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Liquid waste management in the construction sector: a systematic literature review

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ABSTRACT

Liquid waste from construction sites can cause significant negative social, economic and environmental impacts. Generally, liquid waste from construction-related trades' activities, such as product mixing, application and tool washing; stormwater run-off; and leaching of construction material, can pollute surface soil, water bodies and groundwater sources. Therefore, construction projects must have proper management of construction-related liquid waste. This study therefore undertook a systematic literature review (SLR) to analyse the literature on liquid waste management in construction projects. The study used the PRISMA (preferred reporting items for systematic reviews and meta-analyses (method)) framework, and the bibliometric tool, VOSviewer, to analyse and present its findings. The SLR process identified and analysed 49 papers, published between 1992 and 2022, and found that liquid waste management was an often-overlooked area within the construction sector. The review identified three liquid waste focus areas: sources and composition of construction liquid waste; construction liquid waste control methods; and construction liquid waste management. The study's findings identified a lack of integration between research on liquid waste management and research studies on construction site water pollution. The study's contribution highlights the current progress of construction liquid waste management research and identifies the need for future research on efficient and effective implementation of liquid waste management practices in construction projects.

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Construction; liquid waste; liquid waste management; systematic literature review; wastewater

Introduction

The construction industry consumes 16% of the world's water (GBCA 2009). Approximately 17% of water is used for direct functions at construction sites, while indirect activities account for around 25% of water usage (Long 2021). Water is required for various activities during the construction process, such as earthworks; dust suppression; cleaning or wash-down of plant, equipment and tools; washing aggregates; landscaping; concrete batching and curing; and staff amenities (Rahman et al. 2019; WBHO 2019). The construction process generates liquid waste onsite including wash water used in trades' activities, stormwater run-off and groundwater (GBCA 2009; Karunasena et al. 2021). Generally, 20 L of liquid waste is discharged every minute due to construction activities (Karunasena et al. 2021). The type and volume of liquid waste generated from construction sites are impacted by internal factors, such as the stages of construction activities; type of construction; construction practices; and technology onsite and by external factors, such as changes in weather; standards and regulations; and geological conditions (Joshi et al. 2022). The main issue with the liquid waste generated due to construction activities is that it can contain particles, elements and chemicals harmful to humans, animals and the environment (Singh and Singh 2017). The main causes of construction liquid waste entering water bodies and the environment are: erosion from cleared sites; earthwork; stormwater run-off; rain; geography; geology; soil topography; insufficient liquid waste control methods; environmental discharges from wastewater treatment plants; lack of knowledge; issues in design; and lack of funding (Belayutham and González 2013; Belayutham et al. 2016a). These factors can also be identified as the challenges and/or limitations of liquid waste management practices. Consequently, a standardized liquid waste management process is needed for construction projects.

Previous studies on construction liquid waste are very limited in number. Most studies that considered waste management in construction focused on solid waste management aspects (Shooshtarian et al. 2019; Kabirifar et al. 2020; Ferronato et al. 2021; Mydin 2022). Of those studies that investigated liquid waste management, most focused on the physical, chemical and biological properties of liquid waste (Okparanma et al. 2018; Dos Reis et al. 2020), on treatment methods or on reuse of wastewater (Rakshit et al. 2022; Collivignarelli et al. 2019). Only three studies investigated the loopholes in wastewater discharge during construction (Belayutham and González 2013; Ock et al. 2016;

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Karunasena et al. 2021). However, it has been highlighted by researchers that liquid waste management practices are essential in construction (Karunasena et al. 2021; Joshi et al. 2022). Belayutham et al. (2016a) conducted an SLR for the period 1994–2014 on the causes of construction-related water pollution. However, to date, no study has undertaken an SLR on liquid waste management in construction. Therefore, this paper presents the SLR undertaken in the current study to identify prior research (from 1992 to 2022) on construction liquid waste management, with the aim being to understand the current state of the art on existing construction liquid waste practices. This review's findings could be used as a baseline for future research related to liquid waste management in the construction sector.

Research methodology

An SLR follows a transparent, systematized process to gain clear results (Rodrigues and Franco 2022). Petticrew and Roberts (2008) proposed that the SLR process should: 1) clearly plan the review; 2) determine and locate the types of studies; 3) screen and critically appraise the selected studies; 4) synthesize the study findings; and 5) disseminate the findings. Therefore, for the SLR analysis in the current study, PRISMA method (PRISMA 2021), a well-established SLR and meta-analysis method, was used to identify the most relevant contributions to the literature on 'the management of liquid waste discharge during construction'. Even though PRISMA sets the standard for publication, it allows the study's research questions to be clearly defined (Hamzah et al. 2022) and provides a 27-item checklist to assist researchers to conduct a systematic literature search (Moher et al. 2010). The systematic search strategy of PRISMA helps to minimize different types of bias and to effectively synthesize the findings. Therefore, this study selected the PRISMA method to ensure the quality and transparency of the SLR process, when identifying the relevant literature. A relationship and network analysis of the prior literature was conducted to gain an understanding of when research saturation had taken place and to identify areas needing further research. A bibliometric network software tool, VOSviewer, was used to visualize and present the results based on text data, keyword occurrence and authors' co-authorships.

As shown in Figure 1, the SLR methodology of this study consists of three phases: 1) data selection and collection; 2) data analysis and visualization; and 3) synthesis of results and conclusions.

Phase 1: data selection and collection

To perform the SLR, this study followed the PRISMA guidelines and PRISMA flow diagram. The data selection and collection process were based on the three stages (identification, screening and inclusion) specified in the PRISMA flow diagram. As shown in Figure 1, this process was conducted in two steps: literature search and decisions on the eligibility of publications.

