

Waste management beyond the COVID-19 pandemic: Bibliometric and text mining analyses

*Original*

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23 scientific production to date in the field of WM. In this vein, the performance indicators of the  
24 target literature were identified and discussed through conducting a bibliometric analysis. Such  
25 conceptual structure of COVID-19-related WM research, including seven main research themes,  
26 were uncovered and visualized through a text mining analysis as follows: (1) household and food  
27 waste, (2) personnel safety and training for waste handling, (3) sustainability and circular  
28 economy, (4) personal protective equipment and plastic waste, (5) healthcare waste management  
29 practices, (6) wastewater management, and (7) COVID-19 transmission through infectious waste.  
30 Finally, a research agenda for WM practices and activities in the post-COVID-19 era is proposed,  
31 focusing on the following three identified research gaps: (i) developing a systemic framework to  
32 properly manage the pandemic crisis implications for WM practices as a whole, following a system  
33 thinking approach, (ii) building a circular economy model encompassing all activities from the  
34 design stage to the implementation stage, and (iii) proposing incentives to effectively involve  
35 informal sectors and local capacity in decentralizing municipal waste management, with a specific  
36 focus on developing and less-developed countries.

37 **Keywords:** COVID-19, Plastic waste, Healthcare waste, Municipal solid waste, Wastewater,  
38 Personal protective equipment.

## 39 **1. Introduction**

40 The novel coronavirus-caused infectious disease 2019 (COVID-19) pandemic, as the most drastic  
41 health calamity of this century (Chakraborty and Maity, 2020), has severely impacted the  
42 economic, social, and environmental aspects of the global community and human well-being  
43 (Ranjbari et al., 2021c). Disruptions in economic activities and commodity markets (Rajput et al.,  
44 2021), limitations in mobility and industrial activities but at the same time, improving the air

45 quality of the cities (Ambade et al., 2021; Gautam et al., 2021; Gautam, 2020; Ravina et al., 2021),  
46 and challenges in implementing the 2030 Agenda for Sustainable Development (Bherwani et al.,  
47 2021; Ranjbari et al., 2021b) are only a few instances of the pandemic's implications for the global  
48 community. This pandemic through posing a significant increase in healthcare waste generation,  
49 which is an important transmission medium for the virus, has led to creating critical challenges for  
50 waste management (WM) practices globally (C. Chen et al., 2021; Gautam et al., 2022). The  
51 dramatic increase of personal protective equipment waste often ends up being treated by traditional  
52 disposal methods that have gravely pressured incineration and landfill facilities (Wang et al.,  
53 2021). In this vein, the waste generated in the wake of COVID-19, such as masks, gloves, sanitary  
54 papers, and clothing materials needs to be considered as medical waste, highlighting the  
55 importance of safely handling at the household level, and properly treatments at the municipal  
56 level (Musa et al., 2020).

57 However, there are still many uncertainties regarding the effects of the pandemic outbreak on  
58 various waste streams generated from a macro lens. On one hand, COVID-19 restrictions and  
59 partial lockdowns imposed by governments have decreased some industrial and business activities,  
60 which usually generate large amounts of waste (Naughton, 2020). On the other hand, in addition  
61 to increased medical waste, some waste streams such as agricultural waste or household wastes  
62 may increase due to the high demand for home delivery as well as increasing home cooking in the  
63 wake of the pandemic (Dente and Hashimoto, 2020). Consequently, a system thinking approach  
64 (Ranjbari et al., 2019; Shams Esfandabadi et al., 2020), as well as more reliable real-time WM  
65 data is needed to truly map changes in waste generation in the post-COVID-19 era (Naughton,  
66 2020).

67 As a response to the urgent call for action against adverse effects of the pandemic, many COVID-  
68 related studies have been conducted within various domains and disciplines. In this regard, a  
69 massive amount of research has also been conducted focusing on the effects of the pandemic on  
70 WM systems, practices, and different waste streams, such as healthcare WM challenges (de Aguiar  
71 Hugo and Lima, 2021), household food waste (Amicarelli and Bux, 2021; Vittuari et al., 2021),  
72 effective plastic WM during and post pandemic (Vanapalli et al., 2021), solid waste and  
73 environmental impacts (Urban and Nakada, 2021), municipal waste disposal behavior (Vu et al.,  
74 2021), face mask waste generation (Torres and De-la-Torre, 2021), reusing COVID-19 face mask  
75 as a novel solution to the emerging COVID-19 waste issue (Rehman and Khalid, 2021), solid  
76 waste generation and management strategies (Liang et al., 2021), single-use plastic waste (Leal  
77 Filho et al., 2021), behavioral impacts on residential food provisioning, use, and waste (Babbitt et  
78 al., 2021a), perceptions of people towards household waste management in the wake of the  
79 pandemic (Acharya et al., 2021), municipal solid waste management (Yousefi et al., 2021), waste  
80 production in households (Filho et al., 2021), and enabling circular economy model in solid waste  
81 management as a recovery plan post COVID-19 (Sharma et al., 2021).

82 The increasing interest of researchers and academic communities in contributing to COVID-  
83 related WM practices has led to fragmented literature in this domain. As a result, an inclusive  
84 landscape of the pandemic challenges for WM is still lacking in the literature. To the best of the  
85 authors' knowledge, so far, no research has conducted a comprehensive bibliometric review on the  
86 pandemic implications for WM practices. Therefore, to fill this gap, this research aims at providing  
87 a comprehensive review of the COVID-related scientific production to date in the WM field. On  
88 this basis, bibliometric and text mining analyses are conducted to address the following research  
89 questions:

90 **RQ1.** How has the field of research regarding WM in the context of COVID-19 performed?

91 **RQ2.** What are the main research themes of WM in the COVID-19-related scientific production?

92 **RQ3.** What are the potential research gaps and future directions for WM in the post-COVID-19  
93 era?

94 The remainder of this research is structured as follows. The methodology is described in Section  
95 2. The bibliometric results, including the performance analysis and science mapping of the WM  
96 in the pandemic context, are presented and discussed in Section 3. Section 4 provides the research  
97 gaps and future research directions to further develop WM practices considering COVID-19  
98 implications. And finally, Section 5 concludes the main findings and presents the limitations of  
99 the current research.

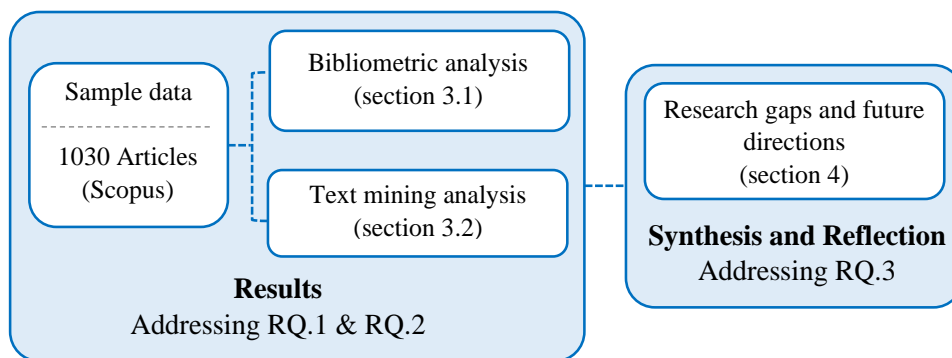
## 100 **2. Research design and methodology**

101 In this research, an analytical method combining bibliometric and text mining analyses adopted  
102 from Ranjbari et al. (Ranjbari et al., 2022, 2021a) was applied to answer the research questions. In  
103 this regard, the bibliometric analysis was used to evaluate and map the performance of WM  
104 research taking COVID-19 implications into account, corresponding to the first research question.  
105 As a part of the bibliometric analysis, bibliographic coupling was conducted, which aggregates  
106 articles in different clusters based on the cited references they have in common in their  
107 bibliographies. Therefore, the formed clusters in bibliographic coupling are made of the sample  
108 articles available in our dataset. On the other hand, a text mining analysis was conducted to  
109 discover the main research themes and trends of the WM literature in the context of the pandemic,  
110 corresponding to the second research question. The text mining analysis was conducted on the

111 titles and abstracts of the articles within our dataset to extract the noun phrases used by the authors.  
112 These phrases are then clustered based on their co-occurrence links (Waltman et al., 2010) to form  
113 the main research themes within the studied field of research. Hence, the clusters built in this  
114 analysis contain the frequent noun phrases applied in the titles and abstracts of the sample articles  
115 in our dataset. Finally, according to the insights provided by the bibliometric and text mining  
116 analyses, research gaps and potential avenues for future studies are presented, corresponding to  
117 the third research question.

