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Review

Current Issues in Combating Chemical, Biological, Radiological, and Nuclear Threats to Empower Sustainability: A Systematic Review

Małgorzata Gawlik-Kobylińska

Command and Management Faculty, War Studies University, Chruściela 103, 00-910 Warsaw, Poland; m.kobylinska@akademia.mil.pl

Featured Application: Potential application in innovations and management sciences, strategy for sustainable development.

Abstract: Combating chemical, biological, radiological, and nuclear (CBRN) threats with novel solutions reduces disasters and accident risks and, at the same time, aids sustainability. This research aims to identify the innovations in combating CBRN threats and verify how they fall within the scope of the Sustainable Development Goals (SDG). The study relies on mixed-method research, including bibliometrics and text-mining used to identify clusters, most frequent words, and codes. The material for the research was 156 publications from the Scopus database from 2017 to April 2022. From the analytical process, textual data served as the indicators of the innovations' directions driven by SDGs. The research results indicated that innovations for combating CBRN threats support sustainability mainly in health and environmental areas, specifically in: SDG 3: Good Health and Well-being; SDG 6: Clean Water and Sanitation; SDG 14: Life Below Water; SDG 15: Life On Land. The research contributes to the landscape of innovations serving sustainable development. Further studies may focus on narrower perspectives, such as environmental protection and health innovations. There can also be concerns about the dark side of CBRN innovations and technologies of dual use.

Keywords: CBRN agents; hazards; toxic industrial materials; chemical warfare agents; sustainable development goals; environment; health

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1. Introduction

Excess amounts of hazardous substances in the environment may hinder the development of a sustainable world. Man-made disasters, natural catastrophes, heavy metals in industries, pesticides in agriculture, relying on non-renewable sources of energy, and even weather conditions are all factors that contribute to the distribution of hazards, which cause severe damage to humans and the environment. Land, soil, water, air, noise, and plastic/microplastic pollution put tremendous pressure on natural resources and the environment [1]. This situation can lead to spreading of diseases, and pathogens such as SARS-CoV-2, further facilitated by migrations [2,3].

Next to the long-term processes posing risks to the environment and human health are incidents caused by CBRN (chemical, biological, radioactive, and nuclear) agents. They can be created intentionally by man, by accident, or by natural sources. It should be added that CBRN hazards are often associated with a weapon of mass destruction [4], specifically when used in terrorist activities, warfighting, or ethnic conflicts [5]. History can provide several examples of incidents caused by CBRN agents. Radiological incidents are among the most disastrous, such as the Three Mile Island accident in 1979, the Chernobyl disaster in 1986, and the Fukushima Daiichi catastrophe in 2011 [6]. Other examples include the release of methyl isocyanate by a chemical plant in Bhopal, India, in 1984 [7]; an attack on the Tokyo subway in 1995 with sarin gas [8]; deliberate contamination of postal items with anthrax in the US Postal Service (New Jersey, 2001) [9]; melamine (a chemical usually used in plastics) used in milk in China, 2008 [10]; and the discovery of caustic, saline red mud (pH 12) that contained toxic trace metals beyond the acceptable levels in Hungary, Ajka (4 October 2010) [11]. Often, tragic catastrophes inspire the creation of legal regulations to counteract similar events. For instance, in Seveso, Italy, a minor chemical manufacturing plant accident occurred, leading to the residential population's greatest exposure to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) [12]. The accident triggered some scientific studies and safety regulations in the industry. Seveso II is the name given to the EU industrial safety regulation. Currently, CBRN threats are the subject of numerous analyses in connection with the war in Ukraine [13], and the probability of releasing dangerous toxic industrial resources (chemical and radioactive) due to warfare is very high.

One solution to counter the threats is an ongoing necessity to create an array of innovative solutions for risk mitigation and defense against hazards. Innovation is understood as duplicable knowledge considered new in the context in which it is introduced and demonstrated [14]. It can be treated as an outcome, a process, and a mindset [15]. According to data presented by European CBRN Innovation for the Market Cluster—ENCIRLCE, innovations in CBRN involve over 1000 projects and activities (funded by, e.g., Horizon 2020, European Defence Agency, NATO, Directorate General for International Cooperation and Development—Centre of Excellence, Erasmus+, European Regional Development Fund) [16]. The topics of innovations include various aspects: CBRNe (CBRN + explosives) detection in containers [17], detection, identification, and monitoring of chemical hazards in the environment [18], reconnaissance in CBRNe incidents [19], CBRN personal protective clothing [20], laboratory capacities in Africa against COVID-19 and other epidemics, CBRN protection of critical infrastructure, and transportation of dangerous goods by road and rail [21].

In combating CBRN hazards, innovations play a pivotal role in supporting the development of a sustainable world, specifically the Sustainable Development Goals (SDG): to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity [22]. Therefore, in the context of the existing threats, as policies and actions should be concentrated on sustainability, it is vital to investigate the directions of the innovations. The investigation will contribute to the landscape of CBRN innovation. Presently, they are traced by leading organizations, such as the MASC-CBRN—an initiative funded by the European Commission (promotes the development of an integrated and comprehensive approach to CBRN events) [23], or CBRN Central, an expert portal on the latest news on homeland security and preparedness for CBRN and explosive (CBRNe) threats [24].

The article aims to identify and analyze innovations related to CBRN threats that can contribute to sustainable development. The study relies on mixed-method research: bibliometrics, as well as computer-aided and manual analyses of data retrieved from the Scopus database from 2017 to 1 April 2022. The following research question (RQ) and corresponding hypothesis (H) were formulated:

RQ: What are the directions of CBRN innovations which can support sustainability?