Literature search

A systematic literature search was conducted in November 2022. To answer the research question (see Table 1), articles that met the criteria presented in Table 1 were considered.

The search was conducted on Scopus and Web of Science databases. The search process was first conducted to detect publications that included the following search items in their titles, abstract or keywords.

Scopus

TITLE-ABS-KEY (('construction industry') AND ('wastewater' OR 'liquid waste' OR 'groundwater' OR 'wash water' OR 'stormwater' OR 'trade water' OR 'trade waste'))

Web of science

TS= ((('construction industry') AND ('wastewater' OR 'liquid waste' OR 'groundwater' OR 'wash water' OR 'stormwater' OR 'trade water' OR 'trade waste')))

Figure 1. Systematic literature review (SLR) methodology.

Table 1. Criteria for literature search.

Research question	How can wastewater generated during construction be managed effectively?
Keywords/Search terms	'wastewater' OR 'liquid waste' OR 'groundwater' OR 'wash water' OR 'storm water' OR 'trade water' OR 'trade waste' AND ('construction' OR 'building development')
Databases	Web of Science, Scopus
Dates the search was conducted	10.11.2022 to 17.11.2022
Years covered	1992–2022
Language restrictions	English only

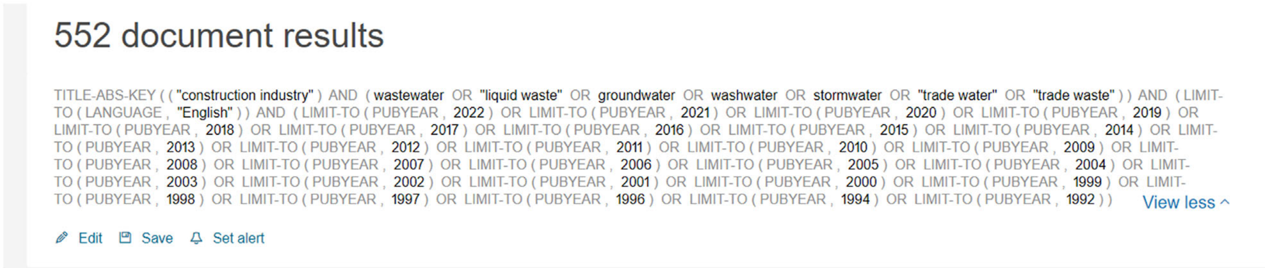

Figure 2. Scopus search.

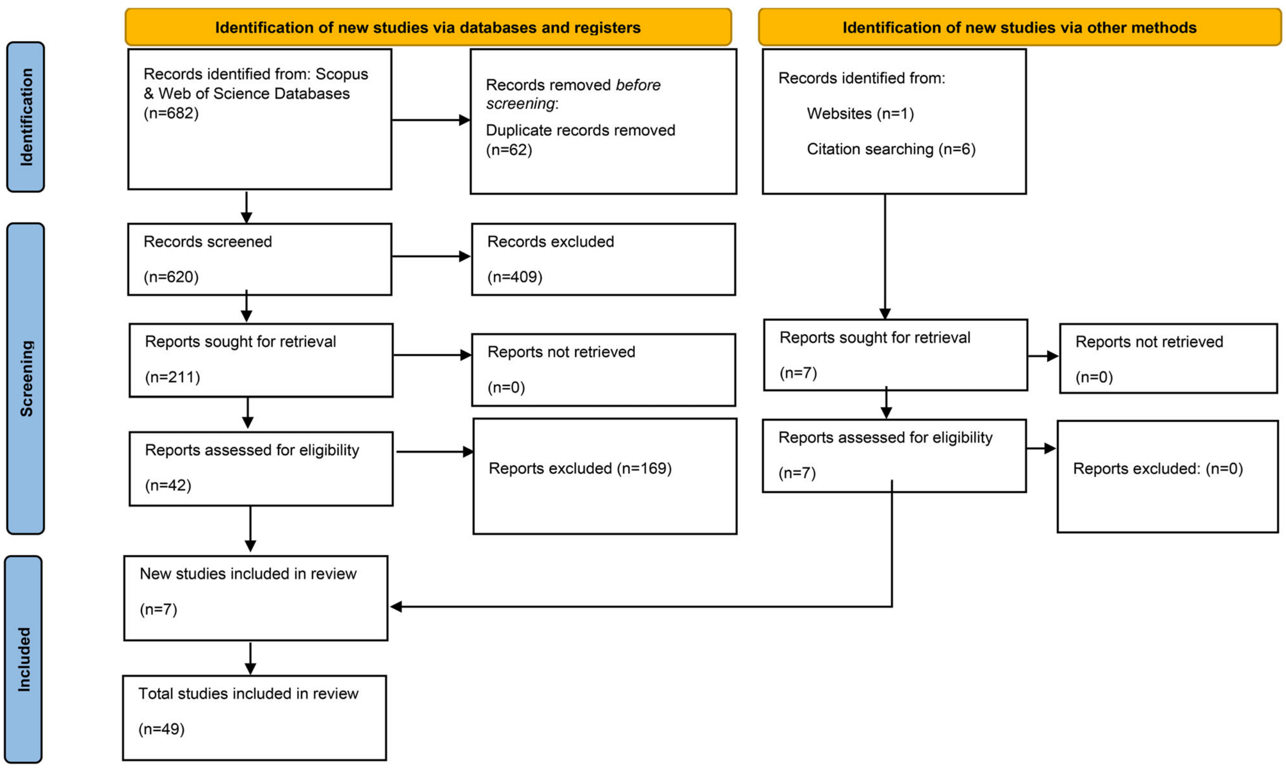

Figure 3. Literature search and eligibility assessment – PRISMA flowchart. Adapted from Page et al. (2021).