118 Fig. 1 illustrates the main structure of this research approaching the research questions.

119



120

121

**Fig. 1.** The research framework design

122

## 2.1. Search string and data collection

123 In order to extract as many relevant studies as possible from the target literature, using a well-  
124 structured research protocol has been widely highlighted in the literature as one of the most  
125 important prerequisites in conducting systematic reviews (Chaudhary et al., 2021; Makrides et al.,  
126 2021; Zahedi et al., 2016). On this basis, a structured search string was formulated using different

127 combinations of the keywords "COVID-19" and "waste" as the main two concepts which shape  
128 the present review. Consequently, the following search string was constructed to collect articles  
129 from the Scopus database: ("COVID-19" OR "pandemic" OR "Coronavirus" OR "SARS-CoV-2")  
130 AND "waste".

131 Since this research aims to map all waste streams considering the pandemic effects, we decided  
132 not to limit the keyword "waste" with different waste streams, such as municipal solid waste,  
133 medical waste, healthcare waste, or plastic waste to cover WM practices for various waste streams  
134 as much as possible. The initial run of the search string on the titles and abstracts of articles in the  
135 Scopus database returned a total of 1567 articles. Due to the recentness of the COVID-19  
136 pandemic, the results were limited to the articles published in 2020 and 2021. Moreover, to ensure  
137 the reliability of the sample data, only peer-reviewed journal articles were included in the research  
138 leading to excluding other types of documents, such as conference proceedings, book chapters,  
139 and editorial notes from the study. Besides, non-English materials were excluded from the  
140 remained articles. As a result, a final sample of 1030 articles was selected as the main data for  
141 conducting the bibliometric and text mining analyses. Table 1 summarizes the steps taken in this  
142 research to construct the final sample.

143 **Table 1.** Steps of the data collection process.

---

<b>Search string</b>	"COVID-19" OR "pandemic" OR "Coronavirus" OR "SARS-CoV-2"  <b>AND</b>  "Waste"
<b>Fields mined</b>	Article titles, abstracts, author keywords, and keywords plus



<b>Database</b>	Scopus
<b>Initial Result</b>	1567 articles
<b>Search date</b>	August 8, 2021
<b>Inclusion criteria</b>	Only peer-reviewed journal articles, only English materials, limited to 2020-2021
<b>Final sample</b>	1030 articles

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144

## 145 **2.2. Data analysis**

146 The bibliometric analysis, as a statistical tool to evaluate the performance of an extensive amount  
147 of scientific production, has been broadly used for science mapping in recent years. This is due to  
148 the capability of the bibliometric analysis in drawing conclusions about the links among articles,  
149 journals, authors, keywords, citations, and co-citations networks (Feng et al., 2017), which  
150 supports researchers in discovering research themes and trends, and future research directions. In  
151 this research, the VOSviewer software version 1.6.16 developed by van Eck and Waltman (2010)  
152 was employed to run the bibliometric analysis. Accordingly, the performance of WM research  
153 within the COVID-related scientific production was investigated and mapped by presenting  
154 bibliometric performance indicators focusing on (i) geographical distribution of publications, (ii)  
155 authors' productivity and influence, (iii) core journals, (iv) articles, and (v) keyword-based  
156 analysis to unfold research tendencies and hotspots. In this regard, data cleaning, as an essential  
157 step in keyword-based analyses to reduce the presence of redundant and useless data (Bresciani et  
158 al., 2021; Ranjbari et al., 2020), was performed in a reasonable manner, for instance by (i)  
159 unification of the English writing styles, (ii) merging singular and plural as well as full and short

160 forms of the keywords, (iii) excluding general keywords without conveying any specific meaning,  
161 such as review or article. Besides, all forms of referring to the COVID-19 pandemic, including  
162 Coronavirus, pandemic, and SARS-COV-2 were transformed into "COVID-19" to more  
163 accurately assess the occurrence of this keywords.

164 In addition to the provided bibliometric indicators, a text mining analysis based on a term co-  
165 occurrence algorithm (Van Eck and Waltman, 2011) using the text mining module of VOSviewer  
166 version 1.6.16 was also conducted on the manuscripts' titles and abstracts (1030 articles) included  
167 in the final sample. As a result, semantic structures and phrase patterns that constructed the main  
168 research themes of WM studies post COVID-19 were identified and visualized. A data cleaning  
169 step was also taken before text mining analysis by (i) unification of the English writing styles, and  
170 (ii) merging full and short forms of the keywords.

## 171 **3. Results and discussion**

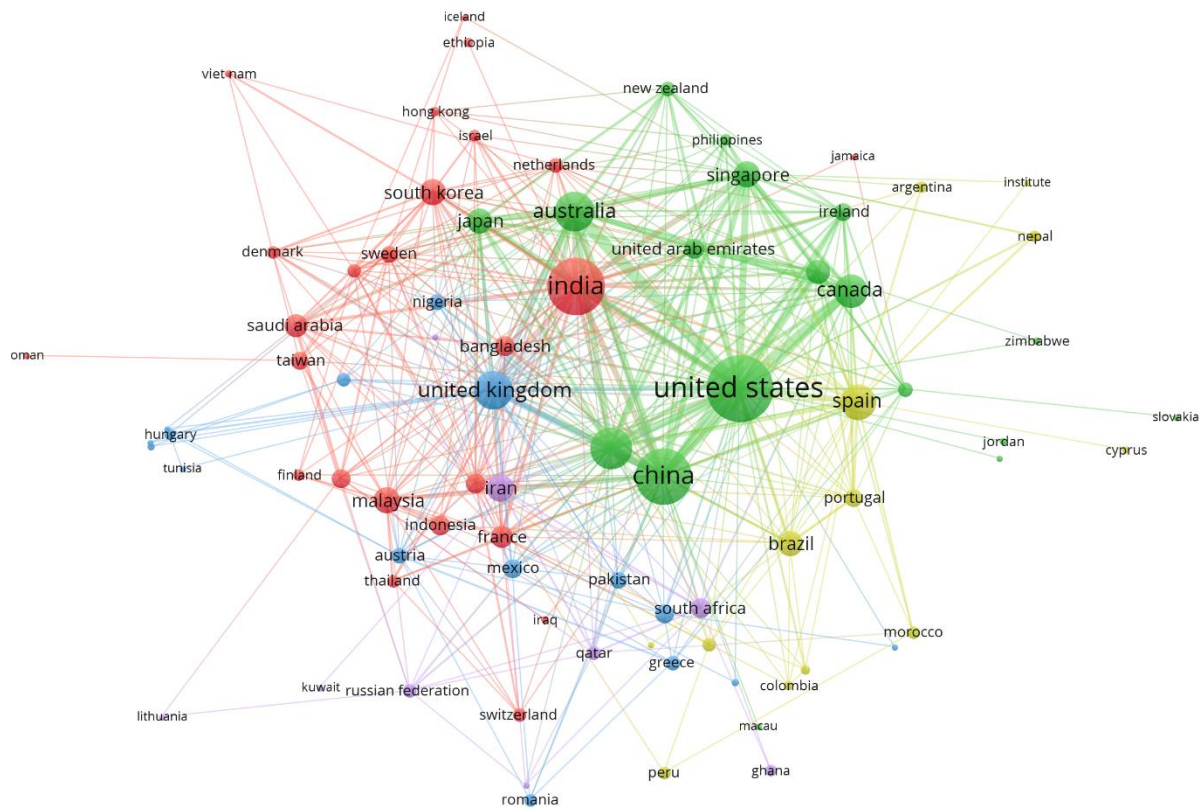
172 In this section, the results of the bibliometric analysis and text mining analysis are presented to  
173 address the first and second research questions, respectively.

