St Germain, Dante

From: Clarence Hixson <budhix@iglou.com>
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To: St Germain, Dante
Subject: exhibits for commissioners 22-ZONE-0073
Attachments: Impact of Sewer Overflow Article.pdf; 1996 SSO policy.pdf

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Direct contact with and proximity to bioaerosols from CSO effluents have been linked to increased elevated risks of **asthma, gastrointestinal illnesses and skin and soft tissue infections in children residing near SO sites** (Brokamp et al, 2017). Also, inadequate water and sanitation infrastructure for disposal and treatment of sewage also contributed to Covid-19 transmission (Eichelberger et al., 2021). SO have been linked to **elevated fecal pathogen concentration** and prevalence of antibiotic resistant bacteria in Germany (Stange and Tiehm, 2020). SO and runoff serve as environmental driving forces of particle-attached pathogens during storms with significant consequence to both ecosystem and public health (Jørgensen et al., 2018; Noyer et al., 2020). SOs and floods serve as potent threat to spread co-resistant and cross-resistant pathogens due to shifts in pathogen communities and this risk is expected to increase with current trend of increased climate change and urbanization (Noyer et al., 2020).

"The Cabinet requires a demonstration that both the sewer system and the WWTP have adequate capacity to transport and treat the durrent **and the anticipated flow from the new connection.**

If there are known active sanitary. sewer overflows in the system, the Cabinet would **deny the sewer line extension,** even if the WWTP had adequate capacity to treat the additional flow, unless the owner of the sewer system is addressing the condition by implementing an approved pian for investigation and remediation.

Discharges from sanitary sewer overflows are **illegal discharges** and indicate that the system does not have adequate capacity to transport the existing flow.
~ It is unwise and irresponsible to add additional flow to a sewer system that does not have the capacity to transport the existing flow."

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"If only it were all so simple! If only there were evil people somewhere insidiously committing evil deeds, and it were necessary only to seperate them from the rest of us and destroy them. But the line dividing good and evil cuts through the heart of every human being. And who is willing to destroy a piece of his own heart?

Aleksandr Solzhenitsyn, The Gulag Archipelago, 1918 - 56.

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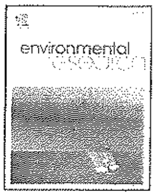

Impact of sewer overflow on public health: A comprehensive scientometric analysis and systematic review

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ABSTRACT

Sewer overflow (SO), which has attracted global attention, poses serious threat to public health and ecosystem. SO impacts public health via consumption of contaminated drinking water, aerosolization of pathogens, food-chain transmission, and direct contact with fecally-polluted rivers and beach sediments during recreation. However, no study has attempted to map the linkage between SO and public health including Covid-19 using scientometric analysis and systematic review of literature. Results showed that only few countries were actively involved in SO research in relation to public health. Furthermore, there are renewed calls to scale up environmental surveillance to safeguard public health. To safeguard public health, it is important for public health authorities to optimize water and wastewater treatment plants and improve building ventilation and plumbing systems to minimize pathogen transmission within buildings and transportation systems. In addition, health authorities should formulate appropriate policies that can enhance environmental surveillance and facilitate real-time monitoring of sewer overflow. Increased public awareness on strict personal hygiene and point-of-use-water-treatment such as boiling drinking water will go a long way to safeguard public health. Ecotoxicological studies and health risk assessment of exposure to pathogens via different transmission routes is also required to appropriately inform the use of lockdowns, minimize their socio-economic impact and guide evidence-based welfare/social policy interventions. Soft infrastructures, optimized sewer maintenance and prescreening of sewer overflow are recommended to reduce stormwater burden on wastewater treatment plant, curtail pathogen transmission and marine plastic pollution. Comprehensive, integrated surveillance and global collaborative efforts are important to curtail on-going Covid-19 pandemic and improve resilience against future pandemics.

1. Introduction

Sewer overflow (SO) is the release of raw or poorly treated wastewater and fecal-derived pathogens into the environment, which could be land, water bodies (e.g. sea, river, swimming pool, etc.), groundwater or air. SO is a threat to the global ecosystem because it pollutes air, groundwater and surface waters (Nad et al., 2019). Therefore, SO control is highly important in megacities due to their ubiquitous impervious surfaces that have disrupted natural hydrology ([illegible] 2018). Consequently, there is an increase in stormwater runoff. Furthermore, many cities discharge pathogen-laden wastewater into water bodies, which can lead to an outbreak of epidemics. Previous outbreaks have been linked to the transmission of food-chain pathogens via pathogen-laden wastewater, person-to-person transmission, and close contact with infected animals (Al-Omari et al., 2019; Caplin et al., 2008; MacKay and Arden, 2015).

Furthermore, recent studies have reported pathogen transmission due to aerolized pathogens and leakages in plumbing systems in hospitals and high-rise buildings (Ding et al., 2021; Gormley et al., 2020; Kotay et al., 2019; Spiklin, 2019; WHO, 2020). Another study also reported sewer overflow into groundwater as a result of faulty sewer pipe joints, sewer leakage, sewer pipe blockage, and poor network repair activities ([illegible] 2021a). Evidences have also emerged on potential Covid-19 transmission via SO of untreated sewage or wastewater (Han and He, 2021). The global cost of the Covid-19 pandemic is estimated to be US$ 16 trillion (Cutler & Summers, 2020) and has caused 2, 462,911 deaths globally (WHO, 2021). This ongoing pandemic is capable of reversing previous developmental achievements in poverty alleviation and public health and hence, global concerted efforts are required to curtail its socio-economic impact. Therefore, it is necessary to prevent SO to curtail the spread of Covid-19. This is important because wastewater and sewage are the final environmental reservoirs of most pathogens (Bogler et al., 2020).

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Stormwater runoff is rainfall that flows over the ground surface including roads, streets, developed and undeveloped lands, rooftops and other paved surfaces. Conventionally, stormwater runoffs are collected in drainage system (or storm sewers) and transported to nearby water bodies while sanitary sewer system transports sewage, domestic and industrial wastewater to the wastewater treatment plant. However, during the 19/20th century, in order to temporarily curb urban flooding in cities, and to reduce construction cost, combined sewer systems were launched in many cities globally, without taking into consideration of their long-term effects ([illegible]). The combined sewer systems transported both stormwater runoff and wastewater to the wastewater treatment plants (WWTP). With increased climate change in cities and increased impervious surfaces in urban areas to meet infrastructural developments, the volume of stormwater runoff increased significantly such that the combined volume of stormwater runoff and wastewater exceeds the capacity of the wastewater treatment plant. This situation results in emergency release of the stormwater runoff and untreated wastewater into receiving water bodies, a term called sewer overflow (SO). The sewer overflow results in pollution of the impacted water bodies such as rivers and streams, serious degradation of their water quality and constitute environmental and public health risks ([illegible]; [illegible]; [illegible]; [illegible]).

Various studies have linked non-point source pollution caused by stormwater runoff to chronic and acute illnesses from exposure through drinking water, seafood and contact recreation (Gaffield et al.; [illegible] et al., 1996; Haile et al., 1999; [illegible]; [illegible]). And the greatest risks from waterborne pathogens were children, elderly, pregnant women and immunocompromised ([illegible]). In addition, urban stormwater runoff is responsible for about 47% of pathogens in stormwater runoff while the remaining is supplied by combined stormwater drainage and sanitary sewer systems discharges which are disposed untreated into receiving water bodies when the stormwater runoff exceeds the WWTP capacity during rainfall ([illegible]). In addition, it is estimated that 1.8 million people globally are at risk of potential Covid-19 transmission if fecal contamination of drinking water sources by sewage and wastewater is not well managed ([illegible]).

Though no link between SO and Covid-19 pandemic has been established, recent studies reported that fecal aerosols transmission of Covid-19 via wastewater through building plumbings is possible and lower than person-to-person transmission via respiratory droplets/aerosols ([illegible] et al., 2021; Gormley et al., 2020; Shi et al., 2021). Direct contact with and proximity to bioaerosols from CSO effluents have been linked to increased elevated risks of asthma, gastrointestinal illnesses and skin and soft tissue infections in children residing near SO sites ([illegible]). Also, inadequate water and sanitation infrastructure for disposal and treatment of sewage also contributed to Covid-19 transmission ([illegible] et al., 2021). SO have been linked to elevated fecal pathogen concentration and prevalence of antibiotic resistant bacteria in Germany ([illegible] and Tiehm, 2020). SO and runoff serve as environmental driving forces of particle-attached pathogens during storms with significant consequence to both ecosystem and public health (Jørgensen et al., 2018; Noyer et al., 2020). SOs and floods serve as potent threat to spread co-resistant and cross-resistant pathogens due to shifts in pathogen communities and this risk is expected to increase with current trend of increased climate change and urbanization (Noyer et al., 2020).