H: Due to the growth of pollution, migrations, and climate change threatening biodiversity [25,26], it is hypothesized that the directions of innovations in the field of CBRN will concern mainly environmental and health issues. The Sustainable Development Goals related to the notions will be supported.

The rest of the paper is organized as follows: The next section discusses the classification of CBRN agents to provide a generic view of the topic, and then the methodological part describes the process of material retrieval and data analysis. In the Results, the bibliometric data and text exploration data are presented using NVivo and VOSViewer tools. Finally, codes and selected innovations described in the literature are juxtaposed with the Sustainable Development Goals. The last part, the discussion, which precedes brief conclusions, concentrates on the relevance of the topic and future research directions.

2. Overview of CBRN Agents

CBRN agents are classified into many areas. The most general classifications divide them into substances used for combat purposes and those used in industries as toxic industrial materials (TIMs). It should be noted that the term TIMs is not synonymous with industrial chemicals (TICs), as it also includes toxic industrial biologicals (TIBs) and toxic industrial radiologicals (TIRs) [27].

Chemical agents can be categorized as TICs and chemical warfare agents (CWAs). Toxic industrial chemicals (TICs) include sulfur dioxide (SO2), hydrogen cyanide (HCN), hydrogen sulfide (H2S), ammonia (NH3), and chlorine (Cl2) [28]. At the same time, chemical warfare agents (CWAs) encompass, for instance, cyclosarin (GF), VX (venomous agent X), tabun (GA), soman (GD), sarin (GB), and sulfur mustard (HD) [29]. Biological agents can be divided into categories A, B, and C. Category A agents are easily transmitted, resulting in high mortality, may cause public panic, and require extraordinary actions. Their examples are anthrax, smallpox, botulism, plague, tularemia, and viral hemorrhagic fevers. Category B agents are moderately easy to disseminate, result in moderate morbidity and low mortality rates, and require enhanced diagnostic capacity surveillance. They can be salmonella, typhus, or ricin. Category C agents are available everywhere, easy to produce and disseminate, and may result in high morbidity and mortality rates. They encompass the Nipah virus and hantavirus [30]. Regarding radiological agents, there are four major types of radiation: alpha (a relatively large subatomic particle—a helium nucleus, within a short range in the air, but it is potentially hazardous in the case of organism contamination); beta (relatively small subatomic particles consisting of electron/positron, within several meters range in the air); neutrons (connected to nuclear materials and the fission process, which are highly penetrating and vary in damage, depending on the energy of the neutrons); and gamma rays which penetrate intensely within a range of kilometers and consist of high-energy electromagnetic waves [31]. Apart from this general classification, there are other views. For instance, according to Bland (2009), chemical agents include nerve agents (organophosphorus compounds), blistering agents (vesicants), cyanides (also known as blood agents), pulmonary agents (choking or lung-damaging agents), incapacitants (mental and physical), toxic industrial chemicals (TICs), riot-controlled agents (RCAs, used by law enforcement agencies), and pharmaceuticals (illicit and commercial drugs). Within biological agents, there are bacteria, including chlamydia and rickettsia, viruses, fungi, and toxins, which can be derived from bacteria, fungi, plants, and animals (venom). Concerning radiological and nuclear hazards, Bland distinguishes four main types of radiation: alpha, beta, neutrons, and Gamma/X-ray radiation and notes that neutrons are usually only present during the nuclear process [32].

The classifications are not entirely clear because many substances that are warfare agents can also be used in industries and medicine, e.g., hydrogen cyanide (HCN), phosgene (COCl2), and botulinum toxin. In addition, some plant protection products have a high level of toxicity, e.g., sarin. Therefore, the essential division category is the purpose and method of using these hazardous substances, which can be described as "dual-use substances". Regardless of intentional or accidental release, the characteristics above reveal the serious harms CBRN agents can cause to human health and the environment. This is due to the different persistence of a substance—it can disappear a relatively short time after exposure or remain in the environment for a longer time. The danger is also related to various routes humans can be exposed to CBRN agents, such as inhalation (gas, vapor, aerosol, droplets, or smoke), ingestion, skin (intact skin, inoculation—intentional break in the skin in order to introduce a CBRN agent, wounds), mucous membranes, or eyes [32].

It should be noted that the continuing process of global industrialization opens up the broader possibilities of accidental release or deliberate misuse of TIMs. If CBRN agents are considered weapons of mass destruction, international legislation prohibits developing, using, and testing these weapons.

3. Materials and Methods

In this study, bibliometric and text-mining analyses were used. Bibliometric analysis, which describes patterns in publications within a given period or body of literature using quantitative analysis and statistics, provided an international research perspective. The text-mining process extracted hidden information from non-structured to semi-structured data [33]. The stages of text mining were: information retrieval (Boolean search rules applied), text analysis (stop words elimination, automatic clusters identification, word frequency queries, and manual coding), information extraction, visualization (presentation of tables and word clouds), and summarization. It is worth mentioning that bibliometrics was possible to perform after the information retrieval stage.