### 174 **3.1. Bibliometric results: performance indicators**

#### 175 **3.1.1. Geographical distribution of publications**

176 The spatial and geographic distribution of articles provides insight into the main active countries  
177 in terms of publication within the waste context in the COVID-19 era. A total of 91 countries have  
178 published articles within our studied field and 82 of these countries are a part of a co-authorship  
179 network. Fig. 2 illustrates the countries' co-authorship network of the WM research post-

180 pandemic, consisting of nodes with different sizes corresponding to the number of articles  
 181 published by a country, and links with different thicknesses corresponding to the strength of the  
 182 co-authorship between each pair of countries. Table 2 provides the list of the top 10 countries in  
 183 terms of the number of published articles, number of collaborating countries (number of links),  
 184 total number of articles co-authored (total link strength), and the number of cites to their articles.



185  
 186 **Fig. 2.** The countries' co-authorship network of WM research post-COVID19 pandemic

187  
 188 **Table 2.** Top 10 countries in terms of the number of published articles, number of co-author countries,  
 189 total number of co-authorship, and the number of cites to their articles

<b>Rank</b>	<b>Published articles</b>	<b>Number of collaborating countries</b>	<b>Total number of documents co-authored</b>	<b>Citations</b>
1	USA (137)	USA (49)	USA (169)	USA (2080)
2	India (101)	UK (42)	China (132)	Australia (1197)
3	China (98)	China, India (39)	Australia (120)	Japan (1036)
4	Italy (55)	Italy (37)	Italy (108)	Italy (988)
5	Australia (48)	Australia (34)	India (105)	China (840)
6	UK (47)	Singapore (29)	UK (94)	India (754)
7	Spain (39)	Spain (28)	Singapore (84)	Spain (486)
8	Canada (34)	Japan (26)	Canada (72)	UK (448)
9	Iran (23)	South Korea (25)	Spain (54)	Mexico (423)
10	Malaysia (22)	Poland, United Arab Emirates (23)	Japan (53)	Ecuador (357)

190

191 As can be seen in Table 2, the USA with 137 articles, 49 collaboration links, 169 co-authorships,  
192 and 2080 citations is ranked first in all four rankings. Although the second and third ranks in these  
193 rankings address different countries, Italy is ranked fourth with 55 articles, 37 co-author countries,  
194 108 collaborations, and 988 earned citations. UK, China, Australia, India, and Spain also appear  
195 among the top 10 countries in all the four lists, but their position differs in each ranking. As the  
196 strength of the links in Fig. 2 shows, most of the collaboration of the USA in their publications  
197 have taken place with Australia (21 co-authorship), Canada (16 co-authorship), and China (15 co-

198 authorship), which are also the strongest links in this network. The next strong collaboration refers  
199 to the co-authorship of Italy with China and the USA, each happening 12 times.

### 200 3.1.2. Authors productivity and influence

201 Research authors play a key role in the evaluation of the development in an academic field (Guo  
202 et al., 2021). A total of 3,348 authors contributed to the research in the field of WM considering  
203 the challenges caused by COVID-19, among whom 80 authors have contributed at least in 3  
204 articles. Table 3 and Table 4 provide the list of authors with the highest number of articles (most  
205 productive authors) and the highest number of citations (most influential authors) in our dataset,  
206 respectively, and also the number of their co-authors and co-authorship. Based on the lists provided  
207 in these tables, M. Kitajima is the most productive and most influential author among the 3348  
208 authors in our dataset.

209 **Table 3.** The most productive authors in WM research post-COVID-19 pandemic

<b>Author</b>	<b>Articles</b>	<b>Citations</b>	<b>Co-authors</b>	<b>Total co-authorship</b>
Kitajima M.	8	848	19	43
Li J.	8	490	22	24
Chen X.	7	24	17	17
Liu Y.	7	72	18	19
Bibby K.	6	714	16	48
Wang J.	6	60	6	9
Wang Y.	6	7	8	8
Zhang L.	6	37	12	16

Ahmed W.	5	713	16	48
Bivins A.	5	538	16	45
Lee J.	5	11	1	1
Li X.	5	18	5	5
Zhang J.	5	132	8	11
Zhang X.	5	103	8	9
Zhang Y.	5	57	6	6

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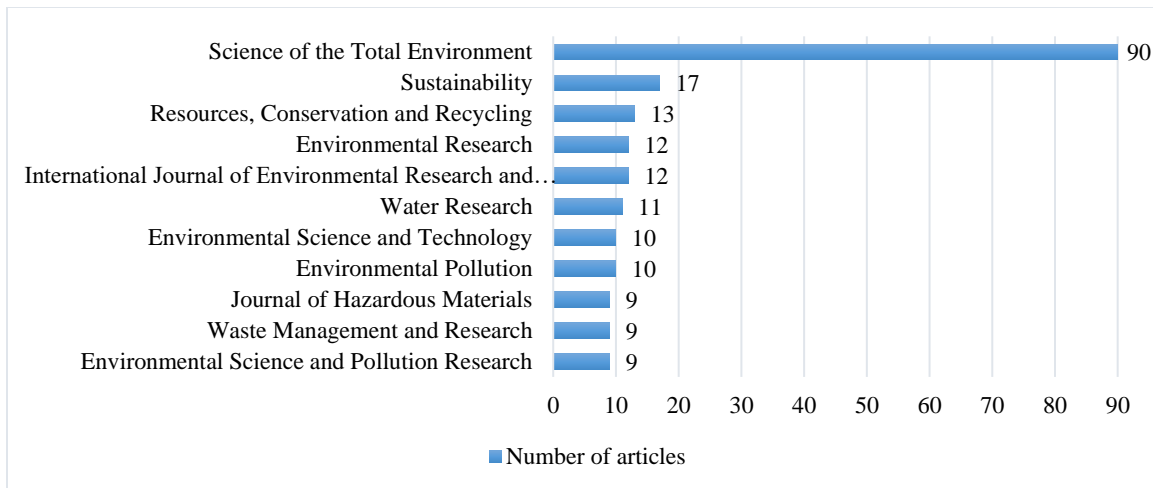
**Table 4.** The most influential authors in WM research post COVID-19 pandemic

<b>Author</b>	<b>Citations</b>	<b>Articles</b>	<b>Co-authors</b>	<b>Total co-authorship</b>
Kitajima M.	848	8	19	43
Bibby K.	714	6	16	48
Ahmed W.	713	5	16	48
Bivins A.	538	5	16	45
Mueller J.F.	538	4	15	44
Simpson S.L.	538	4	15	44
Thomas K.V.	538	4	15	44
Verhagen R.	538	4	15	44
Smith W.J.M.	521	3	15	35
Li J.	490	8	22	24

212

### 213 3.1.3. Core journals

214 The 1030 available articles in the WM field of research post COVID-19 within our dataset have  
215 been published in 351 journals. Out of this pool of journals, 35 have published at least 3 of the  
216 articles in the dataset. Fig. 3 and Fig. 4 focus on the journal publications and show the top ones  
217 based on the number of published articles and the number of citations to their articles, respectively.  
218 As can be seen in these figures, *Science of the Total Environment* has both the largest share of  
219 published articles and the highest number of citations to its articles. Besides, there is a significant  
220 gap between this journal and the second-ranked journals both in terms of productivity and  
221 influence. In fact, while *Science of the Total Environment* has published 90 articles, *Sustainability*  
222 as the next productive journal has published 17 articles, followed by *Resource, Conservation and*  
223 *Recycling* that has 13 articles in our database. Moreover, in terms of the citations earned by the  
224 published articles, *Science of the Total Environment* is followed by *Water Research and Resource,*  
225 *Conservation and Recycling*, with 426 and 297 citations, respectively, which are far away from  
226 the 2759 cites received by *Science of the Total Environment*. Therefore, *Science of the Total*  
227 *Environment* can be regarded as the leading journal in the field of WM post COVID-19 from this  
228 lens of analysis.