Previous studies on SO have mainly focused on monitoring, modelling and controlling SO. For instance, some previous reviews assessed the linkage between constructed wetlands and SO (Botturi et al., 2020; Rizzo et al., 2020; Tao et al., 2014). Other studies focused on quantitative detection of micro-organisms, quantitative microbial/public health risk assessment, pretreatment and disinfection of SO, removal of virus from wastewater, quantitative detection of micropollutants such as pharmaceuticals and industrial chemicals and measurement of impact on microbiological water quality ([illegible]; [illegible]; [illegible]; [illegible]; [illegible]; [illegible]; [illegible]). Also, some studies focused on prediction and monitoring of SO, monitoring of frequency and duration of SO and sensor-based monitoring of freshwater bodies for public health advisory ([illegible]; [illegible]; [illegible]; [illegible]). Some review studies focused on management of emerging wastewater-derived contaminants and wastewater flow, systematic review of stormwater runoff pollution control technologies, urban flood mitigation restoration of rivers affected by SO and remediation of surface waters using constructed wetlands ([illegible]; [illegible]; [illegible]; [illegible]; [illegible]). Limited studies have demonstrated the linkage between SO and public health.

Scientometric review is an effective approach for gaining comprehensive understanding of past, current and emerging research areas through visualization of research trends and progress, identification of multiple relationships among research clusters as well as research gaps for future research ([illegible]; [illegible]; [illegible]; Olawumi and Chan, 2018; [illegible]; [illegible]; [illegible]). Advantages of scientometric review include provision of evidence of impact of researches done, predicts future research directions based on identified research gaps, guides funding provision for identified impactful research at both local and international levels and provides opportunity for collaboration with productive research networks, institutions and countries ([illegible]; [illegible]; Olawumi and Chan, 2018; Yao et al., 2014). While previous scientometric reviews focused on global health systems, coronaviruses, climate change, drinking water treatment technologies, and sustainability and sustainable development to mention a few (Gonzales et al., 2021; [illegible] et al., 2020; Malik et al., 2021; Olawumi and Chan, 2018; Yao et al., 2014), no scientometric review has mapped the linkage between sewer overflow and public health.

On the other hand, systematic review is the comprehensive appraisal and synthesis of available and relevant evidence using reliable, objective and thorough standard research protocols to answer specific research question(s). Advantages of systematic reviews include provision of clear, balanced and impartial summary of findings in an understandable format to facilitate decision making, resolution of conflicts in literature and provision of clear research agenda for grant/funding purposes. Previous systematic reviews focused on green infrastructure developments, stormwater management and challenges, public health policies, interventions and communities of practice and nature-based solutions to reduce impact of flooding on human health, improve socio-economic well-being and public health ([illegible] et al., 2018; Hallinger et al., 2018; Lal et al., 2018; Masters et al., 2017; Qiao et al., 2018; Sohn et al., 2019; Van den Bosch and Sang, 2017; Venkataramanan et al., 2020; Venkataramanan et al., 2019).

Based on review of existing literature, it was observed that studies analysing and providing a comprehensive understanding of the research trend in SO and their linkage to public health are currently not available. To address these weaknesses and fill these research gaps, both scientometric and systematic literature reviews are undertaken in the current study. Therefore, the aim of this study is to establish linkage(s) between sewer overflow and public health using both scientometric analysis and systematic literature reviews. The objectives of this study are to: (i) identify the most influential keywords, journals, scientists, and countries active in sewer overflow and public health research; (ii) reveal the methodological approaches utilized in the studies, their applications and study area; and (iii) highlight prominent and emerging research gaps based on in-depth systematic review of the existing literature. This study is significant because it reveals the link between sewer overflow and public health, as well as emerging research gaps to curtail the ongoing pandemic. Furthermore, this study serves as a consultation toolkit for effective policy making to safeguard public health and improve societal resilience to future pandemics.

2. Research methodology

The review framework adopted in this study is shown in . The review goals were identified and keyword search was conducted in the Scopus database using the phrase "impact of sewer overflow". Filters, such as limiting the language of publication to English and subject area to English and Engineering, were applied. Thus, 43 relevant papers were identified. Furthermore, forward and backward snowballing techniques were utilized to identify additional relevant papers to increase the total number of retrieved papers to 206. These papers were subjected to scientometric analysis with the aid of the VOSviewer software. Thereafter, a systematic review of the retrieved literature was done.

3. Scientometric analysis

3.1. *Keyword cluster analysis*

Keyword cluster analysis identifies 295 keywords in SO research. Four keyword clusters are prominent in the keyword network map shown in Fig. 2. Cluster 1 is displayed in red, cluster 2 in green, cluster 3 in blue, and cluster 4 in yellow. The keyword map illusrates the interrelationship between various keyword clusters. During extreme rainfalls in cities and urban areas, stormwater runoff and sewage are transported through the sewer network to wastewater treatment plants (WWTPs). The combined stormwater and sewage are rich in organic matter, sediments and micro-organisms, such as E.coli and fecal coliforms.

Owing to limited capacity of WWTPs to treat the high volume of stormwater and wastewater received, the excess volume is released into freshwater bodies and coastal waters as untreated sewer overflow. This situation leads to significant pollution of the receiving water bodies. Therefore, they become contaminated with high concentrations of virus and bacteria-laden sediments, metals, and polycyclic aromatic hydrocarbons (PAHs). These pollutants reduce dissolved oxygen of the receiving water bodies and are toxic to aquatic organisms.

Besides, the pathogens in the polluted water bodies directly infect humans when they swim or play in contaminated beaches and rivers or consume water from such waterbodies. On the other hand, indirect infection occurs through the consumption of fishes and crustaceans harvested from contaminated rivers and seas. Another route of indirect infection is through the consumption of vegetables and crops irrigated with poorly treated or untreated water. Direct infection can also take place through close contact with and consumption of zoonotic domesticated, agricultural or wild animals. Furthermore, the occurrence of such infections on a large scale can lead to an epidemic outbreak and pathogen shedding by infected individuals into the sewer network. In order to break the pathogen cycle in a sustainable manner, transmission pathways through WWTP, recreational contact, irrigation and aquaculture, contaminated drinking water, faulty drainage and poor ventilation systems in buildings should be blocked besides isolation and treatment of infected individuals and vaccination.

The top ranked keyword in cluster 3 is "aerosols", which is often underestimated in disease transmission. Aerosolized transmission of pathogens, such as antibiotic-resistant *Pseudomonas aeruginosa* and *Pseudomonas putida*, has been reported in previous studies (Gonzales et al., 2017; Smith, 2019). Likewise, recent studies confirm aerosolized transmission of Covid-19 through air ducts in bathrooms, toilet facilities, and wastewater discharged from WWTPs (Ding et al., 2021; Gholipour et al., 2021; Hwang and Lever, 2008).

The top keywords based on occurrences and total link strength are displayed in Table 1. Based on highest total link strength, the top five keywords are "non-human", "environmental monitoring", "sewage", "wastewater treatment", and "water quality". The low number of occurrences of "public health" (16) and "risk assessment" (20) shows that limited research has been done in these areas. Non-human refers to animals and pathogens such as zoonotic domesticated, agricultural and wild animals, virus, bacteria, protozoa and fungi, etc that facilitate

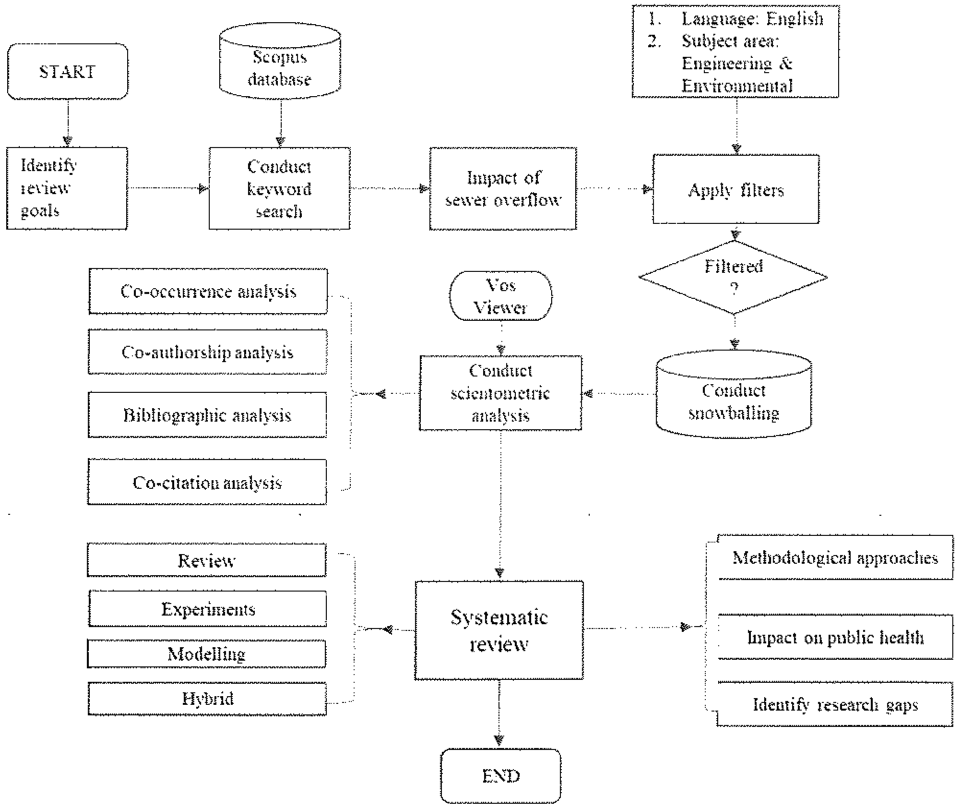

Fig. 1. Review framework.