The first step, information retrieval, allowed for preparation of materials for further analyses. The material used in the research comprised text data (titles, abstracts, keywords), which were retrieved from the Scopus database. The period of analysis was from 2017 to 1 April 2022. Specific keywords and Boolean operators "AND" and "OR" were used to extract the desired content. The formulas were: (TITLE-ABS-KEY (innovation*) AND TITLE-ABS-KEY (CBRN) OR TITLE-ABS-KEY (weapon AND of AND mass AND destruction) OR TITLE-ABS-KEY (chemical AND hazards) OR TITLE-ABS-KEY (biological AND hazards) OR TITLE-ABS-KEY (nuclear AND hazards) OR TITLE-ABS-KEY (radiological AND hazards)) AND (LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017)). All documents were considered (articles, reviews, conference papers, book chapters, conference reviews, notes, books, editorials). Before achieving the final data, thematic accordance was manually checked as an essential criterion for record inclusion or exclusion. However, there were no records removed. The number of identified records was 156. This set was used for the bibliometric analysis that involved the year of publication, publications by country or territory, Scopus subject area, and type of documents. In a further step, the final text data set (.txt), comprised titles, keywords, and abstracts from 156 records, was created. It comprised the material for analyzing the most frequent words, portmanteau words, and clusters. The tools for the task were the VOSViewer application—for clusters and most frequent portmanteau words—and NVivo Word Frequency Query (WFQ)—for single words only. Both applications automatically created the most frequent categories. In these two processes, stop words (irrelevant words) such as "also", "unit", "example", "study", article", "ref.", etc. were eliminated.

Additionally, the text data file was coded manually (assigning a label to a data section). Coding turned qualitative data (texts) into quantitative data (codes) [34]. The process of coding was descriptive. This means that the codes summarize the topic of the excerpt, i.e., a researcher asks what the topic is about [35]. It should be noted that one text snippet could belong to more than one code. This means that, finally, the codes became interconnected.

While the automatic analyses aimed at the identification of basic trends that emerged from the explored texts, the manually created codes were used to verify the clusters, portmanteau words, and word frequency query results; they provided a more complex view of the innovations' directions. Furthermore, the codes were used to analyze the innovations' contributions to SDG's realization. All the processes required the researcher's interpretation of words and clusters. Results of automatic analyses were visualized in the form of word clouds, tables, and diagrams.

Summarization was the last stage of the research. The detailed research design is presented in Figure 1.

Worth mentioning is the fact that the Scopus database provides only a limited set of publications. The search in the Web of Science with the exact keywords (innovation* (Topic) AND weapon of mass destruction (Topic) OR chemical hazards (Topic) OR biological hazards (Topic) OR radiological hazards (Topic) OR nuclear hazards (Topic)) and publication timespan, resulted in 3166 positions. Although the number of records is much greater, such a set might be problematic: the manual search for irrelevant records is more time-consuming and requires the engagement of more researchers. Moreover, Scopus is perceived as more convenient for practical use: it provides broader and more inclusive content coverage [36]. For this reason, the research design relies on the Scopus database only.

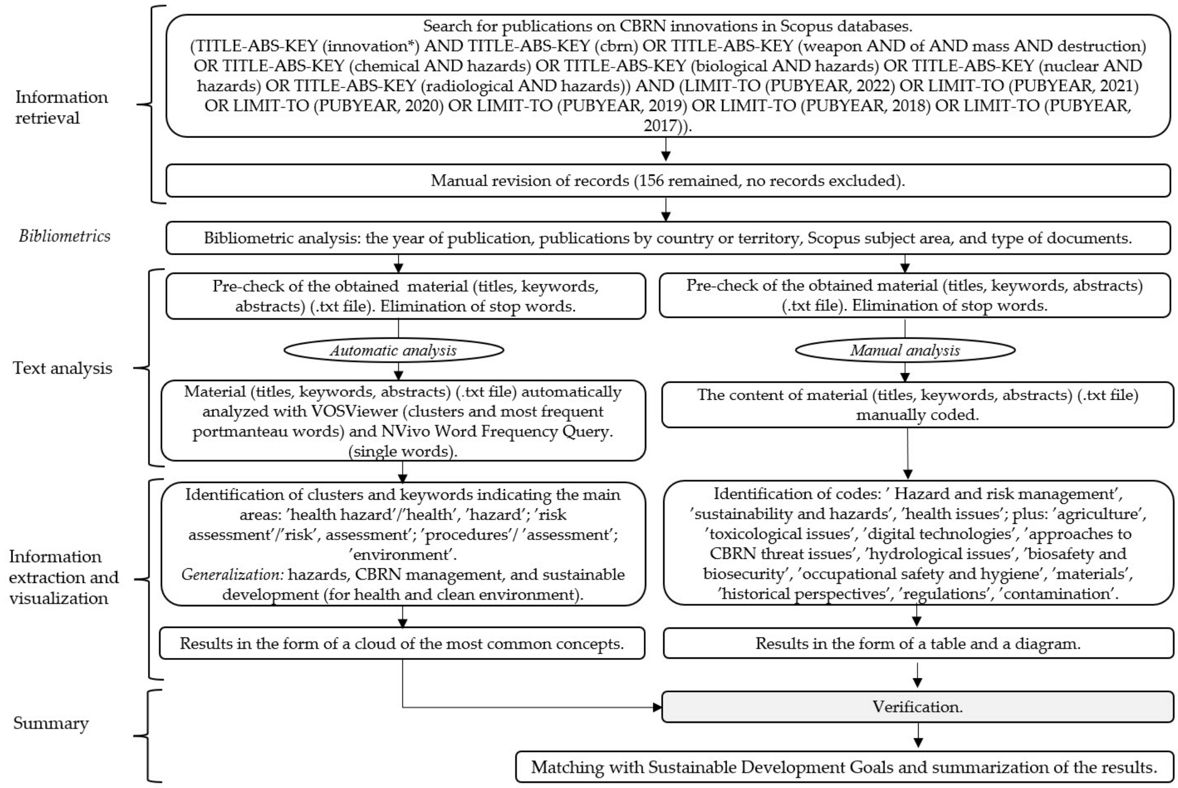

Figure 1. Research process design.

4. Results

The 156 publications retrieved from the Scopus database were analyzed for the year of publication by country or territory, subject area, and document by type. The first bibliometric analysis concerns publications by year (Figure 2).