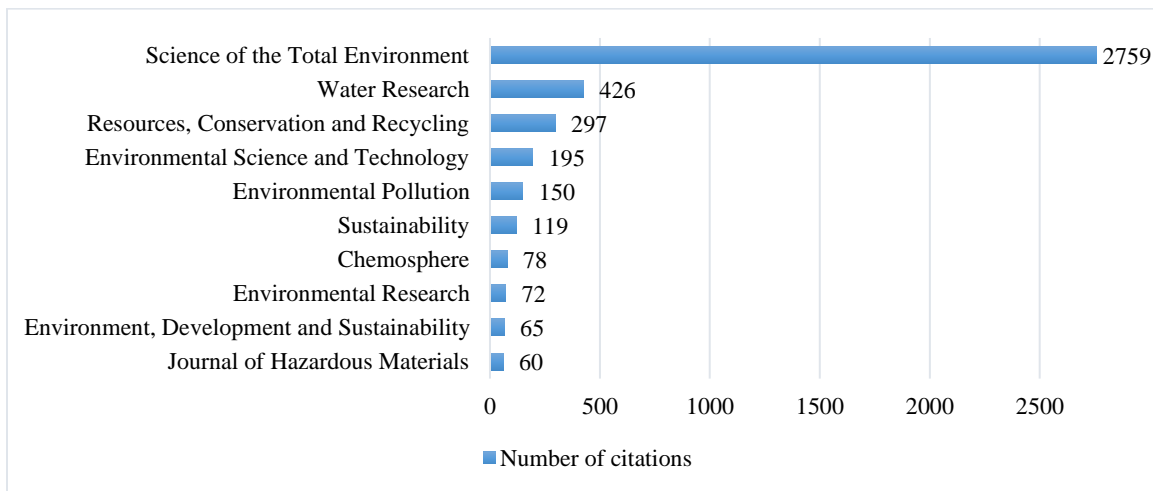


229

**Fig. 3.** Top productive journals in terms of published articles

230

231



232

**Fig. 4.** Top influential journals in terms of the number of citations to their articles

233

### 234 **3.1.4. Articles**

235 In this section, two main analyses are conducted on the articles concerning the citations received  
 236 by the articles and their bibliographic coupling.



#### 237        **3.1.4.1. Influential articles**

238        One of the ways to evaluate the influence of an article on a related research area is to consider the  
239        number of times it is cited (Merigó et al., 2015). Therefore, Table 5 presents the list of the top 10  
240        most cited articles within the WM filed post COVID-19. As shown in this table, two papers share  
241        the eighth position by attracting 123 citations. The most influential article in Table 5 with 394  
242        citations is a research conducted by Ahmed et al. (2020a) that has focused on the first detection of  
243        the COVID-19 virus in untreated wastewater in Australia. Similarly, the first detection of SARS-  
244        CoV-2 RNA in wastewater has been considered in Italy (La Rosa et al., 2020) and Japan (Haramoto  
245        et al., 2020) in the fifth and eighth most influential articles with 193 and 123 citations, respectively.  
246        The existence of SARS-CoV-2 RNA in wastewater treatment plants in Spain and the USA was  
247        investigated by Randazzo et al. (2020) and Wu et al. (2020) in the third and tenth influential articles  
248        with 274 and 101 citations, respectively. Besides, wastewater-based epidemiology is addressed by  
249        Hart and Halden (2020) in the seventh-ranked paper, and a review of the methodologies for the  
250        detection and quantification of SARS-CoV-2 in wastewater and the potential of wastewater  
251        surveillance regarding the pandemic is presented by Kitajima et al. (2020) in the sixth influential  
252        article. Fadare and Okoffo (2020) and Prata et al. (2020) address plastic waste in their research,  
253        and finally, Zambrano-Monserrate et al. (2020) and Saadat et al. (2020) analyze the environmental  
254        effects of the pandemic, as the eighth, ninth, second and fourth highly cited articles within the  
255        studied research area, respectively.

256        Furthermore, considering the journals containing the most influential articles in Table 5, out of the  
257        11 available articles, 7 have been published in *Science of the Total Environment*, which was

258 introduced as the most productive and influential journal in the context of WM post pandemic in  
 259 section 3.1.3.

260 **Table 5.** Top 10 highly cited articles in the WM research within the COVID19 area

<b>Rank</b>	<b>Author</b>	<b>Title</b>	<b>Journal</b>	<b>Citation</b>
1	Ahmed et al. (2020a)	First confirmed detection of SARS-COV-2 in untreated wastewater in Australia: a proof of concept for the wastewater surveillance of COVID-19 in the community	Environmental Science & Technology Letters	394
2	Zambrano-Monserrate et al. (2020)	Indirect effects of COVID-19 on the environment	Science of The Total Environment	356
3	Randazzo et al. (2020)	SARS-CoV-2 RNA in wastewater anticipated COVID-19 occurrence in a low prevalence area	Water Research	274
4	Saadat et al. (2020)	Environmental perspective of COVID-19	Science of The Total Environment	201
5	La Rosa et al. (2020)	First detection of SARS-CoV-2 in untreated wastewaters in Italy	Science of The Total Environment	193

6	Kitajima et al. (2020)	SARS-CoV-2 in wastewater: State of the knowledge and research needs	Science of The Total Environment	175
7	Hart and Halden (2020)	Computational analysis of SARS-CoV-2/COVID-19 surveillance by wastewater-based epidemiology locally and globally: feasibility, economy, opportunities and challenges	Science of The Total Environment	140
8	Haramoto et al. (2020)	First environmental surveillance for the presence of SARS-CoV-2 RNA in wastewater and river water in Japan	Science of The Total Environment	123
	Fadare and Okoffo (2020)	COVID-19 face masks: A potential source of microplastic fibers in the environment	Science of The Total Environment	123
9	Prata et al. (2020)	COVID-19 Pandemic Repercussions on the Use and Management of Plastics	Environmental Science & Technology	113
10	Wu et al. (2020)	SARS-CoV-2 titers in wastewater are higher than expected from clinically confirmed cases	mSystems	101