The search was limited to all publications published in English between 1992 and 2022, and was conducted using 'OR' and 'AND' statements. For example, the Scopus search process is shown in Figure 2.

Figure 3 shows the study's literature search and eligibility assessment flow chart which was developed based on the PRISMA flow chart. Overall, 682 results (552 from Scopus and 130 from Web of Science) were identified through the search process. The results were extracted into comma-separated values (CSV) files and converted to Microsoft (MS) Excel files for analysis. This step helped to extract publication data, remove duplicates and screen publications based on their abstract and topic. In this process, 62 duplicate records were removed. Only publications reporting on studies related to the management of liquid waste generated during the construction process were considered in this analysis. Through the title and abstract screening process, 409 records were excluded as their titles were not relevant to the study's scope and objectives: also excluded were publications without an abstract.

Eligibility of publications

The full texts of the remaining 211 publications were then read, and their eligibility, based on the current study's scope, was assessed. In all, 169 publications were excluded as the studies that they documented had not explored liquid waste generated in the construction process. Finally, the remaining 42 publications were considered eligible for further analysis. Additionally, seven studies were identified through searching websites ($n = 1$) and citations ($n = 6$). Therefore, in total, 49 publications were deemed eligible for further analysis. The Mendeley Reference Manager's open-source tool was used to organize the final set of 49 publications (Mendeley 2019).

Phase 2: data analysis and visualization

The publications identified in Phase 1 were classified based on the articles' construction domains, such as building, infrastructure and industrial. The articles were then reviewed based on research criteria, such as authors, the year of publication, names of journals and conferences, the technique and method used, research objectives, research gap and problem, solutions presented, etc. The bibliometric network software tool, VOSviewer, was used to present and visualize the results. VOSviewer is a popular free tool used in an SLR to identify bibliometric networks based on text data and keyword co-occurrence, and

Table 2. Details of journals.

Journal	No.	Publisher	Field
Environmental Monitoring and Assessment	2	Springer International Publishing	Environmental risks
Environmental Science and Technology	1	American Chemical Society	Environmental science
Expert Systems with Applications	1	Elsevier	Expert and intelligent systems
Hydrological Processes	1	John Wiley & Sons Ltd	Movement and storage of water, run-off, groundwater, sediment
Journal of Civil Engineering and Management	1	Taylor & Francis Ltd	Building materials, geotechnical engineering, constructions technology, economy, management
Journal of Cleaner Production	2	Elsevier	Cleaner production and technical processes, sustainable development, environmental and sustainability assessment, sustainable products and services, governance, legislation, policy for sustainability
Journal of Environmental Management	1	Academic Press	Management and valorization of waste, environmental analysis and assessment, social, economic and policy aspects of environmental management
Journal of Irrigation and Drainage Engineering	2	American Society of Civil Engineers (ASCE)	Water management and conservation, environmental impacts
Materials	1	MDPI AG	Materials science, materials engineering
Nature Environment and Pollution Technology	2	Technoscience Publications	Solid waste management, wastewater treatment and recycling, etc., monitoring, control and management of water and soil pollution
Road Materials and Pavement Design	1	Taylor & Francis Ltd	Road construction
Science of the Total Environment	1	Elsevier	Water quality, environmental remediation of soil and groundwater, environmental impacts of waste or wastewater
Sensors	1	MDPI AG	Machine/deep learning and artificial intelligence (AI) in sensing and imaging
Transportation Research Record	2	SAGE Publications Ltd	Policy, planning, administration, economics and financing, operations, construction, design, maintenance
Waste Management	2	Elsevier	Waste management policy, education, economic and environmental assessment
Water (Switzerland)	1	MDPI AG	Water science, technology, management and governance
Water Practice and Technology	1	IWA Publishing	Water and wastewater treatment and management
Water Research	1	Elsevier	Water cycle, water quality, water management
Applied Ecology and Environmental Research	1	Corvinus University of Budapest	Environmental protection
Water Science and Technology	1	IWA Publishing	Water and wastewater treatment and management
Journal of Construction Engineering and management	2	American Society of Civil Engineers (ASCE)	Science of construction engineering and construction practices
Journal of Environmental Quality	1	John Wiley & Sons Ltd	Environmental science, waste management and disposal, water science and technology
Journal of Applied Sciences	1	Asian Network for Scientific Information	Environmental protection
Public Works Management & Policy	1	SAGE Publications Ltd	Policy, planning, administration
Journal of Infrastructure Systems	1	American Society of Civil Engineers (ASCE)	Civil infrastructure systems
Water and Wastewater International	1	Water and Wastewater International	Earth science

authors' co-authorship networks of terms (Anastasiadou et al. 2021; Zabin et al. 2022; Di Vaio et al. 2023).

Phase 3: synthesis of results and conclusions

The findings derived in Phase 2 were then discussed in relation to the research question to propose recommendations and draw conclusions.

Results and discussion

Analysis of journal articles and conference papers

In this study, 49 publications were analysed, with this including 33 journal articles. Table 2 presents a summary of these journals with associated information, such as the journal name, field of research and number of publications in each journal. Two publications were identified in each of the following journals: *Environmental Monitoring and Assessment*, the *Journal of Cleaner Production*, *Journal of Irrigation and Drainage Engineering*, *Nature Environment and Pollution Technology*, *Transportation Research Record*, *Waste Management* and *Journal of Construction Engineering and Management*. Only one publication was identified in each of the remaining 19 journals. The top publishers with the most publications were Elsevier (5), MDPI AG (3), American Society of Civil Engineers (ASCE) (3), SAGE Publications Ltd (2) and Taylor & Francis Ltd (2). In terms of research areas, the analysed journal articles mainly related to water management and environmental management.