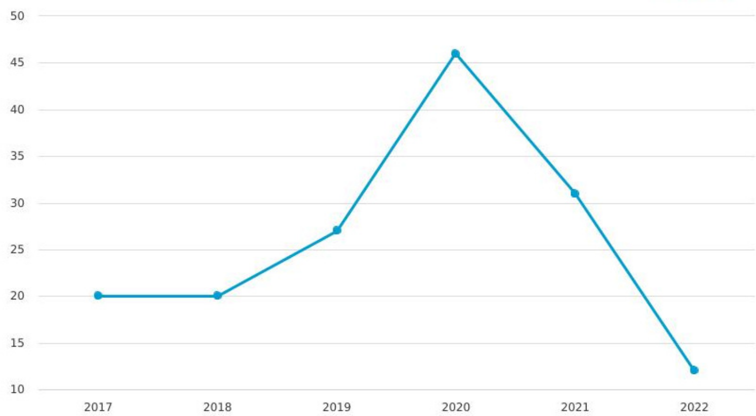

Figure 2. The number of documents by year.

It can be noticed that there was a year-by-year growth in the interest in CBRN innovations; the peak was in 2020. Search results for 2022 are for the first quarter only. It can be implied that the pandemic situation might trigger interest, particularly in biological hazards and their countermeasures, or the number of policies and programs (e.g., European Commission) that were in line with sustainable development. Alternatively, chemical threats such as Syrian chemical weapons activity noticed since 2012 [37] or terrorist attacks [38] may trigger interest. Further observation of the timeline is required to state if there is a drop or increase in interest after the indexation of publications.

Figure 3 represents publications by country or territory.

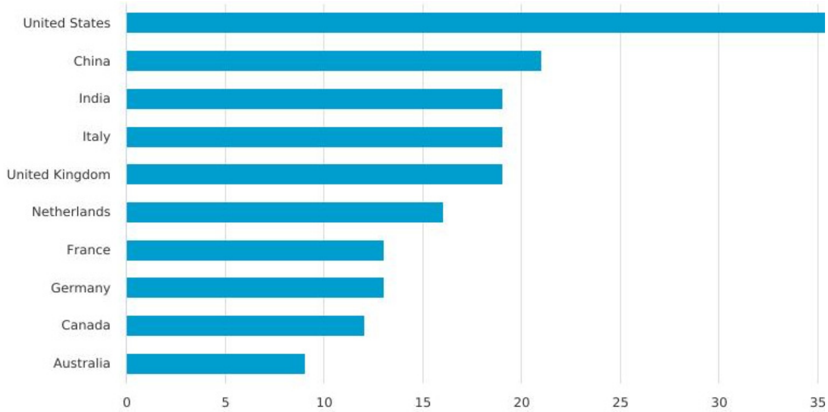

Figure 3. Documents by country or territory.

The CBRN innovations' most prominent publication activities were from the United States and China. India and European countries: Italy, the United Kingdom, the Netherlands, France, and Germany also achieved high records in publications activity. The subsequent analysis concerns the Scopus subject area (Table 1).

Table 1. Documents by subject area.

Documents by Subject Area	Number
Medicine	39
Engineering	37
Biochemistry, Genetics, and Molecular Biology	28
Chemical Engineering	17
Materials Science	16
Agricultural and Biological Sciences	14
Energy	14
Pharmacology, Toxicology, and Pharmaceutics	13
Chemistry	11
Immunology and Microbiology	7
Computer Science	6
Earth and Planetary Sciences	5
Physics and Astronomy	5
Arts and Humanities	4
Health Professions	4
Decision Sciences	3
Multidisciplinary	3
Business, Management, and Accounting	4

Medicine (39), engineering (37), biochemistry, genetics, and molecular biology (28) were the most crucial subject areas. Medical journals cover emergency medicine, which applies to CBRN topics. Engineering might refer to civil, electrical, and mechanical engineering issues, so this term is broad and can cover many papers on innovations. Biochemistry, genetics, and molecular biology issues could be of high interest in cases of both health and environmental aspects. The final bibliometric analysis refers to document type (Table 2).

Articles (68), reviews (39), conference papers (20), and book chapters (17) were the most popular publication types describing CBRN innovations.

Table 2. Documents by type.

Document Type	Number
Article	68
Review	39
Conference paper	20
Book chapter	17
Conference review	6
Note	3
Book	2
Editorial	1

The next stage relied on processing the file with titles, abstracts, and keywords from 156 publications. It aimed to identify the most frequent portmanteau words and clusters. The full counting method was applied, and the type of analysis was co-occurrence. The total link strengths correlate with higher occurrences. From the 2675 keywords, 77 met the threshold. Then, the selected portmanteau words and clusters were manually selected (removing words that did not provide a clear answer concerning the crucial terms accompanying created innovations). They included "male", adult", "middle-aged", and "United States". From the 77, the visualization will cover the 37 most common concepts gathered in four clusters. Figure 4 visualizes the retrieved most frequent portmanteau words and clusters (marked in color) in the VOSViewer map.