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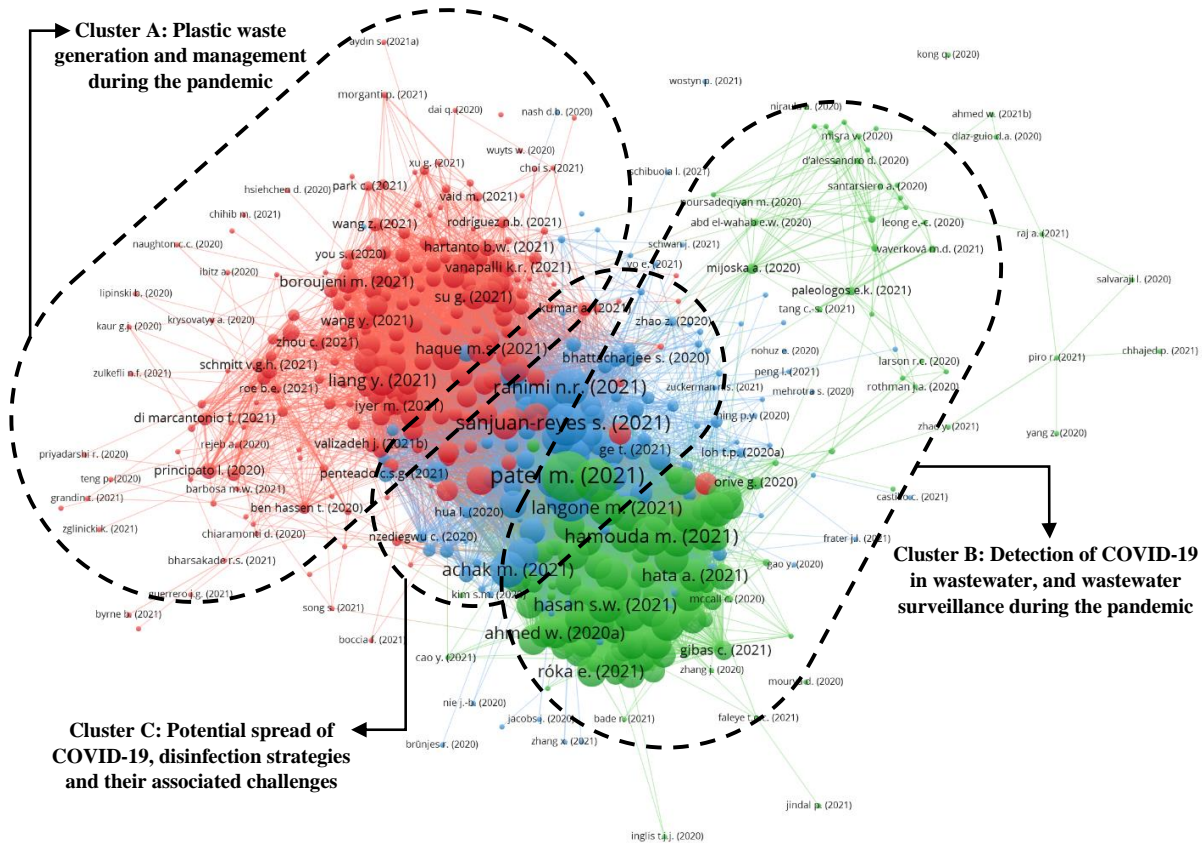
#### 261        **3.1.4.2. Bibliographic coupling of articles**

262        In order to put the articles in relevant categories and show the main themes of the WM research in  
263        the COVID-19 era, bibliometric coupling of the articles was conducted based on the references  
264        that they share. Out of the 1030 research and review articles in our dataset, only 658 documents  
265        had at least one common reference with other documents. Therefore, these 658 articles were  
266        considered for the bibliographic coupling in this section. Fig. 5 visualizes the articles grouped in  
267        three specific clusters. Each cluster is addressed by a different color and is named based on the  
268        main sense of the articles located in it. The size of the bubbles points to the number of citations of  
269        the corresponding article and the link between each pair of articles shows their co-occurrence. The  
270        top 10 highly cited articles of each category are listed in Table 6.

271        The focus of the majority of the papers in research category A (red color in Fig. 5) is on the  
272        generation of plastic waste linked with the usage of face masks (Das et al., 2020; Fadare and  
273        Okoffo, 2020) and other personal protective equipment during the pandemic, as well as related  
274        management of the generated waste (Prata et al., 2020; Sharma et al., 2020; Vanapalli et al., 2021).  
275        This category is supported by articles that share similar references with the plastic waste research  
276        but target the management of pandemic-related waste (Ibn-Mohammed et al., 2021; Peng et al.,  
277        2020). The unsustainable use of single-use plastics to protect people against the pandemic has  
278        exposed ecosystems to several environmental threats by producing a huge amount of plastic  
279        pollution (Sarkodie and Owusu, 2021). On one hand, the increase in waste generated, and on the  
280        other hand, the reduction in the recycling of used materials have posed serious challenges to water,  
281        land, and air (Zambrano-Monserrate et al., 2020). In this regard, the global unprecedented rise of  
282        using billions of face masks to slow down the COVID-19 transmission rate has been under intense

283 debate as a critical environmental issue (Fadare and Okoffo, 2020). Replacing common face  
284 masks, which are produced from petrochemicals derived raw materials, with degradable bio-based  
285 face masks using raw materials that are side-stream products of local industries was proposed by  
286 Das et al. (2020) as a sustainable solution for the pandemic WM.

287 Detection of SARS-COV-2 RNA in wastewater (Ahmed et al., 2020a; La Rosa et al., 2021; Orive  
288 et al., 2020) is the focal point of research category B, which is shown in green in Fig. 5. This  
289 category also includes research on wastewater surveillance post COVID-19 (Daughton, 2020),  
290 which highlights the important role of wastewater-based epidemiology as an effective tool to  
291 manage the pandemic (Ahmed et al., 2020b) and minimize domino effects of COVID-19  
292 restrictions that stress humans and economies (Daughton, 2020). Besides, since wastewater is  
293 relatively affordable and can be easily collected and monitored at different population aggregation  
294 levels, wastewater surveillance in the COVID-19 outbreak can provide a real-time and cost-  
295 effective health assessment rather than case reporting (Thompson et al., 2020). The top 6 papers  
296 in this category have been previously reported among the most influential articles in section  
297 3.1.4.1. Finally, research category C (blue color in Fig. 5) stands mainly based on the research  
298 articles addressing the potential spread of the SARS-COV-2 virus through solid waste (Nzediegwu  
299 and Chang, 2020), wastewater (Zhang et al., 2020), environmental matrices and surfaces  
300 (Carraturo et al., 2020; Mouchtouri et al., 2020), and water (Carducci et al., 2020), and is supported  
301 by research articles addressing preventive measures (Wang et al., 2020) and disinfection strategies  
302 (Ilyas et al., 2020).



303

304 **Fig. 5.** Bibliographic coupling of the articles within the field of WM research post-COVID19 pandemic

305 **Table 6.** Highly cited articles within the main identified research categories.

Research category A:	Research category B:	Research category C:
Plastic waste generation and management during the pandemic	Detection of COVID-19 in wastewater, and wastewater surveillance during the pandemic	Potential spread of COVID-19, disinfection strategies and their associated challenges
<b>Article citation</b>	<b>Article citation</b>	<b>Article citation</b>
<b>Reference</b>	<b>Reference</b>	<b>Reference</b>

---

Zambrano-	356	Ahmed et al.	394	Saadat et al.	201
Monserrate et al.		(2020a)		(2020)	
(2020)					
Fadare and	123	Randazzo et al.	274	Peccia et al.	93
Okoffo (2020)		(2020)		(2020)	
Prata et al. (2020)	113	La Rosa et al.	193	Nzediegwu and	65
		(2020)		Chang (2020)	
Sharma et al.	82	Hart and Halden	140	Zhang et al.	63
(2020)		(2020)		(2020)	
Vanapalli et al.	65	Haramoto et al.	123	Carducci et al.	62
(2021)		(2020)		(2020)	
Mofijur et al.	53	Wu et al. (2020)	101	Carraturo et al.	61
(2021)				(2020)	
Ibn-Mohammed	52	Ahmed et al.	100	Ilyas et al. (2020)	46
et al. (2021)		(2020b)			
Ben Hassen et al.	42	Daughton (2020)	67	Wang et al.	38
(2020)				(2020)	
Das et al. (2020)	38	La Rosa et al.	66	Lacy et al. (2020)	35
		(2021)			
Peng et al. (2020)	33	Orive et al.	66	Ma et al. (2020)	33
		(2020)			

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### 307        **3.1.5. Keyword analysis: research tendencies and hotspots**

308        The analysis of keywords frequency provides a ground for the description of the research domain  
309        and the concentration of the collected articles. After cleaning the keywords data, 1765 unique  
310        keywords were identified, 119 of which had at least 3 occurrences. Then a heat map was developed  
311        for these 119 keywords based on their frequencies in VOSviewer, as illustrated in Fig. 6. As  
312        expected, COVID-19 (representing all forms of referring to the current pandemic) is the most  
313        frequent keyword, as pictured in Fig. 6, and the next main hot spots refer to wastewater,  
314        wastewater-based epidemiology, and personal protective equipment, which are in line with the  
315        research categories identified in the analysis of bibliographic coupling in section 3.1.4.2. To  
316        facilitate the identification of the most frequent keywords, the author keywords with the  
317        occurrence of more than 10 are reported in Table 7.





