studies in which NbS activities are highly interconnected and cannot be explained separately. In particular, due to the multi-functions of forest ecosystem services, the forest sector showed a close relationship with other sectors, as well as a remarkable increasing trend in NbS research in the forest sector. By suggesting the achievements and possibilities of NbS in the liaison between forest and other sectors, future studies should contribute to the wider utilization of forests as a convergent tool for climate change response and solutions to various social issues.

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