The search also identified 12 conferences where relevant papers were published in the conference proceedings. Table 3 presents a summary of these conferences. The conferences' major research areas were related to the environment, energy and earth sciences. Only five of the 12 conference proceedings focused specifically on construction and liquid waste.

This study also identified two reports on liquid waste management and two book chapters on water pollution in construction. As both publications include content highly related to the scope of this study, they were considered in the analysis.

The literature analysis based on areas of publication showed that research into liquid waste management in construction is dispersed across a wide range of research topics, ranging from

Table 3. Details of conferences.

Conference	No.	Publisher	Field
Winter Simulation Conference	1	Institute of Electrical and Electronics Engineers Inc.	Construction
IECA Virtual Annual Conference and Expo 2021	1	International Erosion Control Association	Environment, energy and earth sciences
E3S Web of Conferences	1	EDP Sciences	Environment, energy and earth sciences
IOP Conference Series: Earth and Environmental Science	1	IOP Publishing Ltd	Environment, energy and earth sciences
World's Largest: Soil and Water Event – Environmental Connection 2017	1	International Erosion Control Association	Environment, energy and earth sciences
MATEC Web of Conferences	1	EDP Sciences	Environment, energy and earth sciences
IOP Conference Series: Materials Science and Engineering	1	Institute of Physics Publishing	Materials science and engineering
44th Australasian Universities Building Education Association (AUBEA) Conference	1	Deakin University	Construction
Annual Conference of the International Group for Lean Construction (IGLC)	1	IGLC-21	Construction
American Society of Mechanical Engineers (ASME) Energy-Sources Technology Conference and Exhibition (ETCE)	1	US Department of Energy – Office of Scientific and Technical Information	Environment, energy and earth sciences
International Erosion Control Association Conference	1	Erosion Control Association	Construction, environment, energy and earth sciences
2010 International Conference on Management and Service Science	1	Institute of Electrical and Electronics Engineers Inc.	Construction

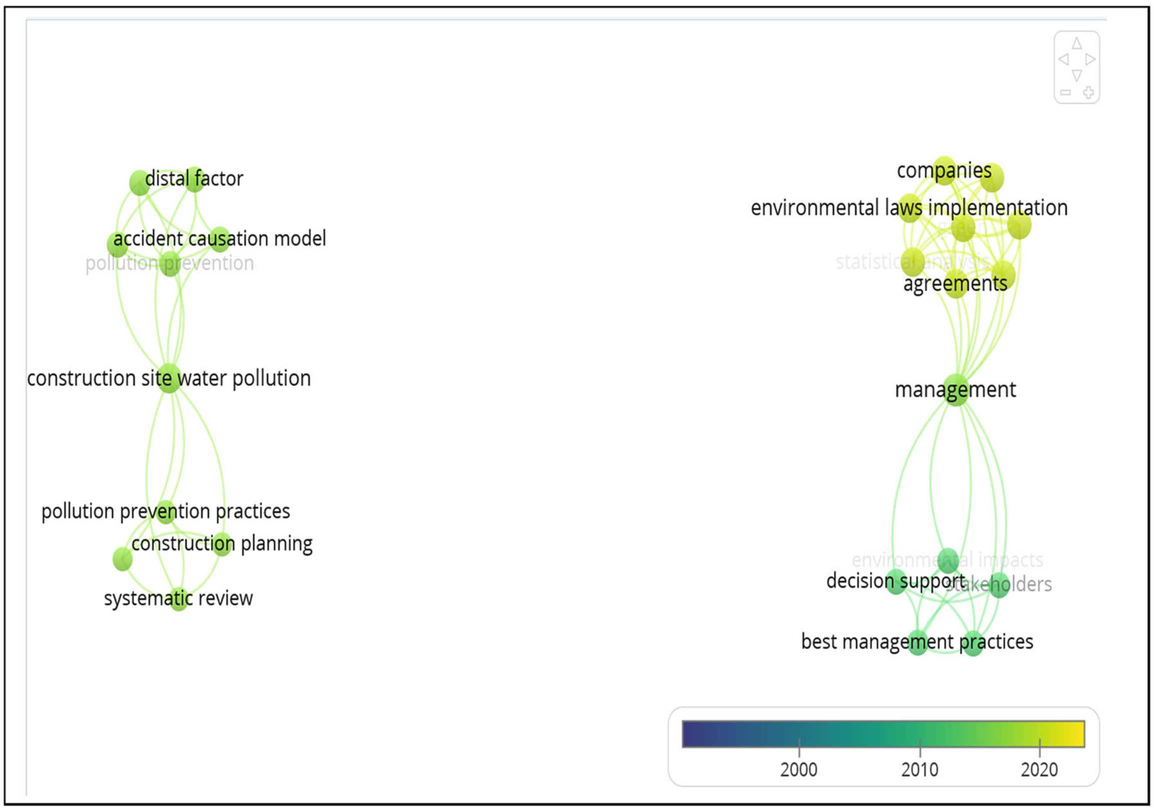

Figure 4. Keyword co-occurrence by year.

environmental pollution to construction management, with no saturation reached in a specific area.

Keyword co-occurrence analysis

The keyword co-occurrence analysis was conducted using the VOSviewer tool. This analysis utilized a full counting method and consisted of 24 screened terms, with one being the minimum number of occurrences for a keyword.