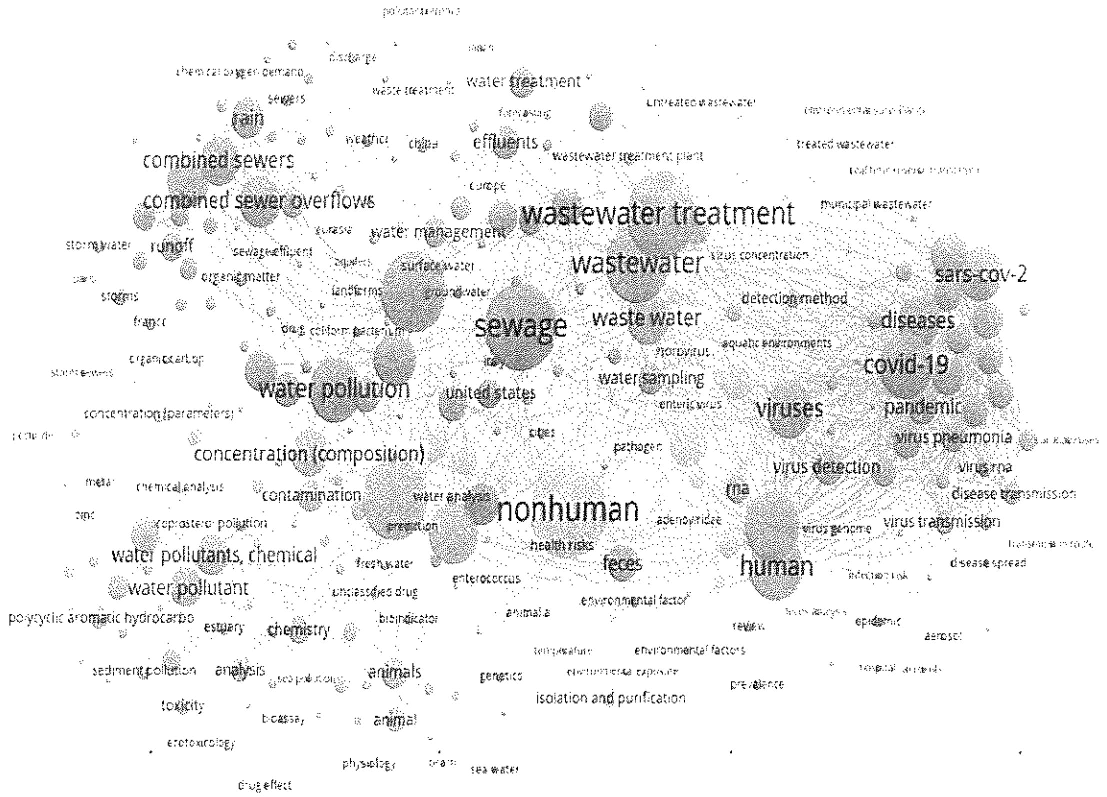

Fig. 2. Co-occurrence of keywords network.

Table 1
Top keywords based on highest number of occurrences.

Keywords	Occurrences	Total link strength
Non-human	62	1873
Environmental monitoring	61	1868
Sewage	57	1426
Wastewater treatment	57	1417
Water quality	53	1082
Human	45	1426
Covid-19	43	1119
Water pollution	43	941
Controlled study	40	1166
Viruses	38	1122
Sars-COV-2	36	884
Wastewater	35	1179
Rivers	35	895
Combined sewer overflow	34	754
Sewer network	34	683
Combined sewers	33	764
Risk assessment	20	496
Public health	16	470

transmission of infectious diseases in humans. More than 60% of all known human pathogens are zoonotic which originate in animals but can cross-infect humans and 75% of new pathogens detected within the last three decades originated from animals (Taylor et al. 2001; Jones et al., 2008). Understanding their dynamic evolution as multi-host pathogens in terms of their evolutionary, environmental and climatic interactions is important to prevent or reduce their transmission and human infections. Therefore, environmental monitoring of sewage and wastewater treatment as well as water quality for domestic and industrial purposes and updating their various treatments are crucial to mitigating pathogen transmission and should be pursued and funded complementarily with vaccination.

3.2. *Journal contribution analysis*

In terms of journal contribution to the research on SO, *Science of Total Environment (STOTEM)* contributes 20.1% of all the assessed papers. This was followed by *Water Research* (8.5%) and *Marine Pollution Bulletin* (7%). Also, *STOTEM* has the biggest node (Fig. 3(a)) and highest total network link strength (TLS) of 4684, as displayed in Table 2. Despite that *Water Research* publishes a lower number of research articles, its impact factor of 9.13 is higher than the 6.55 of *STOTEM*, as displayed in Fig. 3(b).

Correlation analysis shows that TLS and citations are highly correlated with the number of published articles, each having a correlation coefficient, r = 0.869 and r = 0.795, respectively. On the other hand, citations is moderately correlated with TLS (r = 0.615) and impact factor (r = 0.508) (Sojobi, 2016). The higher impact factor of *Water Research* may be attributed to its higher co-citations of 557 and co-citation TLS of 46,019 when compared with *STOTEM's*, as shown in Fig. 3(c). This implies that for any journal to increase its impact factor, it must prioritize increasing its co-citations, linkage with other journals and number of published articles. Out of the 21 publishing outlets, Elsevier tops the chart by publishing 30.9% of the assessed journals, followed by Springer 11.8%, Wiley 10.3%, and Taylor & Francis 8.8%. This implies these four publishers are responsible for 61.8% of the journals reviewed. In addition, 92.5% of these journals are hosted in England, USA, Netherlands, and Germany.

3.3. *Authors' citation network, co-citation network, and document citation density*

Author's citation network analysis revealed 10 clusters, which were displayed in Fig. 4. Cluster 1 (red) is represented by Jones D. I. with 16 items, and cluster 2 (green) is represented by Harwood V. J. with 15 items. Also, Bertsch P. M., Kitajima M., and Carducci A. are in clusters 3

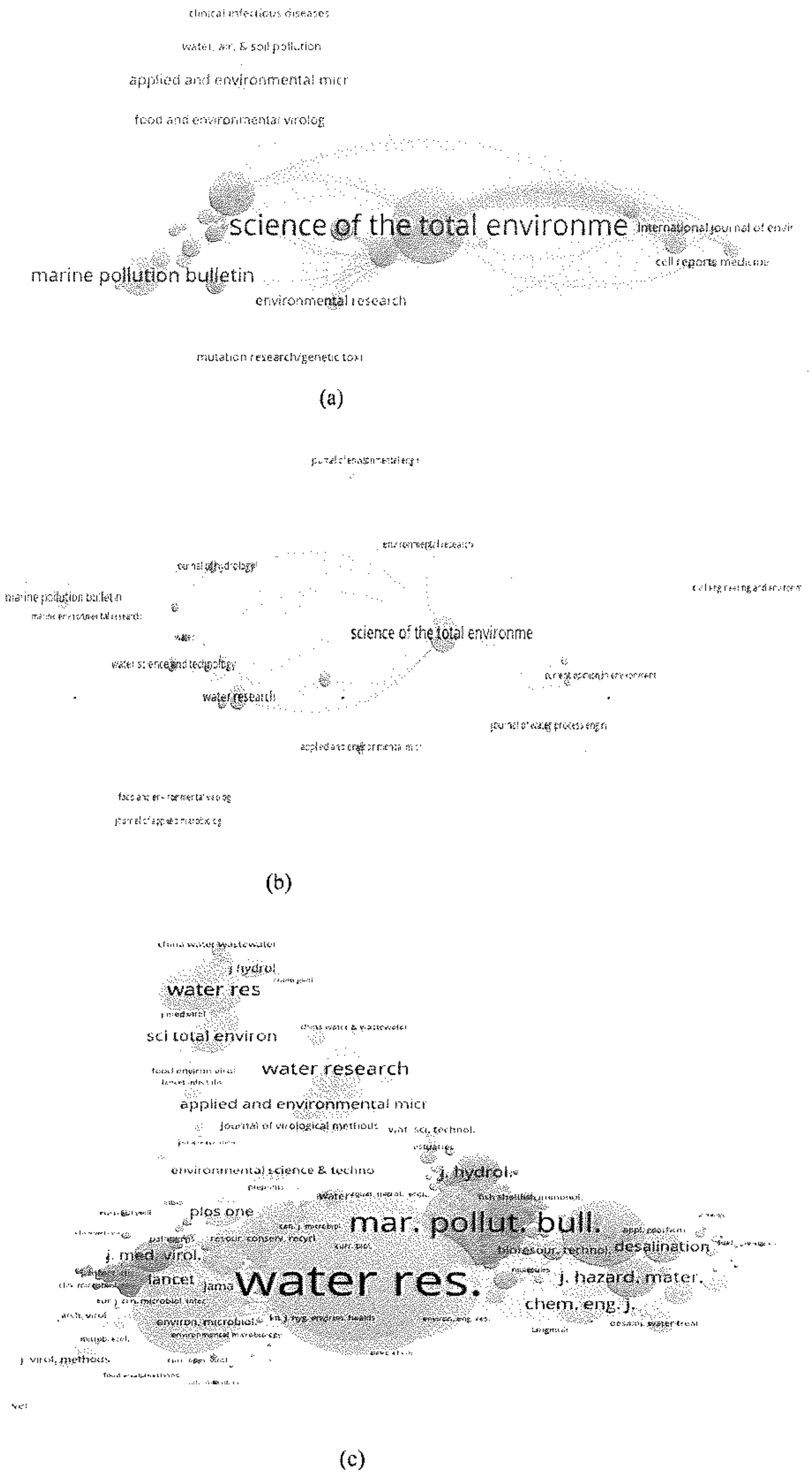

Fig. 3. (a) Network of journal contribution. (b) Publication outlets by documents (c) Publication outlet based on co-citations.