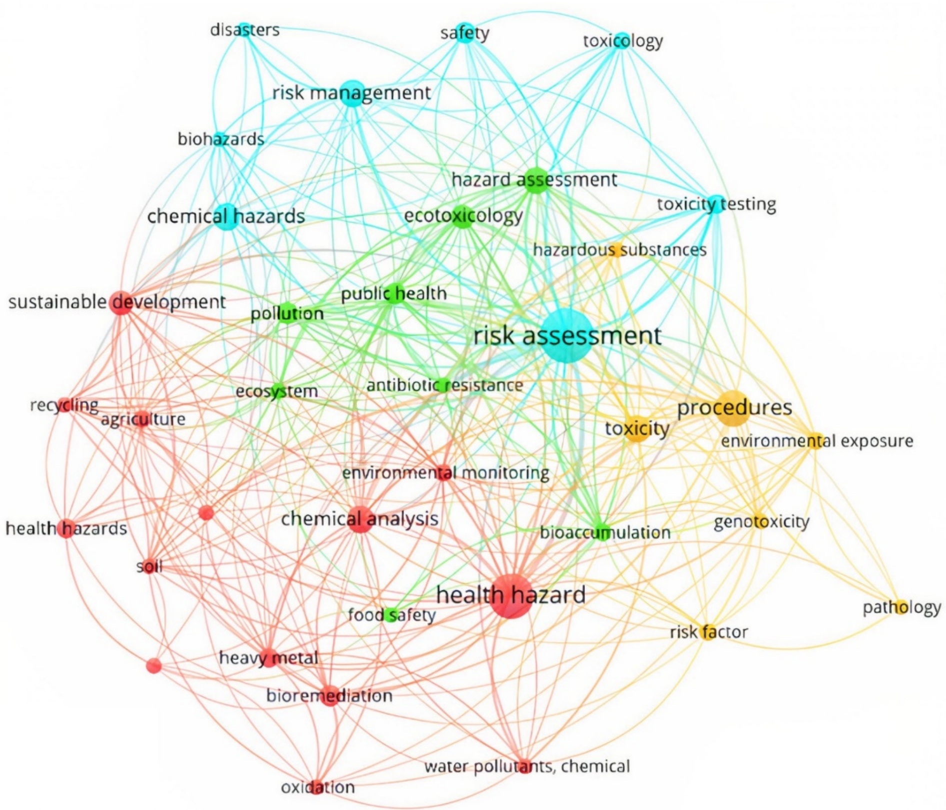

Figure 4. The VOSViewer analyses of titles, abstracts, and keywords from 156 documents indexed in the Scopus database.

The interconnected mind map shows the regularities in the frequency of the terms and the correlations between them. There are four groups of clusters with two dominating: the most popular is "health hazard" (red), and the second is "risk assessment" (blue). The red cluster comprises environmentally oriented and chemical topics, specifically "chemical analysis", "sustainable development", "agriculture", "environmental monitoring", "heavy metal", or "water pollutants". In the blue cluster, apart from "risk assessment", the two most popular notions are "risk management" and "chemical hazards". This cluster focuses on crisis management issues such as "toxicity testing", "risk management", "disaster", "safety", "chemical hazards", and "biohazard", which are the most popular among CBRN threats. The yellow cluster put forwards "procedures" and "toxicity". Here, environmental and toxicity topics prevail. In the last cluster, green, there are various topics from "hazards assessment", "public health", "pollution", "ecotoxicology", to "antibiotics resistance", and "food safety". It is not possible to identify its direction. In the fourth cluster of words, "hazard assessment" and "ecotoxicology" are highlighted. This cluster map proves that chemical and biological threats are very frequent regarding health and the environment.

Analyzing the map and generalizing the identified concepts, regardless of the word frequency, can interfere with the main themes: hazards, CBRN management, and sustainable development (for health and a clean environment). Regarding the hazards, there are general concepts, e.g., "pollution", "health hazards", "hazardous substances", and "water pollutants". Hazards of certain types are most often chemical (but biological ones also appear): "chemical hazards", "toxicity", "toxicology", "heavy metal", "bioaccumulation", "genotoxicity", "chemical", "oxidation", etc. Concepts related to CBRN management are "environmental exposure", "environmental monitoring", and "toxicity testing". The remaining words are closely related to the intended use of available resources for health and a clean environment, hidden under the terms "sustainable development", "bioremediation", "recycling", "agriculture", and "ecosystem".

The same file was processed by the NVivo software (Word Frequency Query function, which allows for exploring the text data). After eliminating stop words, the system switched 20 items with a minimum length of three (the software works on single words). The generated word cloud visualizes the data. The result is presented in Figure 5.

Figure 5. NVivo Word Frequency Query cloud.

The cloud shown in Figure 5 confirms the previously observed relationships (Figure 3). The two most common terms are "health" and "risk", supplemented by the notions of "hazard", "assessment", and "environmental". The remaining words can be broken down into three collections: hazards (e.g., "hazards", "toxicity", "exposure"), CBRN management (e.g., "assessment", "management", "detection", "risk/s"), and sustainable development for health and a clean environment (e.g., "health", "safety", recycling", "environment"). The remaining words, such as "water", "chemistry", and "human", complement the remaining notions and specify the most popular issues. This data set indicates similarity to the previous one generated by the VOSViewer app. There are repetitions of words such as "health" and "risk" as well as "environmental" and "assessment". Although the NVivo data are simplified (only single words appear), they can be generalized within the same framework.

In both queries, the terms relate to the fields of medical science, engineering, biochemistry, and environmental protection. Further, industrial risk management and safety are prominent, but they can be topics of publication in various journals. Medical sciences, engineering, and biochemistry are evident within the Scopus subject area. Industrial risk management can apply to decision sciences and environmental protection to chemical engineering, which were placed in other positions in Table 1.

Descriptive codes were created after identifying words and clusters in two different applications. Chunks of text were analyzed in terms of their semantic scope and defined. The complete list of the codes is presented in Table 3.

Table 3. Codes' names and their number of references in the text file.