In the keywords used in the co-occurrence analysis, four clusters were found, as shown in Figure 4. As shown, the biggest nodes for each of the four clusters are management, construction site water pollution, environmental law implementation and accidental causation model. It should be noted that studies on stormwater pollution are considered under construction site management. Studies on wash water, groundwater or trade water are not presented under site water pollution or construction site management. Furthermore, management and environmental law implementation are interrelated. However, it should also be noted that no relationships are found between keywords related to management and environmental law implementation with construction site water pollution. The results show the lack of research on the impact of the implementation of legislation on construction site-related water pollution. The analysis results also

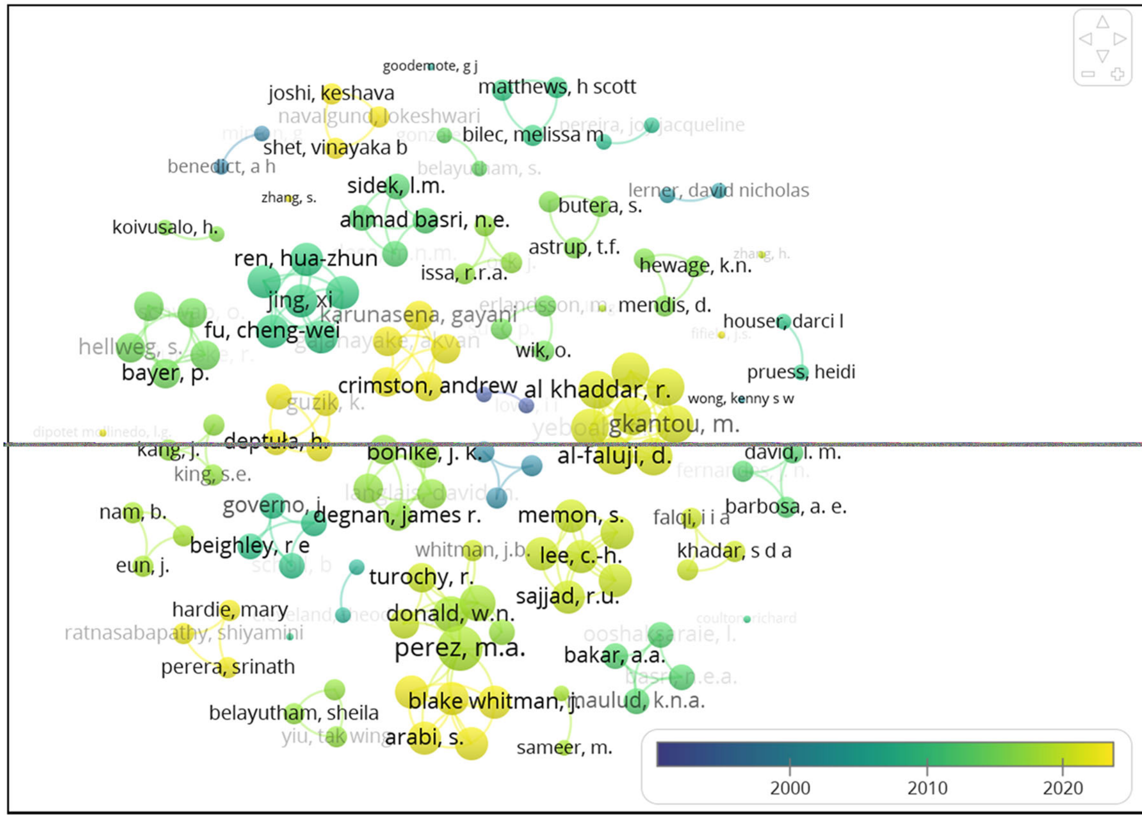

Figure 5. Authors' co-authorship network based on year.

show that keywords related to management and environmental law occur in articles published between 2012 and 2020, whereas keywords related to construction site water pollution occur in articles published between 2014 and 2020. This illustrates that construction liquid waste management has traditionally been viewed from a water pollution perspective, with the focus on management and legislative practices being a more recent development.

Authors' co-authorship analysis

The analysis of authors' co-authorship was conducted with the VOSviewer tool using the full count method. The analysis considered the minimum threshold of authors as two, with seven authors meeting the threshold. However, all authors are included in the analysis, as shown in Figure 5. The top 10 authors are Perez, M.A. (6 documents; link strength: 20); Donald, W.N. (6 documents; link strength: 17); Zech, W.C. (6 documents; link strength: 17); Fang, X. (3 documents; link strength: 9); Al Khaddar, R. (1 document; link strength: 7); Al-Faluji, D. (1 document; link strength: 7); Alkizwini, R.S. (1 document; link strength: 7); Alyafei, A. (1 document; link strength: 7); Gkantou, M. (1 document; link strength: 7); and Hashim, K.S. (1 document; link strength: 7). Link strength indicates the number of co-authorship links of a given researcher with other researchers (van Eck and Waltman 2017). As shown, overall, the publication dates of the author cluster range from 1992–2022. The largest cluster is for the top four authors, ranked by link strength, with publications between 2016 and 2022.

The co-authorship analysis shows that researchers in this area work very much in siloed research groups with very little cross-collaboration. This finding, together with previous findings in the journals and keywords analyses, illustrates that research is carried out with a focus on specific topic areas, most probably guided by the researchers' research interests and expertise, rather than the significance and potential impact of research outcomes.

Country-wise analysis

Figure 6 presents the country-wise distribution of studies on construction liquid waste management.

These findings show that, other than in the United States of America (USA), studies on construction-related liquid waste management are lacking in most parts of the world, including Australia. The analysis findings show that studies on construction liquid waste management and published in research publications have been conducted in countries in North America, Europe, Asia and Oceania. The USA has the highest number of studies while other countries, such as New Zealand, China, Australia and Malaysia, have very few publications.