Table 2
Top 10 journals based on number of documents.

Journal	Docs	Citations	Total link strength	Impact Factor	Publisher	Host country
Science of the total environment	40	743	4684	6.551	Elsevier	Netherlands
Water research	17	967	896	9.13	Pergamon-Elsevier Sci. Ltd	England
Marine pollution bulletin	14	184	181	4.049	Pergamon-Elsevier Sci. Ltd	England
Chemical engineering journal	8	374	1320	10.652	Elsevier Science SA	Switzerland
Water Science & technology	6	56	273	1.638	IWA	England
Environmental Science & Technology	5	486	0	7.864	IWA	England
Journal of Water Process Engineering	5	88	1188	3.465	Elsevier	Netherlands
Applied and Environmental Microbiology	5	258	208	4.016	Amer Soc Microb.	USA
Environmental Research	4	73	892	5.715	Academic Press Inc Elsevier Sci	USA
Journal of Hydrology	4	109	78	4.5	Elsevier	Netherlands

NB: IWA = IWA Publishing; Amer Soc Microb. = American Society for Microbiology.

(blue, 14 items), 4 (light aquamarine, 14 items), and 5 (medium purple, 9 items), respectively. In addition, clusters 6 (turquoise), 7 (orange), and 8 (dark brown) have Ahmed W. (7 items), Scherchan S. P. (6 items), and Rose J. B. (6 items), respectively. Lastly, Bibby K. is in cluster 9 (pink, 6 items), while Haramoto E. is in cluster 10 (light coral, 3 items). The authors with the highest co-citation/publication network in terms of node size are Kitajima M, Ahmed W, Haramoto E, Katayama H., and Bibby K.

Co-citation networks analysis also revealed that Kitajima M. had the biggest node in terms of co-citation with the highest TLS of 22 due to his collaborations with several top authors. These top authors include Haramoto E., Ahmed W., Rose J. B., and Bibby K. Therefore, it is expedient for researchers to establish research network with several active researchers in their field or related fields. As shown in Table [illegible], the co-citation network is favourable to both Haramoto and Kitajima as their recent papers ranked among the top 10 highly cited papers.

Kim et al. (2018), with the highest number of citations (163), examined the removal of emerging contaminants in wastewater and water. The second highly cited paper ([illegible]) investigated the adsorption of priority contaminants, such as metals and PAHs, to sediments in urban stormwater. The paper revealed that the discharge of untreated SO poses serious risk of polluting the receiving water with highly contaminated sediments. The third highly cited paper by [illegible] reviewed worldwide occurrence and health implications of adenovirus. The paper showed that adenovirus infection can be acquired through the consumption of contaminated water and aerosolized droplets during swimming in recreational waters, such as public swimming pools and coastal waters.

The fourth highly cited paper ([illegible]) investigateed the impact of SO on receiving waters during intense rainfall for both dry and wet seasons. The study established significant microbial and physical degradation of the receiving water due to resuspension, transport, and discharge of microbial-imparted sediments, especially during the wet season. An earlier study reported the presence of human adenovirus and human polyomavirus in a river due to contamination with human sewage ([illegible]). The authors warned of the potential public health concerns that result from the cross-reaction between human and animal viruses.

Fig. 5 showed document citation density map. The top highly cited articles appear in yellow. These documents contain the basics of research on SO and public health. Also, as shown in Table 5, 61.8% of the papers reviewed in this study are published by Elsevier (30.9%), Springer (11.8%), Wiley (10.3%), and Taylor & Francis (8.8%).

3.4. *Country analysis*

In terms of publications, the top six countries in the areas of SO and public health are the USA, China, Spain, Australia, Japan, and Canada with 53, 23, 19, 18, 16, and 15 publications, respectively. Country analysis by co-authorship also revealed that the USA has the biggest node, followed by China and Spain, as displayed in Fig. 6. Also, there are ten country clusters in Fig. 6. Cluster 1 comprises Brazil, Finland,

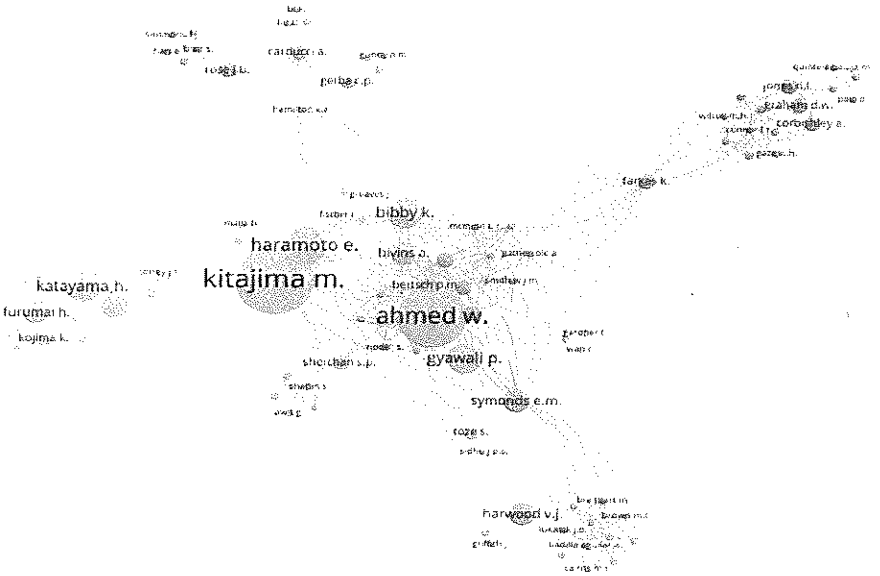

Fig. 4. Clusters of authors citation/publication network.

Table 3
Top 35 highly cited articles based on web of science metric.

S/N	Article	Citations	S/N	Article	Citations	S/N	Article	Citations
1	[illegible]	163	13	Fries (2016)	82	25	Bonneau (2017)	54
2	[illegible]	159	14	[illegible]	77	26	[illegible]	53
3	[illegible]	136	15	[illegible]	75	27	[illegible]	52
4	[illegible]	132	16	[illegible]	73	28	[illegible]	52
5	[illegible]	118	17	Hata (20130	72	29	[illegible]	48
6	Phillips (2012)	116	18	Askarizadeh (2015)	71	30	Muthukamaran (2011)	49
7	[illegible]	114	19	[illegible]	70	31	Ryu (2011)	45
8	[illegible]	107	20	[illegible]	61	32	[illegible]	43
9	[illegible]	104	21	[illegible]	58	33	[illegible]	43
10	[illegible]	96	22	[illegible]	47	34	Bofill-mas (2013)	42
11	[illegible]	89	23	[illegible]	57	35	[illegible]	42
12	[illegible]	82	24	[illegible]	57			

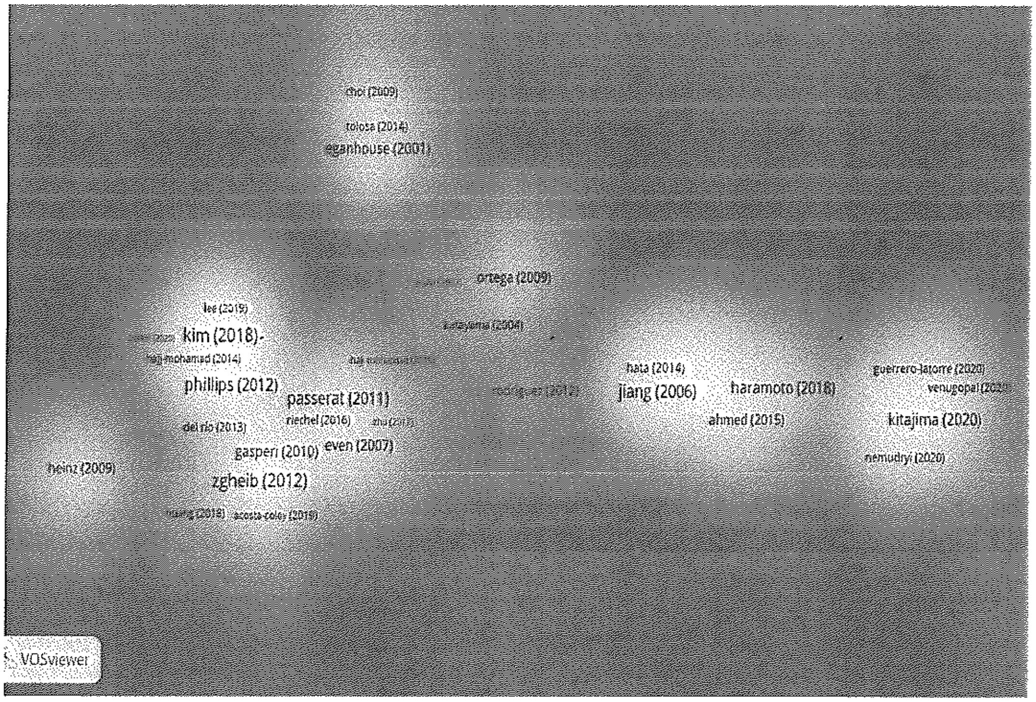

Fig. 5. Document citation density.