Codes' Names	Number of References in the Text File
Hazard and risk management	30
Risk assessment	*12*
Waste management	*9*
Detection	*2*
Sustainability and hazards	22
Chemical hazards	*10*
Circular economy and green chemistry	*2*
Health issues	19
Agriculture	17
Foods	*7*
Fertilization and protection against pests	*4*
Toxicological issues	15
Digital technologies	13
Artificial intelligence—AI	*4*
Educational innovations	*2*
Virtual, augmented, mixed reality	*1*
Approaches to CBRN threats issues	9
Risks and insecurities	*5*
Hydrological issues	7
Water	*6*
Biosafety and biosecurity	7
Occupational safety and hygiene	6
Materials	5
Historical perspectives	3
Regulations	3
Contamination	2

Smaller units (subtopics) were distinguished within the codes, contributing to the basic code unit. As it can be noticed, several codes contain subtopics (so-called "children" in NVivo nomenclature). The code "hazard and risk management" includes "risk assessment", "waste management", and "detection"; "sustainability and hazards" includes "chemical hazards" and "circular economy and green chemistry"; "digital technologies" involves "artificial intelligence—AI", "educational innovations", and "virtual, augmented, mixed reality"; "agriculture"—"foods" and "fertilization and protection against pests"; and "hydrological issues"—"water". The relations between codes and the subtopics are visualized in Figure 6.

It can be observed that "hazard and risk management", "sustainability and hazards", and "health issues" became the three most prominent elements of the content analysis. Further topics included "agriculture", "toxicological issues", "digital technologies", "approaches to CBRN threat issues", "hydrological issues", "biosafety and biosecurity", "occupational safety and hygiene", "materials", "historical perspectives", "regulations", and "contamination".

Concerning the word frequency queries (NVivo and VOSViewer), manually created codes were embedded in all identified most frequent words, portmanteau words, and clusters. They provided more detailed information about the content of publications.

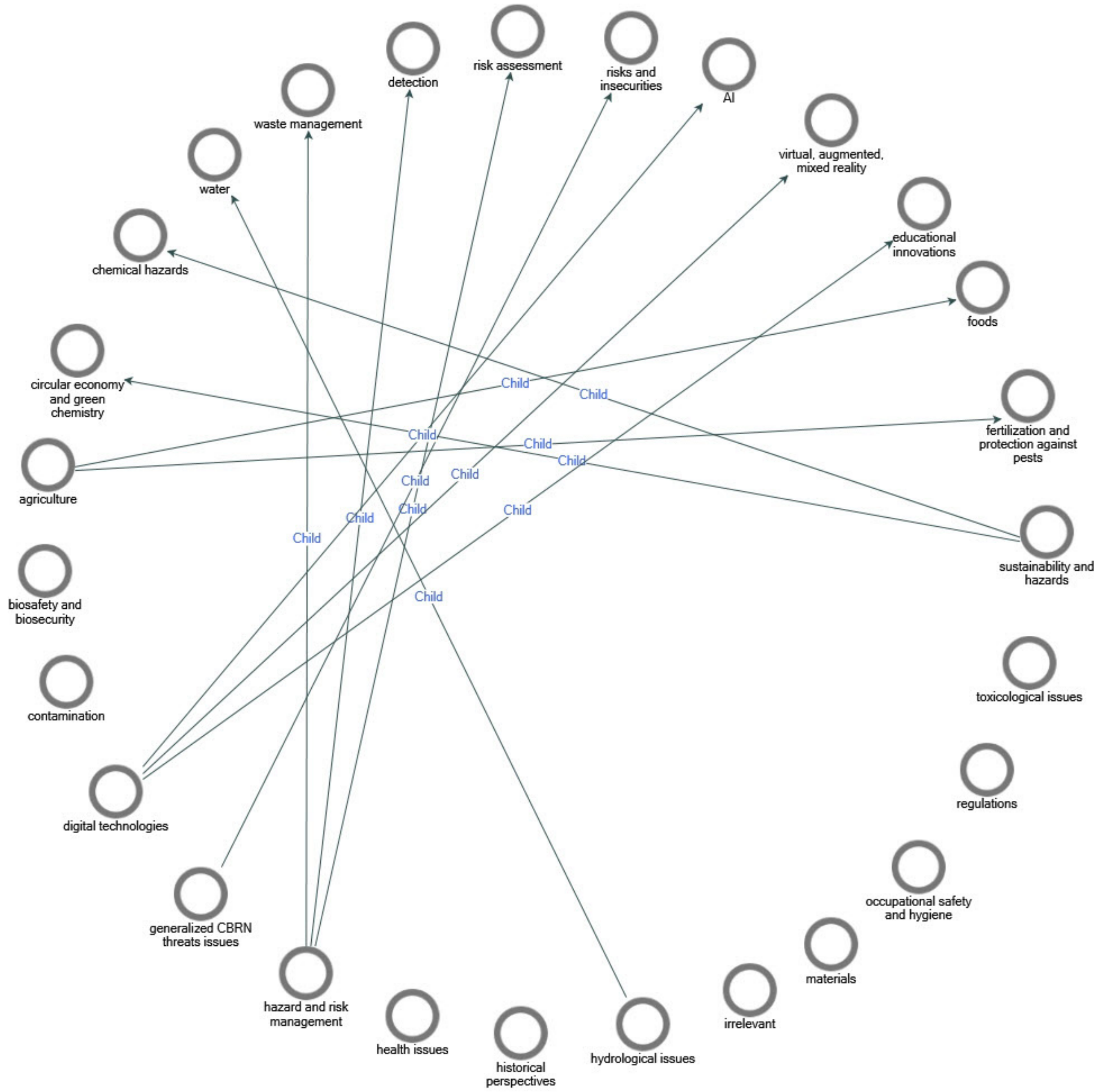

Figure 6. Relations between codes.