Therefore, to understand the impact of liquid wastewater management during construction in different parts of the world, more investigation is required. The saturation of studies from one country can indirectly influence these results by being generalized across other jurisdictions. These generalizations may not portray an accurate picture given that construction processes and impacts on the environment, as well as countries' legal structures are different across regions. This is exacerbated by the recent increase in the number of papers focusing on management and regulatory aspects which can vary drastically across different countries.

Focus areas of construction liquid waste management research

This section reports the results from the SLR in which 49 articles were analysed to identify liquid wastewater management

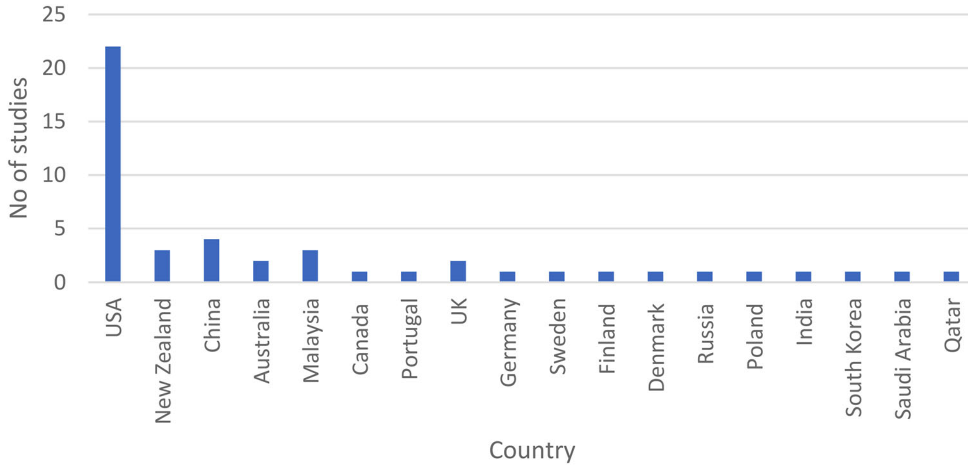

Figure 6. Country-wise breakdown.

Table 4. Focus areas.

No.	Focus area	Subcategories
1	Sources and characteristics of liquid waste	• Pollutants leaching from building materials. • Pollutants leaching from materials used in road/earth construction. • Pollutants from washing machinery, tools and vehicles • Total suspended solids (TSS)
2	Construction liquid waste control methods	• Prevention of groundwater contamination • Stormwater run-off control and control of leaching material • Reuse and recycling • Use of advanced information technology (IT) tools
3	Construction liquid waste management	• Liquid waste discharge management • Regulatory requirements

practices during construction. The keyword occurrence analysis showed that the studies in relation to liquid waste management can be under two areas 1. construction site water pollution and 2. management of construction site water pollution. However, based on full text analysis of the articles, the research outputs of these studies contributing to construction liquid waste and management area can be further categorized under three major focus areas: 1) sources and characteristics of liquid waste; 2) construction liquid waste control methods; and 3) construction liquid waste management. Table 4 summarizes the findings under each focus area.

Sources and characteristics of liquid waste

The sources of construction liquid waste vary based on the processes which created the waste. Wastewater can be created by construction activities such as the airlifting process for cleaning bore piles; cleaning of tools and equipment; washing of construction material; discharge of water used in concreting; and demolition (Belayutham et al. 2016b; Degnan et al. 2016; Kazaz et al. 2021). These forms of liquid waste can contain various pollutants. According to one study (Butera et al. 2015), erosion, run-off and sediment are the most common sources of wastewater generation in construction. Erosion is caused through clearing the site; works near sensitive areas; earthworks; stormwater run-off; natural factors (soil, topography, rain, geography); control facilities (unavailability, insufficient, not well-maintained systems); designers' issues (documentation error, failure to cooperate, lack of enforcement, knowledge deficiencies, design fault); unfavourable season (winter, rainy); being either planned or pushed due to contractors' issues (process error, negligence, poor practices, waiting time and delays during earthwork and site development); schedule change; and clients' issues (limited land area, lack of funding) (Belayutham and González 2013; Butera et al. 2015; Belayutham et al. 2016b).

Construction liquid waste can be categorized under physical characteristics, chemical characteristics and biological characteristics (Kang et al. 2016). Few studies investigate the physical characteristics of liquid waste, for example, total suspended solids (TSS) (Houser and Pruess 2009; Belayutham and González 2013; Sillanpää and Koivusalo 2015; Degnan et al. 2016; Kang et al. 2016; Mansour et al. 2019). Several studies investigate the chemical properties of liquid waste (Kang et al. 2016; Kazaz et al. 2021) highlighting that washing tools, equipment and materials can release toxic chemicals (e.g. oil, grease, solvents, paint, cleaning agents, hydrocarbons, etc.) into wastewater. Some studies assess the toxic impacts of heavy metals; nitrate (NO_3) sources; polymer composites; and ash mixed with hot-mix asphalt leaching from industrial mineral waste in road and earth construction (Schwab et al. 2014; Tasneem et al. 2017; Liu 2018; Wakida and Lerner 2002; Mollinedo 2021). These studies highlight that pollutants, such as those listed, can cause groundwater contamination. One study (Degnan et al. 2016) investigates how the demolition process in construction can release toxic contaminants into liquid waste. A lack of studies in the literature investigating biological characteristics (microorganisms) is apparent as construction wastewater does not contain biological components (Kang et al. 2016).

It can be concluded that, with the most common source of construction liquid waste being erosion and stormwater run-off, its toxicological effects could be minimal. However, even though other forms of liquid waste are low in volume compared to stormwater and groundwater, their toxicological effects need to be more carefully considered.