Mexico, New Zealand, Switzerland, Taiwan, and Vietnam. Cluster 2 includes Colombia, Ecuador, Portugal, Spain, and Romania. Belgium, Canada, France, Luxembourg, and Ireland form cluster 3, while cluster 4 consists of Austria Denmark, Ethiopia, Germany, and Kenya. In cluster 5, there are India, Indonesia, Israel, Netherlands, and Singapore. Furthermore, cluster 6 consists of China, Hong Kong, Nigeria, Saudi Arabia, and South Korea. Similarly, Egypt, Italy, Japan, and Thailand comprise countries in cluster 7, whereas Malaysia, Qatar, UAE, and UK make up cluster 8. In cluster 9 are Australia, Bangladesh, and Sri Lanka, while Costa Rica and the USA are found in cluster 10. Therefore, there are 48 countries in all the clusters. This implies that only few countries are involved in studies on SO in relation to public health.

4. Systematic review

A systematic review of the retrieved literature showed that six methodological approaches have been applied to the study of SO, as portrayed in Fig. 7. Majority of the studies (49%) utilized field sampling and laboratory experiments, whereas review papers and modelling studies were 24% and 15%, respectively. In addition, about 5% of these papers used a hybrid method by combining both experimental and modelling approaches.

4.1. *Combined field sampling- and laboratory experiment-based studies*

In this category (Table 4), field samples were taken from the field for laboratory testing. Field samples are usualy taken from diverse places, such as inlets, outlets, and within WWTP, SO outfalls, rivers, seawater, estuaries, and bays. Other sources include harbours, beaches, pump, hospital wastewaters, drainage systems, septic tanks, manholes, farms, drinking water treatment plants (DWTPs), air, and toilet surfaces. Four kinds of tests have been reported in the literature, as shown in Fig. 8(a). Microbiological analyses are the most frequently used testing method to determine the microbiological compositions of sewage, SO, and associated impact on a sewer network and receiving waters. Pathogenic organisms of concerns are Covid-19 RNA (ribonucleic acid), *E. coli*, intestinal enterococci, enteric adenovirus, norovirus, and enterovirus. Others include human polyomaviruses (HPyVs) and papillomaviruses (HPVs), Aichi viruses, somatic coliphages, salmonella, and norovirus genogroup 1 (NoVG1) to mention a few. Accurate understanding of the microbial (pathogen) type and its concentration is useful for designing appropriate treatment system in the WWTP. In addition, such

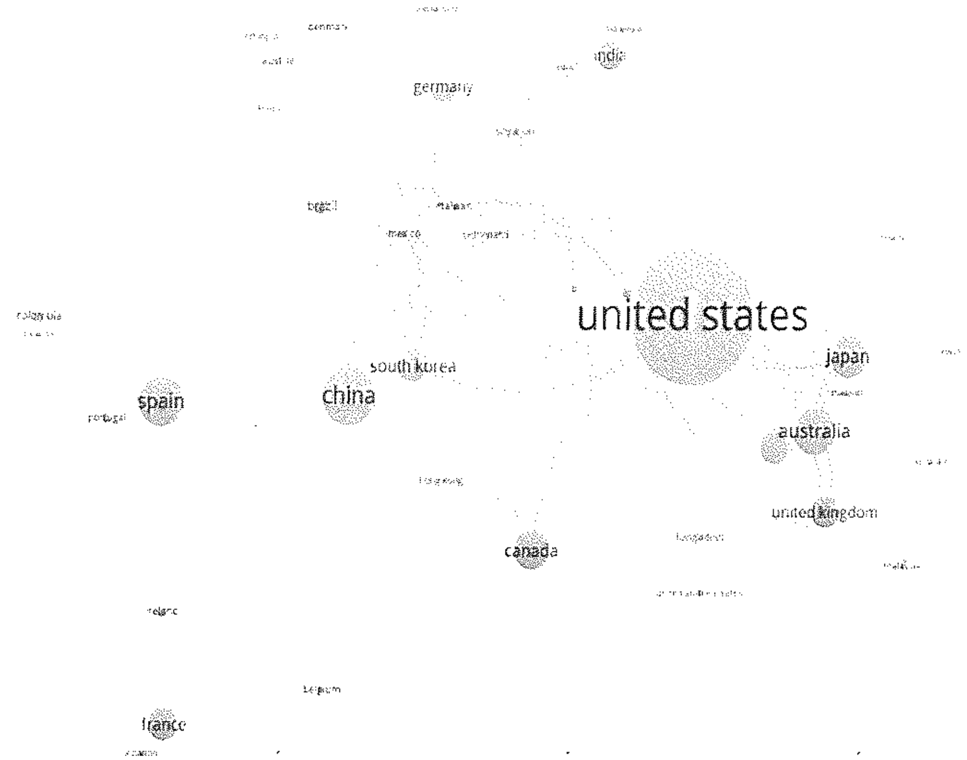

Fig. 6. Co-authorship network by country.

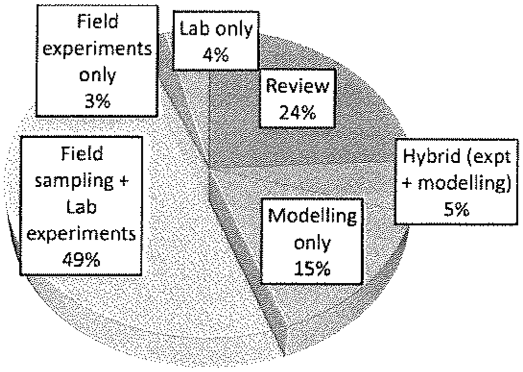

Fig. 7. Breakdown of methodological approaches.

knowledge is useful to guide the selection of sourcewater intake for irrigation and public water supply.

Physico-chemical analyses was ranked as the second highest used tests. These tests focused on physico-chemical properties of sewer overflow, such as turbidity, salinity, heavy metals, PAHs, pharmaceuticals, and personal care products. Furthermore, combined physico-chemical and microbiological analyses approach seeks to decipher the relationship between physico-chemical parameters and microbiological indicators. Often, some correlations were found between some physico-chemical parameters and microbial indicators. On the other hand, the least popular test is the hybrid physico-chemical and biological analyses. This test focused on ascertaining the toxicity and genotoxicity of SO contaminants on selected aquatic organisms, such as fishes, oysters, and mussels. However, this method is seldom employed because it is capital, human, and equipment intensive. However, it is crucial to understanding the impact of SO contaminants. Therefore, more studies on physico-chemical and microbiological analyses are required to show the importance of SO on aquatic organisms living in impacted water bodies and humans who utilized the water bodies for recreation, public water supply and irrigation.

Analysis of these studies showed that various recovery and detection methods have been used for Covid-19 RNA, which makes comparison difficult. Most studies utilize quantitative real-time reverse transcription polymerase chain reaction (RT-qPCR) to quantify pathogens identified in wastewater. With respect to pre-treatment for recovery purposes, a recent study reported that there is no need for pre-treatment of wastewater (WW) samples to improve the recovery of Covid-19 RNA (Ahmed et al., 2020a). Removal of pre-treatment requirement ensures rapid, accurate and cost-effective detection of Covid-19 RNA in wastewater specimen. For the detection of Covid-19 RNA in WW, several authors have used different assays (analytes), such as Taqman assay (Medema et al., 2020), N assay, and Orf1b assay (Baldovin et al., 2021). Other assays include duplex (Haramoto et al., 2021) and Taqpath (Kumar et al., 2020b), which are quite effective in detecting Covid-19 RNA in WW. However, E gene and N gene are more effective analytes in Covid-19 RNA detection compared to RdRp, Orf1ab and S genes (Arora et al., 2020). Another study also reports that ORF1ab, N protein genes, and S protein genes output similar C_T values (Kumar et al., 2020c). These above results imply that future studies are required to streamline and standardize the recovery and detection methods (protocols) in wastewater-based epidemiology (WBE) to facilitate comparison of various WBE researches. In addition, Covid-19 RNA has been detected in wastewater between 2 days and 3 weeks before any clinical report of Covid-19 (Nemudryi et al., 2020; Trottier et al., 2020).