3	Wastewater-based epidemiology	36	13	Disinfection	12
4	Personal protective equipment	30	14	Environmental impact	11
5	WM	28		Plastic pollution	11
6	Food waste	23		Transmission	11
7	Sewage	22	15	Environmental pollution	10
8	Medical waste	20		Face mask	10
9	Sustainability	19		Public health	10
10	Lockdown	16		Virus	10
11	Biosafety	14			

---

323

324 Since the keyword COVID-19 has a significantly higher frequency (422 occurrences) in  
325 comparison with the second most frequent keyword (wastewater with 47 occurrences), it has a co-  
326 occurrence with many of the keywords. Based on Table 8, COVID-19 has a pivotal role and  
327 appeared alongside wastewater, wastewater-based epidemiology, and personal protective  
328 equipment in the author keywords list of 43, 31, and 24 articles, respectively. However, to provide  
329 a clearer picture of the most frequent pairs of keywords, without considering “COVID-19”  
330 keyword, the most frequent pairs of keywords ignoring “COVID-19” are provided in Table 9.  
331 Personal protective equipment and WM, and also wastewater and wastewater-based epidemiology,  
332 both are the most frequent pairs of keywords with 7 occurrences. Circular economy and  
333 sustainability, and virus and wastewater both are ranked as the second most frequent pairs each

334 appearing in 6 documents. The third rank goes to 4 pairs, including biosafety and laboratory,  
 335 consumer behavior and food waste, sewage and wastewater, and wastewater and water, each with  
 336 5 occurrences.

337 **Table 8.** The most frequent pairs of author keywords considering COVID-19 as the pivotal keyword

<b>Keyword 1</b>	<b>Keyword 2</b>	<b>Frequency</b>
COVID-19	Wastewater	43
COVID-19	Wastewater-based epidemiology	31
COVID-19	Personal protective equipment	24
COVID-19	WM	22
COVID-19	Sewage	19
COVID-19	Food waste	15
COVID-19	Lockdown	15
COVID-19	Medical waste	15
COVID-19	Biosafety	14
COVID-19	Sustainability	13

338

339

340 **Table 9.** The most frequent pairs of author keywords excluding COVID-19 from the list of keywords

<b>Keyword 1</b>	<b>Keyword 2</b>	<b>Frequency</b>
Personal protective equipment	WM	7

Wastewater	Wastewater-based epidemiology	7
Circular economy	Sustainability	6
Virus	Wastewater	6
Biosafety	Laboratory	5
Consumer behavior	Food waste	5
Sewage	Wastewater	5
Wastewater	Water	5

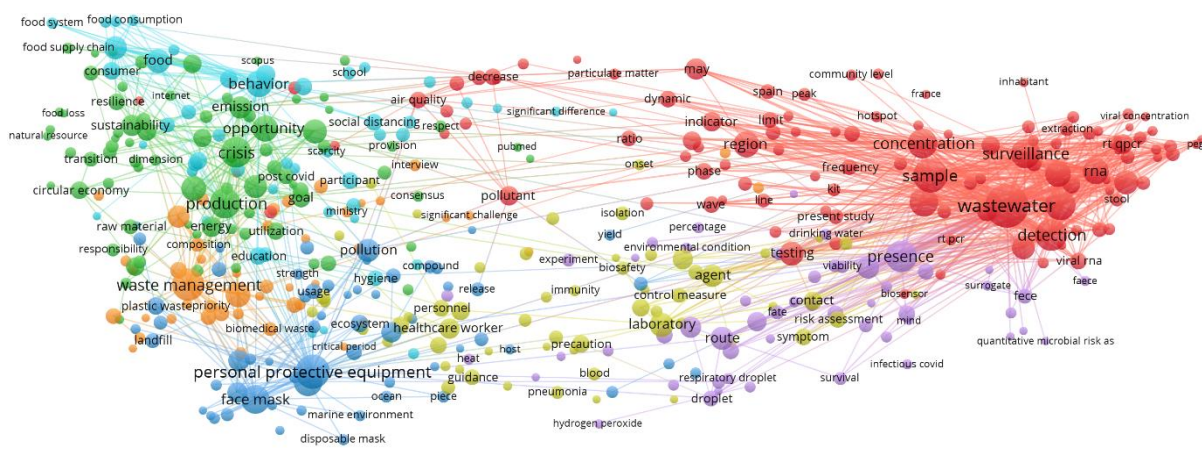
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341

### 342 **3.2. Text mining results: thematic conceptualization**

343 The text mining analysis was conducted on the titles and abstracts of the 1030 collected peer-  
344 reviewed journal articles of our sample to uncover hidden semantic structures and research themes.  
345 After cleaning the data, 16,345 unique noun phrases were identified. In order to base the analysis  
346 on the sufficiently frequent terms, a minimum of 5 occurrences was considered as a criterion for  
347 the selection of phrases, leading to the selection of 853 noun phrases. Then, to remove the general  
348 terms (e.g. article, research, etc.) and focus on the main topic of this research, the 60% most  
349 relevant identified terms were considered in the analysis based on the statistical method applied in  
350 the VOSviewer software (Van Eck and Waltman, 2011). The obtained list of 512 terms was then  
351 checked manually to remove the remaining general terms, which do not point to a specific research  
352 theme, such as COVID-19 pandemic, coronavirus-caused infectious disease, and Middle East  
353 respiratory syndrome. As a result, 454 unique phrases remained, which were used to build clusters  
354 based on the co-occurrence of the terms to reveal the research themes in the WM research post  
355 COVID-19 era. The seven major themes identified include (1) household and food waste, (2)

356 personnel safety and training for waste handling, (3) sustainability and circular economy, (4)  
 357 personal protective equipment and plastic waste, (5) healthcare waste management practices, (6)  
 358 wastewater management, and (7) COVID-19 transmission through infectious waste. Fig. 7  
 359 presents the thematic structure of the COVID-related WM research. Similar to Fig. 6, the size of  
 360 the circles and the links between them show the occurrence of identified terms and their co-  
 361 occurrence, respectively.