Construction liquid waste control methods

As shown in Table 4, most studies related to construction liquid waste management are focused on control methods and techniques. Studies on liquid waste control methods and techniques can be found under prevention of groundwater contamination; sediment control; stormwater run-off control; control of leaching building and construction materials; and reuse and recycling of liquid waste. Control strategies proposed by several studies for the prevention of groundwater contamination include planning construction development that is fit for the site layout; determining the limits of land clearing and shaping; minimizing excavation; trenching activities; proper housekeeping; preserving topsoil; and assigning designated areas to collect liquid waste from the construction work (Goodemote 2005; Faucette et al. 2009; Coulton 2010; Butera et al. 2015; Belayutham et al. 2016a, 2016b; Alyafei et al. 2020). Findings in the literature also reveal that most studies are focused on prevention and control of stormwater run-off and sediment control. Several studies discuss chemical treatment methods such as sedimentation and neutralization (Kang et al. 2016); coagulation and sedimentation (Kang et al. 2016); adsorption and electrochemical techniques (Kang et al. 2016); and the flocculated sediment polyacrylamide (PAM) method (Minton and Benedict 1999; Karunasena et al. 2021). A few studies investigate mechanical control strategies such as drainage control and slope stabilization (Butera et al. 2015; Belayutham et al. 2016b); horizontal directional drilling (Lowe and Watkins 1994); and sediment barriers (Zhang 2021; Faucette et al. 2009). Another study investigates biological treatment processes (aerobic and anaerobic) (Kang et al. 2016). Studies related to stormwater control in construction sites explore control measures such as site layout management; election of construction methods; the construction schedule; sequencing matters of concern such as land clearing and grading during the wet season, construction phasing for minimal exposure and construction sequencing to reduce equipment activities; changes to the natural slope and drainage system; sampling and monitoring stormwater suspended solids; and use of wire-backed non-woven geotextile silt fences (EPA 2009; Belayutham and González 2013; Butera et al. 2015; Belayutham et al. 2016b; Degnan et al. 2016; Sameer and Rustum 2017). The review highlighted that most studies focus on managing stormwater rather than wash water or liquid waste that could include chemical or biological pollutants.

Several studies consider the application of advances in drone technologies and information technologies for stormwater and sediment control, with this being an important research area. Within this domain, a few studies investigate expert systems for solving erosion and the sediment control problem generated by construction activities. These systems include the knowledge-based expert system, Multi-Criteria Erosion and Sediment Control (Alyafei et al. 2020); the decision support system for groundwater, surface water, and abstraction and return waters (Xu et al. 2010); Autodesk Building Information Modelling (BIM) tools and Civil 3D tools identifying an optimal detention pond location (Ooshaksaraie et al. 2012); the RP^{3}CA (River Pollution Prevention Plan during Construction Activity) expert system with geographic information system (GIS) functions to mitigate stormwater pollution (Perera et al. 2021); and SEDspread, a spreadsheet-based application for sizing temporary sediment basin parameters (Perez et al. 2016, 2017, 2019). Studies such as (Kozicki et al. 2021) and (Sajjad et al. 2019) investigate the use of unmanned aerial vehicles for inspecting erosion and sediment control on sites, with these vehicles aiding the implementation of construction stormwater practices on sites. Studies also explore the application of deep learning-based object detection principles and images to accurately conduct construction stormwater inspections on construction sites (Liu 2018; Kozicki et al. 2021). These novel technologies aid engineers, contractors and decision makers on construction projects in effectively and efficiently planning erosion and sediment control. Unsurprisingly, most studies on the use of digital technology such as machine learning, drones and BIM for stormwater and sediment control can be found in more recent years between 2015 and 2021.

Recycling and reuse of liquid waste generated in construction processes are another area that several studies investigate. Recycling of wastewater purifies the water and eliminates unpleasant odours (Donald et al. 2016). Recycling of effluent in the construction industry includes the filtration electrocoagulation method; biological treatment (aerobic and anaerobic processes) and electrochemical techniques (Barbosa et al. 2012; Perez et al. 2015; Kang et al. 2016; Wong 2002); and the closed loop wastewater recycling system for treatment of wastewater from manual washing of machines and construction equipment (Suer et al. 2014; Donald et al. 2016; Kang et al. 2016). The treated wastewater can be reused for other purposes. Two studies (Ock et al. 2016; Ahmad 2022) highlight that proper housekeeping is important for the control of construction liquid waste. Machinery, concrete mixers and tools should be cleaned outside the construction site, with the wastewater discharged at a designated place. It is also highlighted that appropriate discharge of sewage from toilets at the construction site needs to be ensured (Ahmad 2022). Overall, studies focus more on recycling and/or reuse of stormwater and effluent generated in construction sites, and less so on recycling and/or reuse of wash water which can contain more harmful chemicals.

Construction liquid waste management systems

Few studies investigate a framework for liquid waste management, with a specific focus on stormwater, sediment control and the impact of sewer discharge of construction waste. Studies (Belayutham et al. 2016b) and (Butera et al. 2015) propose that construction-related stormwater management systems need to consider the site layout, construction methods and construction schedule. Under site layout, sensitive areas need to be considered, such as easily compacted soil, natural preservation areas, drainage channels, protection for native soil and natural vegetation areas, fencing in relation to the existing tree canopy, proper signage, staging area, storage areas and washing bays (Butera et al. 2015; Belayutham et al. 2016b). Construction methods for work such as trenching and excavation need to reduce and minimize activities that involve soil compaction, while trees or woody vegetation should be cut rather than pushed over with equipment, excavations should be restricted in sensitive areas and equipment with the least ground pressure should be used (Butera et al. 2015; Belayutham et al. 2016b). Phasing the activities is also important. Therefore, when scheduling the project, the following points need to be considered: establishing phases of construction within the work zone; developing the sequence of construction and methods to be used within the phases and schedule; phasing the grading and earthmoving operation to expose the smallest practical area for the shortest possible time; and scheduling large disturbance activities, such as clearing, grading and heavy construction activities during dry season (Butera et al. 2015; Belayutham et al. 2016b). One study (Ahmad 2022) investigates the development of a construction waste management system from the perspective of the supply chain and green sustainable development. Although the study has not entirely focused on liquid waste management, it highlights that the logistics, capital flow and information flow of the operating network need to be considered for an effective waste management system. In addition, one study (Belayutham et al. 2016b) highlights that construction liquid waste management needs to consider planning its operation to fit the existing site features; establishing erosion and sediment practices; scheduling activities; selection of proper methods, materials and equipment; access route, site layout and management; inspection; maintenance; training; enforcement; housekeeping; etc.