Fig. 8 (b) displayed the breakdown of the physico-chemical analysis methods. GC-MS (gas chromatography-mass spectrometry) has been applied in quantifying contaminants in aquifer and marine waters, and sediments. (Costa et al., 2011; Schenzinger et al., 2019b). The contaminants analysed include organic pollutants, such as PAH, PCB

Table 4
Summary of studies that combine field sampling with laboratory experiments.

Category	Summary/Remark	References
Physico-chemical analyses	Major contaminants transported during SO are persistent in nature and include heavy/trace metals, PAHs, PCBs, DDTs, DEHP, VOC, PPCPs and plastics. Source control, pre-treatment of SO and environmental monitoring are recommended, while sucralose, coprostanol and caffeine are prescribed for contaminant tracing.	([illegible])
Microbiological analyses	Studies advocate environmental protection through improved water and WWT plans, public enlightenment, and enhanced WBE surveillance due to detection of Covid-19 in WW. Fecal-derived aerosols and fomite dominate Covid-19 transmission. Standardized protocol for Covid-19 is required.	([illegible])
Physico-chemical & Microbiological analyses	SO increases pathogen concentration by 127–2387% due to sediment resuspension. Pre-treatment of SO is recommended to reduce sediments and pathogens. Environmental surveillance of rivers, beaches and drinking water sources to minimize public health risk is urgent.	([illegible])
Physico-chemical and Biological indicators	Contaminated sediments promote bioaccumulation of organic and metallic contaminants in aquatic organisms resulting in genotoxic effects and biodiversity reduction. Also, it is important to avert marine plastic pollution.	([illegible])

(polychlorinated biphenyls), pesticides, and hydrocarbons. Alongside, special biomarkers (such as coprostanol) and bioassay have been used to quantify an increase in pollution concentration during SO as well as the genotoxic effects ([illegible]). Spearman rank correlation, principal component analyses (PCA) and correspondence analyses have been utilized to reveal the source of contamination and establish the relationship between sediment contaminants and genotoxicity ([illegible]).

ICP-MS (inductively coupled plasma mass spectrometry) is useful for the quantification of non-metals, metalloids and metals, major cations, and trace elements in marine waters, marine sediments and their distribution ([illegible]). ICP-MS is also used to confirm their bio-accumulation in aquatic organisms during SO. ICP-AES (inductively coupled plasma atomic emission spectrometry) provides a robust, rapid, multi-element analysis of solutions. This technique has been applied to detect the presence of heavy metals and trace elements in water, stormwater and sediment samples ([illegible]). ICP-AES is also called ICP-OES (inductively coupled plasma optical emission spectrometry). However, its limitations include unsuitability for halogens and inert gases, higher limit of detection, and inaccurate identification due to spectral overlap. Other limitations include higher cost and expert requirement compared to ICP-MS (Levine, 2021; [illegible], 2020). While ICP-AES is better for analysing TDS, ICP-MS has a higher sensitivity (ppt) due to the use of mass-spectral techniques compared to ICP-AES, which relies on photon emission (Levine, 2021).

Furthermore, LC-MS (liquid chromatography-mass spectrometry) is applied to simultaneously analyse a broader range of compounds compared to GC-MS, and has high sensitivity and specificity ([illegible], 2009). LC-MS has been applied to detect and quantify micro pollutants, such as endocrine disrupting compounds (EDC) and pharmaceutical and personal care products (PPCP). Others include alkylphenols in wastewater and sediments in sewer network, rivers, and WWTP effluent, SO outfalls and fish tissues (Bunker et al., 2020; De los Rios et al., 2012; De Melo et al., 2019; [illegible] et al., 2018; Haji Mohammadi et al., 2019; [illegible]). Hierarchical analyses and cross-connection index have also been applied to characterize the contamination level, its potential source and prioritize remediation ([illegible]). The limitations of LC-MS are its high initial costs, ion suppression, and reproducibility limited to stable internal standards.

In addition, ion chromatography has been recognized as a global reference method for analysing anions and cations in environmental samples, such as water and wastewater ([illegible]). It has been applied in the analyses of major ions including Ca^{2+}, HCO_3, Na^+, and inorganic ions ([illegible]). Its advantages include reliability, high accuracy and precision, high selectivity, high speed, high separation efficiency, and low cost of consumables. Further developments are required for full automation, to extend its applications, improve speed and ion selectivity, lower limits of detection and quantification ([illegible]).

[illegible] (c) showed the breakdown of the hybrid biological and microbiological methods. While traditional PCR focuses on end-point detection, RT-PCR (real-time PCR) focuses on detection of PCR amplification from the early phases and throughout the reaction phases to the end of reaction. Also, while RT-PCR is semi-automated, RT-qPCR is fully automated and facilitates fast detection and quantification of pathogens, including Covid-19. The disadvantages of traditional PCR are low precision and sensitivity and non-automation. The major disadvantages of both RT-PCR and RT-qPCR are requirement of capital-intensive equipment, time-consuming, labour intensive, and limitations of inadequate supply of RNA extraction kits and relatively scarce qPCR machines (Esbin et al., 2020).

Sanger sequencing (SS) is useful for detection of pathogen mutations and has been utilized in the identification of Covid-19 variant in WWTP and antibiotic-resistant pathogens in plumbing systems (Smith, 2019; Westhaus et al., 2021). Compared to SS, genome sequencing (GS) is faster, requires less personnel and less space requirements, and has higher throughput and cost-effective. GS has been applied in the

Table 5
Summary of modelling-based studies.

Category	Summary/Remark	References
AI modelling	AI modelling approach is used in multi-objective optimization of urban sewer systems to minimize pollution load, operational cost, for cost-effective epidemiological modelling, hindcasting of past SOs, and prediction of pollution in waterways. AI has also been utilized to identify dominant factors which cause microbial pollution and biodiversity loss in waterways and their interactions. This approach is useful in hydraulic modelling and optimization of hydraulic structures.	([illegible])
Multi-technique	Simulates impact of SO on the environment, contributions of different factors, and assesses efficiency of different intervention measures. With the aid of GIS and indices, multi-technique is useful in delineating areas of different environmental risks, prioritize monitoring of SO for different pollutants, characterize rainfall patterns that contribute to SOs, and guide emergency preparedness. Studies in this category recommend optimizing WWTP efficiency, improving capacity of sewer networks, reducing density of or illicit sewer connections, and proper placement of SO outfall.	([illegible])
Numerical	Numerical approach utilizes multi-objective optimization of treatment of WW in terms of CO_2 emission and cost-benefit, multi-media modelling of chemical contaminants, and prediction of water level during and after water spill during SO.	([illegible])
Statistical	Statistical approach elucidates rainfall and non-rainfall factors responsible for SOs. It is utilized for quality assessment and classification of coastal waters in terms of risk, and it reveals frequency of contamination. Studies in this group recommend control of new developments, provision of sewage/solid waste disposal systems, pre-screening and WWTP treatment of SO to avoid pollution and mitigate risks to tourists and residents. Estimated loss of US$ 25 billion dollars has been reported in the Caribbean due to pollution.	([illegible])

identification of various virus strains in WW and cluster identification ([illegible] et al., 2020; [illegible] and [illegible], 2012; [illegible] et al., 2020; Schuster, 2008). The major disadvantages of GS are high initial capital cost, sequencing errors, and time-consuming data analysis. To maintain high accuracy, recent studies recommend combining SS and GS ([illegible] et al., 2019; [illegible] et al., 2016; [illegible] et al., 2020).

Plate counting relies on manual counting of colonies of fecal coliforms, which grow on plates (dish) after specific incubation period and temperature. Plate counting has been used to detect and quantify bacteria, fecal and total coliforms in river water, wastewater and public facilities ([illegible] et al., 2019; [illegible] et al., 2014; [illegible] et al., 2019). Analysis of the results with PCA and cluster analyses revealed anthropogenic pollution from WWTP, and the pollution level did not exhibit seasonal variation. However, plate counting is unsuitable for virus detection and quantification ([illegible] et al., 2013). Alternatively, most probable number (MPN) method can be utilized as a substitute for plate counting. MPN has been applied in quantifying fecal indicators in estuarine water and mussel tissues ([illegible] et al., 2017; [illegible] et al., 2006). Though a study reports comparable results from both methods, however MPN method is less labour-intensive ([illegible] et al., 2005).

4.2. Review-based studies

Occurrences of coronavirus 1 (SARSCoV-1) in 2003, Eastern respiratory syndrome coronavirus (MERS-CoV) in 2012, and Ebola virus in 2014 were forewarnings to the recent Covid-19 outbreak. The contagious nature, persistency and mutation of Covid-19, illegal trade of endangered species, and expanding global travels make the containment of Covid-19 very difficult (Elsamadony et al., 2021). Furthermore, the spread and containment of outbreaks (particularly Covid-19) depend on the level and timeliness of control measures, environmental conditions, treatment facilities, and social conditions (Arslan et al., 2020). Co-infection with fungal, bacterial, influenza, and other diseases increases health risks by reducing the immunity of infected patients (Jones et al., 2020b).

The natural environment, which serves as the mediator for pandemics, has been inadequately explored (Ji et al., 2021). A recent study reported that majority of infections are transmitted in an indoor setting or in a transportation system (Mohapatra et al., 2021; Qian et al., 2020).