The final stage relied on matching the codes to Sustainable Development Goals. The 17 SDGs are: (1) No Poverty, (2) Zero Hunger, (3) Good Health and Well-being, (4) Quality Education, (5) Gender Equality, (6) Clean Water and Sanitation, (7) Affordable and Clean Energy, (8) Decent Work and Economic Growth, (9) Industry, Innovation, and Infrastructure, (10) Reduced Inequality, (11) Sustainable Cities and Communities, (12) Responsible Consumption and Production, (13) Climate Action, (14) Life Below Water, (15) Life On Land, (16) Peace, Justice, and Strong Institutions, and (17) Partnerships for the Goals [22]. Table 4 presents the results of the analysis of codes in the context of SDGs.

Table 4. The NVivo analysis of titles, abstracts, and keywords from 156 documents indexed in the Scopus database.

Code	Content Selected Examples	SDGs
Hazards and risk management *Including risk assessment, waste management, detection*	Safety assessment of nanomaterials using an advanced decision-making framework [39]; management of cytotoxic and radioactive wastes from hospitals [40]; insect detection on an unmanned ground rover [41]; embracing complexity and managing risk: PSM challenges in the specialty of chemical innovation [42]; a methodology for overall consequence assessment in oil and gas pipeline industry [43]; innovations in pollution prevention and resource recovery for a sustainable future [44].	3, 6, 7, 9, 11, 12, 14, 15
Sustainability and hazards *Including chemical hazards, circular economy, and green chemistry*	Sustainable exposure prevention through innovative detection and remediation technologies [45]; sustainable environmental quality [46]; social sustainability in green and sustainable chemistry [47]; circular bioeconomy growth to face the increasing industrial risk [48]; the intersection of green chemistry and Steelcase's path to the circular economy [49].	3, 6, 11, 12, 14, 15
Health issues	Prevention of infectious diseases [50]; using heavy metals [51]; electronic cigarettes and awareness of their health effects [52]; insects as feed and human food and the public health risk [53]; nanomaterials and their adverse effects on human health [54]; cytotoxic and radioactive wastes from hospitals [40].	1, 2, 3
Agriculture *Including fertilization and protection against pests, food*	Technological innovations in the processing of fermented foods [55]; insects as feed and human food and the public health risk [53]; innovation and optimization in potato cultivation protection [56]; biofertilizer as an alternative to synthetic fertilizers [57].	1, 2, 6, 14, 15
Toxicological issues	Identification, assessment, and prioritization of ecotoxicological risks [58]; non-toxic building products [59]; nanotechnology in agriculture: opportunities, toxicological implications, and occupational risks [60]; botulinum neurotoxins [61]; new approach method for regulatory toxicology [62]; developmental and reproductive toxicity testing [63]; toxicological predictions of engineered nanoparticles [64].	3, 6, 11, 14, 15
Digital technologies *Including AI, virtual, augmented, mixed reality, educational innovations*	Utilization of new digital technology to eliminate unwanted manual tasks [65]; cyber-physical systems to counter CBRN threats (real-time monitoring and analysis) [66]; enhancing human reliability with artificial intelligence and augmented reality tools for nuclear maintenance [67]; a teaching tool based on the concept of "learning by doing" [68]; experiential learning of physiochemical and bacteriological properties of water using virtual labs [69]; artificial intelligence systems for nuclear energy security and sustainability [70].	4, 9
Generalized CBRN threat issues *Including risks and insecurities*	Insecurity and governance in an age of transition [71]; responsible governance of biosecurity [72].	3, 6, 7, 9, 12, 13, 14, 15, 17
Hydrological issues *Including water*	Current water conservation practices in textile wet processing [73]; tunnel vision in current chemicals management cannot deal with the unknown risk of synthetic chemicals in aquatic systems [74]; experiential learning of physiochemical and bacteriological properties of water using virtual labs [69]; advanced modeling and innovations in water resources engineering [75].	6, 14

Table 4. *Cont.*

Code	Content Selected Examples	SDGs
Biosafety and biosecurity	A global biosafety strategy research framework with specific implications for China [76]; innovative biosafety training model [77].	2, 3, 6, 12, 14, 15
Occupational safety and hygiene	Issues related to exposure to biological and chemical agents—evaluation and tools for prevention, surveillance of work-related stress, from blood sampling to result [78]; nanotechnology in agriculture: opportunities, toxicological implications, and occupational risks—with highlighted importance for occupational safety practices and policies [79]; electronic industry and exposure to hazards [80]; new digital technology to eliminate unwanted manual tasks [65].	3, 8
Materials	Nanomaterials and their harmful effects on human health [54].	9, 12
Historical perspectives	History, biohazards, and norms contained in the UK sanitary bin industry since 1960 [81]; toxic and carcinogenic substances in cigarette smoke with historical views [82].	16, 17
Regulations	How omics technologies can enhance chemical safety regulation: perspectives from academia, government, and industry [83].	16, 17
Contamination	Treatment technologies for PAH-contaminated sites [84]; an innovation for heavy metal contamination in the soil environment [85].	3, 6, 14, 15

It should be stressed that the category "Irrelevant" was excluded from the repertoire of codes. In this category were included issues such as cryptocurrencies as new "financial weapons of mass destruction" [86] or strictly specialized medical issues, such as radiotherapy for cervical cancer [87].

By scoring of most frequently appearing SDGs, it can be inferred that innovations for combating CBRN threats and empowering sustainability concerns: SDG 3: Good Health and Wellbeing (eight times); SDG 6: Clean Water and Sanitation (eight times); SDG 14: Life Below Water (eight times), and SDG 15: Life On Land (seven times). The enlisted SDGs can be embedded within two central notions: health and environment.