Only four studies investigate the regulatory requirements associated with construction liquid waste management, two of which explore the regulatory requirements and practices related to liquid waste generated during construction projects in Australia (Perez et al. 2015; Kazaz et al. 2021). Both studies stipulate that improvements are needed in Australia's current regulatory framework and level of awareness related to trade wastewater management. Tilford et al. (2000) and Begum and Pereira (2008) suggest that a legal framework for understanding the impacts of construction liquid waste is required to improve contractors' awareness. A study in Saudi Arabia, Mendis et al. (2015) highlight that more attention needs to be given to construction-related wastewater discharges, with further investigation necessary in the area of auditing and increased availability of review teams on environmental practices. A study in Canada investigates the rework/waste generation due to ambiguity/errors in construction contract documents (Ock et al. 2016). The study highlights that ambiguity in contractual clauses can lead to ineffective management of construction waste, including liquid waste. A life cycle assessment model developed by Bilec et al. (2010) to aid decision making is used to analyse the impact of construction liquid waste.

As the above analysis shows, few studies investigate approaches for better liquid waste management in the construction process (Ooshaksaraie et al. 2012; Schwab et al. 2014; Butera et al. 2015; Mendis et al. 2015; Perez et al. 2015; Belayutham et al. 2016b; Kang et al. 2016; Kazaz et al. 2021; Perera et al. 2021; Ahmad 2022). Moreover, most studies focus on controlling or reducing the biological, chemical and physical properties of liquid waste or on methods and techniques for controlling the liquid waste generated on construction sites (Belayutham and González 2013; Butera et al. 2015; Perez et al. 2015; Belayutham et al. 2016a, 2016b; Degnan et al. 2016; Donald et al. 2016; Kang et al. 2016; Perez et al. 2016, 2017, 2019; Sameer and Rustum 2017; Tasneem et al. 2017; Liu 2018; Sajjad et al. 2019; Whitman et al. 2019; Zhang 2019, 2021; Mollinedo 2021; Alyafei et al. 2020; Fifield 2021; Karunasena et al. 2021; Kazaz et al. 2021; Kozicki et al. 2021; Joshi et al. 2022). Section 3.4 discusses the current lack of integration between research on liquid waste management and research studies on construction site water pollution. This study's review highlights the lack of research on system-wide analysis of liquid waste management in the construction sector. A system-wide understanding is important as liquid waste management relies heavily on the regulatory environment and existing infrastructure within a region. Given the site-specific nature of construction projects and construction's temporary nature, more attention needs to be paid to how liquid waste management fits into a region's water and wastewater management system. Therefore, further investigation is needed on the relationship of liquid waste management practices with the construction industry and the associated regulatory framework.

Conclusion

In conclusion, this study has conducted a systematic review of studies in the literature on liquid waste management in construction. The study used the PRISMA framework combined with the bibliometric tool, VOSviewer, to analyse and present the findings. The PRISMA framework helped to systematically collect and screen the literature, with 49 records filtered from 682 records through this process for analysis. The VOSviewer visualization helped to map the links between keywords and authors' co-authorship. This process helped to develop a deeper understanding of the status and development of construction liquid waste management as a research area. The number of relevant papers identified for this review highlights the lack of research focus on liquid waste management within the construction sector. This is in stark contrast to solid waste management in the construction sector, which the construction and waste management disciplines both have as their focus. The lack of research does not necessarily mean that liquid waste is less important than solid waste from either social or ecological points of view. The socio-environmental impacts of construction liquid waste can be significant, with negative impacts on natural water systems and sewer and wastewater infrastructure, while construction waste is typically considered to be inert material.

The analysis of author networks found that research on construction liquid waste has been carried out in a very single discipline-oriented manner, with very few transdisciplinary studies. Collaboration across research teams is found to be minimal: this can result in research being guided by the researchers' research interests and expertise, rather than the significance and potential impact of research outcomes. The current study's findings show the lack of integration between research on liquid waste management and the research studies on construction site water pollution. In the 30-year time period investigated between 1992 and 2012, most studies focused on construction liquid waste characteristics and sediment control mechanisms. However, from 2000 to 2022, the amount of research on the management and regulatory factors of construction liquid waste has been gradually increasing. This review's analysis of 49 publications identified the following three focus areas related to liquid waste management in construction: construction liquid waste sources, construction liquid waste control methods and construction liquid waste management. This study also highlighted that most studies focus on management methods for stormwater and groundwater, with minimal focus given to recycling and reuse activities, especially to wash water from trades' activities which can have higher levels of pollutants. Future studies could undertake further investigation on effective management of liquid waste, and on regulatory requirements and methods that can best address the prevailing challenges in liquid waste management. Therefore, the contribution of this study is to highlight the current progress in construction liquid waste management research and to highlight the need for future research on efficient and effective implementation of liquid waste management practices in construction.

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