Seven potential pathogen transmission routes have been identified, as shown in Fig. 9 (a). The largest four modes of transmission based on mentions in some review-based studies are sewage/wastewater (30%), aerosol (21%), fecal-oral (20%), and skin/surface transmissions (14%) (Arslan et al., 2020; Cahill and Morris, 2020; [illegible] et al., 2021; Elsamadony et al., 2021; Ji et al., 2021; Jones et al., 2020b; Kitajima et al., 2020; [illegible] et al., 2020). This implies greater attention should be given to the sewage/wastewater transmission routes which has been grossly underestimated.

Sewage/wastewater transmission occurs during direct contact with untreated or poorly-treated sewage containing pathogens from infected persons either due to the use of shared public facilities or during care-giving. Transmission also occurs while working at WWTP, during maintenance of sewer/plumbing systems and through the use of untreated/poorly treated sludge/wastewater for farming. In addition, fecal-oral transmission results from the consumption of contaminated water from poorly maintained and inadequately treated water distribution systems ([illegible] et al., 2020).

Likewise, aerosol transmission can be caused by poor ventilation and plumbing systems in residential buildings, hospitals, commercial complexes and restaurants, and transportation systems. It also occurs through direct contact with respiratory droplets and is prevalent in countries with poor outdoor air quality ([illegible] et al., 2020). A recent study reveals that although Covid-19 droplet is highly transmissible under favourable temperature and humidity conditions, face masks are effective in reducing transmission in both outdoor and indoor environments (Zhao et al., 2020). Aerosol transmission also occurs in WWTPs and surrounding communities (Gholipour et al., 2021; Pasalari et al., 2019).

Skin/surface transmission occurs through direct contact with infected surfaces and recreational waters (Cahill and Morris, 2020; Jones et al., 2020b; Liu et al., 2020; Saawarn and Hait, 2021). Transmission through marine foods/vegetables occur from consumption of poorly cooked aquatic foods harvested from infected waters and uncooked vegetables irrigated with contaminated water. Vector transmission is caused by rodents and insects in residences and restaurants, while solid waste transmission is attributable to direct contact with solid wastes generated by infected persons and human cadavers.

Percentage distribution of the research focus of the assessed papers are shown in Fig. 9 (b). The most popular research focus is on Covid-19

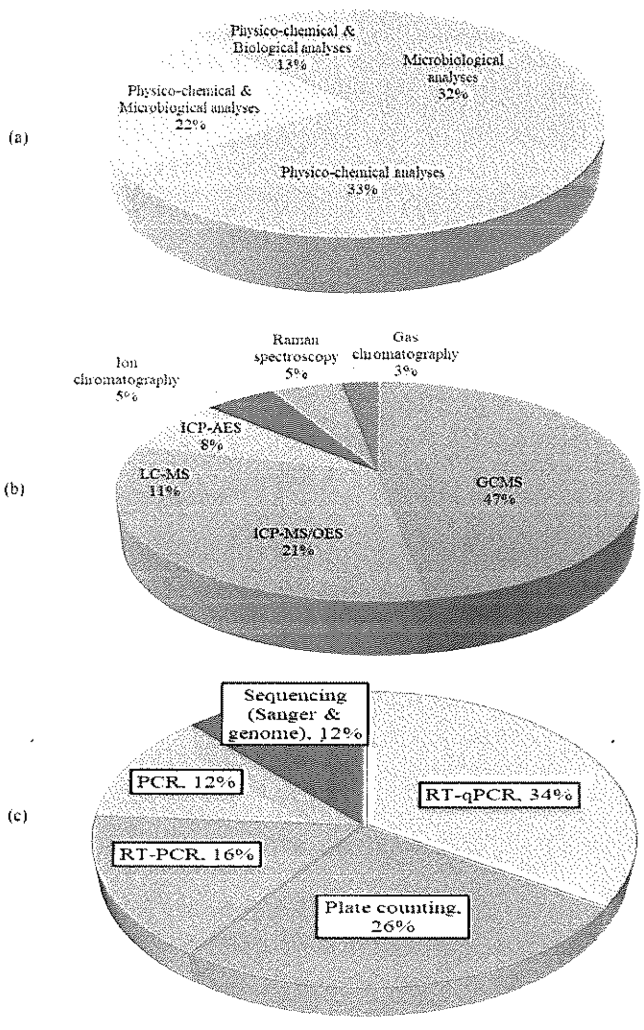

Fig. 8. Breakdown of (a) field sampling and laboratory approach; (b) physico-chemical analyses methods; and (c) biological/microbiological methods.

(71%), followed by adenovirus, norovirus and polyomavirus (10%), bacteria and protozoans (5%), and plastic wastes (5%). Measures recommended to mitigate pathogen transmission and improve public health are also listed in Fig. 9 (c). The top three measures comprise optimized treatment of water and wastewater (32%), promotion of point-of-use treatment (POUT) and water, sanitation and hygiene (WASH) (19%), and surveillance (17%). Other measures include enforcing the use of PPEs, such as face masks, improving solid waste management, and formulating enabling policies and social interventions. Policy and social interventions may include social distancing and lockdowns, restriction of recreational activities in contaminated beaches, and providing welfare packages for low-income earners. While most efforts and funding have been chanelled towards healthcare and social interventions in terms of vaccination, lockdown and facemasks, greater research efforts and funding should be directed towards optimization of water and wastewater treatment, publicity of point-of-use water treatment as well as WASH to curb ongoing pandemic in a cost-effective sustainable manner. Point-of-use water treatment and personal hygiene have been found effective in mitigating bacterial, viral and protozoan waterborne pathogens (Abbaszadegan et al., 1997; Brown and Sobsey, 2012; Clasen et al., 2008; [illegible] and [illegible], 2006; Sojobi et al., 2014, 2015)

It is also important to improve ventilation in buildings and enforce good plumbing practices to minimize aerosol-pathogen transmission and promote high-impact collaborative research. Prevailing poor design and maintenance of ventilation, air condition and plumbing systems facilitate rapid pathogen transmission in high occupancy, high rise buildings (Correia et al., 2020; Lin et al., 2021; Lipinski et al., 2020). Therefore, to provide safe indoor environments, present buildings need to be redesigned to avoid connections between rooms via ventilation systems and discontinue the use of centralized ceiling ventilation systems (Pease et al., 2021; Tang et al., 2006). In addition, monitoring should be put in place to ensure compliance and regular maintenance of updated ventilation and plumbing systems in existing public and private buildings and future building projects.

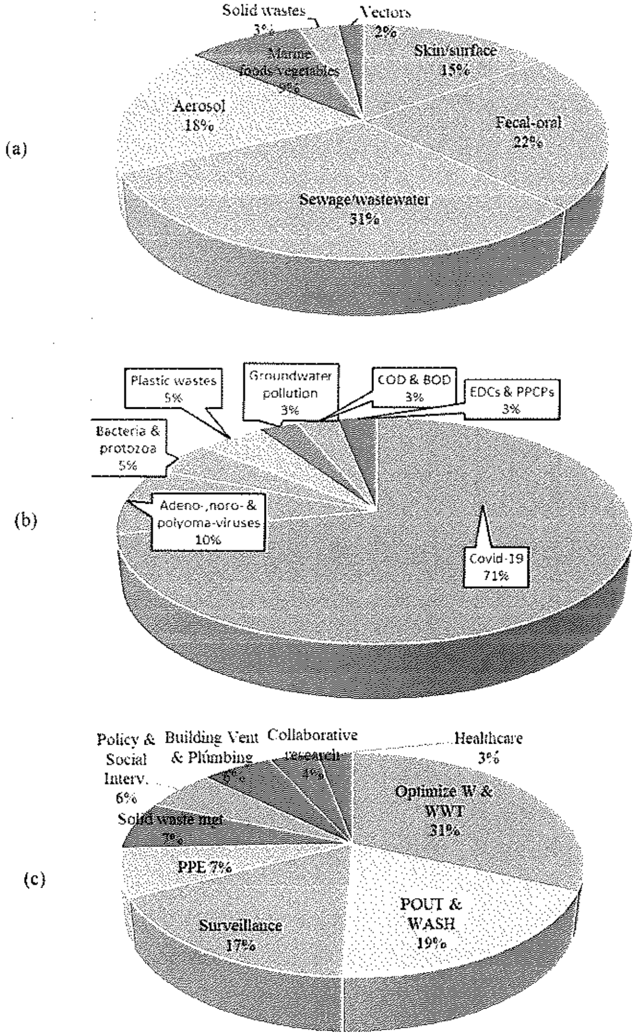

Fig. 9. Percentage distribution of (a) potential pathogen (Covid-19) transmission routes; (b) research focus of reviewed papers; and (c) measures to mitigate pathogen transmission and improve public health.

Investment in vaccine development is also important to improve community immunity against pathogens. While vaccine deployment is necessary to prevent high mortality, severe economic disruption and major adjustment to our way of life (Graham, 2020), due considerations must be given to avoid common pitfalls of vaccine developments such as antibody-dependant enhancement, low vaccine safety, rapid decline of antibodies and low vaccine efficacy in neutralizing Covid-19 mutants. Considering the huge cost of vaccine development and the short time-frame for vaccine development, the various trials need to be carefully designed to make the most of the derived data without violating regulatory requirements. Scaling up vaccine mass production and delivery to all regions of the world poses a logistic challenge ([illegible]) that can be overcomed through intergovernmental and inter-private organizational co-operations.