362

- |            |   |            |  |
|------------|---|------------|--|
| Cluster #1 | <span style="color: cyan;">■</span> Household and food waste                                | Cluster #5 | <span style="color: orange;">■</span> Healthcare waste management practices          |
| Cluster #2 | <span style="color: yellowgreen;">■</span> Personnel safety and training for waste handling | Cluster #6 | <span style="color: red;">■</span> Wastewater management                             |
| Cluster #3 | <span style="color: green;">■</span> Sustainability and circular economy                    | Cluster #7 | <span style="color: purple;">■</span> COVID-19 transmission through infectious waste |
| Cluster #4 | <span style="color: blue;">■</span> Personal protective equipment and plastic waste         |            |  |

363 **Fig. 7.** Major research themes in COVID-related WM research

364 The first cluster refers to the household and food waste (cluster #1) considering the pandemic  
 365 effects on the waste generated, consumer behavior and lifestyle, and food systems. The main terms  
 366 in this research theme are behavior, food, food waste, consumer, household, food consumption,  
 367 food system, lifestyle, sanitizer, and household waste. On this basis, the pandemic has highly  
 368 impacted the food consumption and purchasing habits of people (Pappalardo et al., 2020) leading  
 369 to create many challenges for food systems and businesses all around the world. In this vein, the

370 changes in food consumption behavior in the post-COVID era may be related to price increase  
371 concerns, food waste awareness, and safety (Güney and Sangün, 2021). This research theme has  
372 been mainly focused on stockpiling and food waste during the COVID-19 pandemic (Brizi and  
373 Biraglia, 2021), food waste reduction in times of crisis (Malefors et al., 2021), household food  
374 waste behavior (Qian et al., 2020), food waste generation (Heikal Ismail et al., 2020), and safety  
375 and food packaging (Kitz et al., 2021). Babbitt et al. (2021b) showed that the increased food  
376 purchasing behavior of households to gain self-sufficiency during the pandemic has increased  
377 waste through bulk purchasing and stockpiling. In another study, Filho et al. (2021) denoted that  
378 the COVID-19 lockdowns have resulted in higher consumption levels of take-away food and  
379 packaged products. Based on their research evidence, 45–48% of the participants reported  
380 consumption growth of fresh food, packed food, and food delivery due to longer stays at home.  
381 Nevertheless, despite the potential increase in food waste generated during the pandemic, Vittuari  
382 et al. (2021) showed a considerable reduction in declared household food waste due to uncertainty  
383 and increased availability of time at home by Italian households. Moreover, the research conducted  
384 by Ben Hassen et al. (2021) revealed that although the pandemic has increased the consumption  
385 levels of local food products due to food safety concerns, it has improved the awareness of people  
386 towards food, leading to food waste reduction.

387 The second identified research theme focuses on personnel safety and training for waste handling  
388 (cluster #2). The main terms included in this cluster are healthcare worker, infectious disease, staff,  
389 diagnosis, personnel, professional, training, medical staff, and the healthcare system. The critical  
390 role of healthcare sector staff in providing adequate infection control and proper medical WM  
391 procedures was underlined by Aleanizy and Alqahtani (2021) to highlight the importance of  
392 knowledge and awareness regarding COVID-19 infection control and WM activities in healthcare

393 facilities. In addition to healthcare personnel, workers in other sectors, such as wastewater  
394 treatment plans (Zaneti et al., 2021), and municipal waste centers need to be trained regarding  
395 safely handling the medical waste generated due to the pandemic outbreak. Sustainability and  
396 using the potentials of the circular economy (cluster #3) has constructed the third research theme  
397 of WM research taking COVID-19 into account in the target literature. The circular economy  
398 approach, as a tool to promote sustainable development at the local and global scales, has gained  
399 momentum (Shevchenko et al., 2021c, 2021a). In this regard, sustainability, supply chain,  
400 recycling, circular economy, resilience, raw material, reuse, and sustainable development goal  
401 have appeared frequently within the context of research in this area. Developing circular networks  
402 and creating circularity to reduce waste, and to return resources to the production cycle was  
403 proposed by Alonso-Muñoz et al. (2021), as a cure to make the supply chains resilient against the  
404 pandemic adverse effects. Designing eco-design process of face masks based on circularity and  
405 life cycle assessment (Boix Rodríguez et al., 2021), recycling of the materials of the disposable  
406 filtering masks (Battezzore et al., 2020), the potential of agri-food loss and waste to contribute  
407 to a circular economy (Osorio et al., 2021), blockchain-based forward supply chain and WM  
408 practices for COVID-19 medical equipment and supplies (Ahmad et al., 2021), safe WM during  
409 the pandemic and circular economy implementation (Pikoń et al., 2021), and the interplay of  
410 industry 4.0 and circular economy for developing a smart healthcare waste disposal system  
411 (Chauhan et al., 2021) have constructed the bottom line of this research theme. In this regard, smart  
412 cities with a special focus on using smart technologies, such as Internet of Things, big data  
413 analytics, and cyber-based decision support systems can better support solving WM problems  
414 (Shevchenko et al., 2021b).

415 Personal protective equipment and plastic waste (cluster #4) has been identified as one of the  
416 prominent research clusters in COVID-related WM research. The major keywords and terms in  
417 this research themes are mask, face mask, plastic, plastic waste, landfill, contaminant, plastic  
418 pollution, surgical mask, polymer, and disposable mask. The high demand for personal protective  
419 equipment such as face masks, as the main equipment to protect humans against the pandemic, has  
420 led to approximately 1.6 million tons/day of plastic waste worldwide (Boix Rodríguez et al., 2021).  
421 Consequently, the disposal of such an unprecedented amount of personal protective equipment has  
422 posed significant challenges to WM practitioners and societies (Nowakowski et al., 2020), such as  
423 environmental pollution (Lee et al., 2021), recycling difficulties (Maderuelo-Sanz et al., 2021),  
424 redesigning and reduction of single-use plastics and personal protective equipment (Patrício Silva  
425 et al., 2020), and threat to the marine environment and coastal regions (Chowdhury et al., 2021;  
426 Dharmaraj et al., 2021). Rizan et al (2021) reported a total of 106,478 tonnes of CO<sub>2</sub> emission as  
427 the carbon footprint of distributing personal protective equipment during the first six months of  
428 the COVID-19 pandemic in England. Their scenario modeling of environmental mitigation  
429 strategies showed that UK manufacture would have reduced the carbon footprint by 12%, reusing  
430 gowns and gloves by 10%, eliminating gloves by 45%, and maximal recycling by 35%. However,  
431 imposing strict regulations for the public to properly dispose of face masks has become a  
432 significant challenge for governments worldwide (Dharmaraj et al., 2021). This highlights the  
433 importance of proposing effective and innovative solutions for face mask WM (Rehman and  
434 Khalid, 2021), such as using biodegradable materials in face mask production, recycling by  
435 obtaining liquid fuels through pyrolysis, and encouraging reusable and washable masks (De-la-  
436 Torre et al., 2021; Haddad et al., 2021).



437 The next research theme belongs to healthcare waste management practices (cluster #5) which is  
438 in line with the previous research theme. The main focus of the research included in this cluster is  
439 on challenges imposed by the pandemic outbreak on the healthcare facilities. In this vein, terms  
440 such as medical waste, waste generation, waste disposal, incineration, infectious waste,  
441 transportation, biomedical waste, healthcare waste, and hazardous waste have occurred frequently  
442 within the titles and abstracts of the research articles. In this cluster, the importance of proper  
443 healthcare waste management has been highlighted by many scholars in terms of controlling the  
444 environmental transmission of COVID-19 (Shammi et al., 2021), perception and attitudes towards  
445 medical waste disposal (Islam et al., 2020), water, sanitation, hygiene, and waste disposal practices  
446 as COVID-19 response strategies (Islam et al., 2021), energy generation from hazardous waste  
447 during the pandemic (Valizadeh et al., 2021), selection of the best healthcare waste disposal  
448 techniques (Manupati et al., 2021), bio-medical waste incineration (Thind et al., 2021), assessment  
449 of healthcare waste disposal technologies in terms of energy, environment, and economy (Zhao et  
450 al., 2021), and healthcare waste separation behavior (F. Chen et al., 2021). Wastewater  
451 management (cluster #6) and COVID-19 transmission through infectious waste (cluster #7) are  
452 considered as the mainstream research frontier regarding the prevention of SARS-CoV-2  
453 transmission. The main terms within the wastewater management research theme are wastewater,  
454 detection, surveillance, concentration, wastewater treatment plant, and sewage. On the other hand,  
455 presence, route, exposure, particle, surface, droplet, sludge, and aerosol are some of the main terms  
456 in the research theme of COVID-19 transmission through infectious waste. The research in these  
457 clusters have principally investigated the concentration of SARS-CoV-2 in wastewater (Cao and  
458 Francis, 2021), wastewater surveillance (Róka et al., 2021), Monitoring changes in COVID-19  
459 infection using wastewater-based epidemiology (Pillay et al., 2021), SARS-CoV-2 transmission

460 channels (Abd El-Wahab et al., 2020), and occupational exposure to SARS-CoV-2 in wastewater  
461 treatment plants (Dada and Gyawali, 2021).