5. Discussion

In this study, it was assumed that due to the growth of pollution, migrations, and climate change threatening biodiversity, the directions of innovations in the CBRN field would mainly concern environmental and health issues. Sustainable Development Goals related to these notions would be supported. This hypothesis was confirmed by computer-aided analyses of words and clusters, manual coding of the content created from 156 publications indexed in the Scopus database (2017–April 2022), and matching of the codes with the SDGs and indication of the most frequent SDGs.

As the research was based on bibliometrics and text mining, which included the creation of clusters, word/portmanteau word frequency queries, and coding, it had numerous limitations. The main concern is the interpretation of research results. One researcher interpreted single words, portmanteau words, and clusters. On the one hand, it can be treated as a weakness of the study; on the other hand, the meaning of the extracted data was explicit, so the potential biases in the interpretation could not be significant. Regarding the interpretation and subjectivity, there was another issue—coding. One researcher also created the codes. However, many of them can be treated as equivalents of the words and clusters. In this way, any risk of misinterpretation is low. The same situation concerns matching of the SDG to the codes. Again, the topical analysis relied on the explicit semantic meaning of the data, which can be perceived as justification for the researcher's point of view.

Finally, a limitation is the choice of database (Scopus) and keywords. Therefore, as a further endeavor, the research could be repeated with another database and a set of keywords closely related to innovations in CBRN-related topics. For instance, a more detailed analysis could involve the Web of Science database, which, as was stated before, provides a greater number of publications for analysis. The quantitative and qualitative data could then be compared. Moreover, due to the database limitation, a large number of publications on CBRN innovations from grey literature, such as websites of projects, agencies, companies, or the Google Scholar engine, were not taken into account. The topics covered issues such as radiation monitoring [88], radiological hazard detection and identification [89], chemical hazards detection, identification, and monitoring [18], a simple particle separation technology for speeding up nuclear waste cleanup [90], an international nuclear fusion research and engineering megaproject—International Thermonuclear Experimental Reactor (ITER) [91], and AI and interoperable simulation for pandemics and crisis management [92]. A final limitation lies in formal considerations in the field of nuclear weapons. For obvious reasons, there are no literature reports on this subject. All activities in this area are prohibited, and unlawful research in this field is kept in the strictest secrecy.

Future research may concern the misuse of the CBRN innovations by non-state actors such as criminal organizations or terrorists. In the literature, there are examples of scenarios in which technology supports terrorist activities; for instance, stealing radiological material from a hospital and selling it via the Dark Web to target civilians using a drone [93]. Further, critical technologies for CBRN terrorism are considered drones (used to deliver a weapon of mass destruction), the Dark Web (obtaining dual-purpose materials or equipment), malware (for chemical, biological, radiological, or nuclear facility cyberattacks), synthetic biology (resurrecting viruses), and 3D printing (DIY proliferation has new prospects) [93].

Other authors indicate the IT technology, including artificial intelligence and robotics [94]. Regarding new biotechnologies, computational biology and bioinformatics can also be misused to develop pathogens with enhanced virulence, drug resistance, or improved stability to withstand harsh environmental conditions. Additionally, an aggressor could harness bio-pesticide knowledge to release organisms or toxins harmful to humans, animals, and crops [95]. Such a concern triggers countermeasures that rely on developing codes of conduct to encourage responsible science and CBRN security education [96], based on state-of-the-art, motivating, and engaging activities performed in the CAVE Automatic Virtual Environment [97]. A safe approach could also rely on security, specifically in information technologies [98], and IoT-standardized solutions [99].

Research directions can also be focused on specific perspectives such as environmental protection. For example, widely described in literature topics related to waste batteries treatment [100–103], removal of radioisotopes from wastewater after "dirty bomb" decontamination [104], explosion hazards [105], or improvement of biogas production [106,107]. This kind of analysis would require a specific range of keywords and strict limitations to extract the relevant literature positions.

6. Conclusions

This systematic literature review revealed that the innovations for combating CBRN threats and empowering sustainability could apply to two main notions: health and environment, which are reflected in the selected Sustainable Development Goals. Basic analyses indicated topics related to hazards, CBRN management, and sustainable development (for health and a clean environment). Then, coding provided the insight into the publications' directions and uncovered more topics which apply to: "agriculture", "toxicological issues", "digital technologies", "approaches to CBRN threat issues", " hydrological issues", "biosafety and biosecurity", "occupational safety and hygiene", "materials", "historical perspectives", "regulations", and "contamination". When juxtaposed with the codes with SDGs, the scoring of their frequency indicated that innovations mostly apply to Good Health and Wellbeing (SDG 3), Clean Water and Sanitation (SDG 6), Life Below Water (SDG 14), and Life On Land (SDG 15)—domains of health and environment.

The study's findings contribute to the landscape of innovative solutions that support sustainable development. They can be utilized in innovations and management sciences, as well as strategy for sustainable development. Undoubtedly, the principles of sustainable development set the desired directions of development; however, pursuing only clean products while eliminating waste streams requires advanced technologies using hazardous substances that have associated risks. The desire to minimize costs results in the globalization of production, i.e., the use of large amounts of hazardous substances in installations operated by people who may cause a civilizational disaster. Furthermore, the activity of non-state actors, terrorists, and their misuse of CBRN innovations, may violate the endeavors to build a sustainable future. All these factors must be considered and create the need to develop CBRN innovation; this is crucial in times of uncertainty, conflict, migrations, pandemics, and environmental pollution. Since risk management involves specific procedures and is based on historical events and anticipated threats, the innovations' directions should also be analyzed and evaluated.

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