#### 462 **4. Research agenda: gaps and potential avenues**

463 According to the performance indicators and thematic structures provided in the previous section  
464 through the bibliometric and text mining analyses, to address our third research question, we  
465 identified the following main research gaps and potential directions as the research agenda for WM  
466 post COVID-19:

467 • ***Adopting a system thinking approach for WM practices.*** As highlighted by Naughton (2020),  
468 there is a need for more real-time WM data and systems thinking approach regarding COVID-  
469 19 effects on waste generation and composition. However, due to the causal-effect links of the  
470 interconnected challenges imposed by the pandemic on WM activities, there is still a significant  
471 gap in the literature. This requires establishing a systemic framework to monitor and properly  
472 manage the pandemic crisis implications for WM practices as a whole. Accordingly, modeling  
473 and simulating the long-term effects of COVID-19 on waste generation and formulating  
474 appropriate policies are highly recommended for future research. The outputs of such research  
475 not only are helpful for COVID-19-recovery plans but also can be generalized and used as a  
476 guideline for handling similar crises in the future.

477

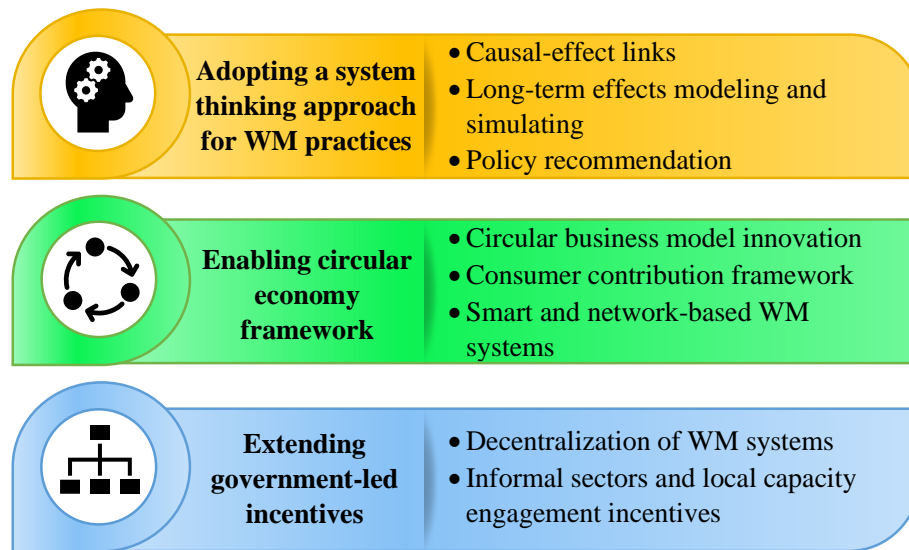
478 • ***Enabling circular economy framework.*** On one hand, the outbreak of the COVID-19 pandemic  
479 has led to an unprecedented demand for using personal protective equipment, in particular face  
480 masks, which generate a huge amount of waste across the globe. On the other hand, due to the  
481 infectious nature of the generated healthcare waste, reusing, repairing, and recycling programs

482 of such waste have faced serious challenges. Although limited research has been conducted on  
483 the potential of circular economy approaches to mitigate the effects of the pandemic on waste  
484 (Kumar et al., 2021; Pikoń et al., 2021; Sharma et al., 2021), research in this area is still in its  
485 immaturity stage and so far from practice and implementation in the real world. Therefore,  
486 building a circular economy framework from the design stage to the implementation stage is of  
487 high importance to effectively deal with COVID-related waste. On this basis, (i) innovative  
488 solutions to keep materials and products within the cycle as long as possible, (ii) consumer  
489 contribution to the circular economy transition in the healthcare industry, and (iii) developing  
490 smart and network-based WM systems to support WM activities towards a circular economy  
491 focusing on waste prevention and reduction, are proposed as potential avenues for further  
492 research in WM research agenda post COVID-19.

493

494 • ***Extending government-led incentives.*** In line with the research conducted by Sharma et al.  
495 (2021), decentralization of WM systems and practices with a bottom-to-top approach is  
496 recommended for policy-makers and authorities to better manage the newly emerged waste post  
497 the pandemic. We believe that there is no better time than now to plan for involving local  
498 communities in the WM activities. In this regard, developing encouraging plans and incentives  
499 to effectively involve informal sectors and local capacity in municipal waste management,  
500 especially in developing and less-developed countries, remarkably deserves to be deeply  
501 investigated in future research.

502 Fig. 8 summarizes the main directions for future research on WM practices in the wake of the  
503 pandemic.



504

505

**Fig. 8.** Future research agenda for WM research post COVID-19 era.

506

## 5. Conclusion

507 This study provided an inclusive map of the WM research in the context of the COVID-19  
 508 pandemic by conducting bibliometric and text mining analyses on a total of 1030 peer-reviewed  
 509 journal articles in the Scopus citation database. As a result, the performance of the COVID-related  
 510 scientific production in the WM field was mapped through analyzing and discussing bibliometric  
 511 performance indicators, including (i) geographical distribution of publications, (ii) authors  
 512 productivity and influence, (iii) main contributing journals and publications, and (iv) keyword-  
 513 based analysis to unfold research tendencies and hotspots. Besides, by conducting bibliographic  
 514 coupling, the following three main clusters of research in WM post COVID-19 were identified:  
 515 (a) plastic waste generation and management during the pandemic, (b) detection of COVID-19 in  
 516 wastewater, and wastewater surveillance during the pandemic, and (c) potential spread of COVID-  
 517 19, disinfection strategies and their associated challenges. The salient research themes of the target  
 518 literature were also identified by conducting text mining analysis on the titles and abstracts of the

519 articles as follows: (1) household and food waste, (2) personnel safety and training for waste  
520 handling, (3) sustainability and circular economy, (4) personal protective equipment and plastic  
521 waste, (5) healthcare waste management practices, (6) wastewater management, and (7) COVID-  
522 19 transmission through infectious waste.

523 The provided insights support researchers and policy-makers to better understand the effects of the  
524 pandemic on generating various waste streams and emerged challenges for WM practices and  
525 activities. As such, a research agenda based on the main research gaps was proposed for further  
526 studies, focusing on (i) system thinking approach to properly manage the pandemic crisis  
527 implications for WM practices as a whole, (ii) building a circular economy model from the design  
528 stage to the implementation stage, and (iii) proposing incentives to effectively involve informal  
529 sectors and local capacity in decentralizing municipal waste management, especially for  
530 developing and less-developed countries. Nevertheless, there are some limitations to this research.  
531 First, the sample data was retrieved from the Scopus database. Therefore, incorporating other  
532 databases, such as Web of Science, may enhance the reliability of the present research and further  
533 extend the findings. Second, non-English documents were excluded from our search, potentially  
534 missing some specific studies and practices in WM at a micro-level.

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