Combination of molecular imaging and serial CT imaging with artificial intelligence, clinical data and genomic studies, and combination therapy of selected vaccine candidates and natural medicine simultaneously is important to make the most of vaccine investment and human labours for optimized, efficient and sustainable vaccine development ([illegible] et al., 2020; [illegible]; [illegible]; [illegible]; [illegible]). Such integrative and multidimensional approach provide functional insights beyond limited human knowledge and provide predictive biological and mathematical models based on AI/machine/statistical learning to be developed to support rational and effective vaccine development and precision medicine which takes into account differences in individual susceptibility to disease and severity of illness ([illegible]; [illegible]; [illegible]). Besides, recent studies have revealed that combination of western medicine and traditional (natural) medicine recorded higher efficiency than vaccine alone in both moderate and critical cases owing to the bioactive compounds of natural medicine which improved cure rate and recovery, inhibited inflammation and improved lung conditions ([illegible] et al., 2021; Dai et al., 2020; Huang et al., 2021; Liang et al., 2021; Li et al., 2020; Wang et al., 2021a; Zhang et al., 2020). A recent study recommended the use of gene ontology enrichment analysis, compound target network analysis, gene network analysis and cytoscape analysis to unravel the virogenomic signatures and identify potential vaccine and natural medicine compounds for effective vaccine development ([illegible] et al., 2020). To ensure equitable access, assistance should be given to low-income developing countries in Africa that may likely become the epicenter of the next wave of Covid-19.

Furthermore, several studies have reported the detection of Covid-19 in wastewater and sewage due to virus shedding in urine and feces (Dhama et al., 2021; [illegible] et al., 2020; Saawarn and Hait, 2021; [illegible]). Covid-19 is persistent in wastewater and sewage (3–14 days) and CoV bioaerosols (up to 16 h), which poses serious public health risks (Dhama et al., 2021; Kitajima et al., 2020). Therefore, it is important to limit recycling of sewage and application of wastewater in irrigation and organic fertilizer. The risk of Covid-19 infection is further heightened by inefficient WWT (wastewater treatment), leaking sewer pipes, plumbing systems and septic tanks (Ji et al., 2021). Prior to the emergence of the Covid-19 pandemic, WW pretreatment and recycling with bioaccumulation considerations are highly encouraged in irrigation (Al-Gheethi et al., 2019; Hamamoto et al., 2018). However, the emergence of this pandemic has prompted several studies to recommend banning WW/sludge recycling for irrigation and recreational facilities ([illegible] et al., 2020; Collivignarelli et al., 2020; [illegible] et al., 2020; Saawarn and Hait, 2021). Nevertheless, few studies advocate improving irrigation standards and disinfection to avoid the risk of food-chain transmission of Covid-19 (Dhama et al., 2021; Lahrich et al., 2021). Furthermore, some recent studies showed that Covid-19's major transmission route include fecal/urine-oral/ocular transmission through direct person-to-person contact and consumption of contaminated drinking water (Dhama et al., 2021; Jones et al., 2020b; Tran et al., 2021). In addition, potential Covid-19 transmission in wastewater to recreational waters has also been reported in another study (Cahill and Morris, 2020). Curtailing such transmission media poses a herculean challenge in both developed and developing countries. In addition, wastewater-irrigated agriculture portends another dangerous route for food-chain transmission through consumption of infected fishes and vegetables (Hamamoto et al., 2018). To guarantee public safety, advanced and integrated multi-barrier approach is required (Mohan et al., 2021).

Covid-19 fatality and recovery depend on existing environmental conditions, innate immunity of infected persons, and associated health conditions ([illegible]). To improve environmental conditions, it is pertinent to maintain sewer networks, upgrade and optimize operations of WWTPs, improve community sanitation, and ban open defecation. Also, application of wastewater effluent for irrigation and ban on utilizing sewage sludge as fertilizer are recommended ([illegible]; [illegible]; [illegible]; [illegible]; [illegible]; [illegible]). Recent studies advocate tertiary WW treatment with NaClO and UV at appropriate dosage, high temperature between 56 and 70 °C, and longer retention time to eliminate the virus ([illegible]; [illegible]). Developing countries require external assistance in WWTP and solid waste management infrastructures, capacity development and policy interventions to mitigate high risk of Covid-19 transmission in Africa ([illegible] et al., 2021; [illegible]). To improve personal immunity, low-cost household water treatment processes, such as boiling of drinking water, public awareness on WASH (water, safety and hygiene), strict personal/hand hygiene, and mask wearing are recommended ([illegible]; [illegible]; [illegible] et al., 2020). A recent study also recommended cost-effective maintenance of sewer networks, construction of new sewer networks, and combined optimization of sewer network, WWTPs and DWTP ([illegible] et al., 2018).

To curtail the present Covid-19 pandemic and future pandemics, environmental surveillance is essential. WBE epidemiological surveillance is recommended alongside standard protocol for pathogen detection and quantification (Collivignarelli et al., 2020; [illegible] et al., 2021; Jiang, 2006; [illegible] et al., 2020; Polo et al., 2020). However, environmental surveillance should encompass other infectious virus such as adenovirus, norovirus, polyomavirus, bacteria and protozoa, plastic wastes, groundwater pollution, COD (chemical oxygen demand and BOD (biological oxygen demand) which directly impact aquatic organisms, EDCs (endocrine disrupting compounds) and PPCPs (pharmaceuticals and personal care products) found in wastewaters and polluted surface waters, In addition, protection of drinking and recreational waters against aerosolized Covid-19 is important because Covid-19 survives longer in water than wastewater ([illegible] et al., 2020; [illegible]). Optimized and standardized protocol facilitates global comparison, creation of useful database and enhances research collaboration (Michael-Kordatou et al., 2020) (Michael-Kordatou et al., 2020). Environmental surveillance should cover waste, food, water, and funeral services. Also, social and healthcare institutions should be strengthened (Gwenzi, 2021). To minimize aerosolized (Covid-19) pathogen transmission, micro-bubble generator, as well as improved building plumbing and ventilation systems have been recommended (Al Huraimel et al., 2020; [illegible] et al., 2021; [illegible] et al., 2021). Another study recommends protection of fragile water sources from industrial and anthropogenic pollution ([illegible] et al., 2019). To remove persistent emerging contaminants of public health concern from water and WW, recent studies recommend ultrasonication, membrane treatment and nanoadsorbents ([illegible] et al., 2017; Joseph et al., 2019; [illegible] et al., 2019). The emerging contaminants include EDCs, PPCPs (pharmaceuticals and personal care products) and heavy metals.

Plastics constitute 60–80% of global marine debris and is a major environmental concern because it poses threat to marine wildlife, human food chain accumulation and biomagnification (Lestari and Trihadiningrum, 2019; [illegible] et al., 2021; [illegible], 2015). The endemic global marine plastic pollution is a reflection of inadequate solid waste management on land and arose due to stormwater transport of plastic wastes from land sources into water bodies during SO. Dangers of plastic include accumulation of organic contaminants by microplastics, biofilm formation and growth, biodiversity reduction, transmission of invasive species and diseases (Beaumont et al., 2019; Compa et al., 2019; Gorman et al., 2019; Jahnke et al., 2017). Besides the hazardous and non-biodegradable nature of marine plastics, plastic ingestion and entanglement of marine animals contribute to the death of thousands of marine wildlife and reproduction impairment ([illegible]; [illegible]; [illegible]; [illegible]). Therefore, marine plastic pollution has been identified as a planetary boundary threat to marine ecosystem and human health which may be irreversible if left unchecked ([illegible]; [illegible]). Suggested solutions include plastic waste recovery, promotion of plastic recycling in construction and commercial products; source reduction, increased environmental awareness and mobilization of international actions towards global marine plastic governance ([illegible]; [illegible]; [illegible]; [illegible]; [illegible]; [illegible]; [illegible]).

Groundwater pollution occurs through sewer exfiltration (leakage) from sewer network, infiltration from surface water and storm runoff ([illegible]; [illegible]; [illegible]; [illegible]; [illegible]). While sewer leakage occurs due to deterioration of aged sewer/pipes infrastructure, sewer defects and poor rehabilitation ([illegible]; [illegible]; [illegible]; [illegible]; [illegible]), infiltration is determined by the aquifer characteristics, hydraulic loading and pipe/sewer material ([illegible]; [illegible]). With the poor state of sewer infrastructure globally ([illegible], 2014; [illegible]), pathogens can easily be transmitted into the environment leading to disease outbreaks ([illegible]; [illegible]). Therefore, improvement in surface water quality, upgrading sewer infrastructure and ensuring regular rehabilitation of urban sewer network contribute towards groundwater protection, reduction of pathogen transmission and improved public health.

EDCs and PPCPs are emerging, toxic and hazardous contaminants with the capability of altering natural hormones thereby affecting the health of contaminated humans/wildlife ([illegible] et al., 2020; [illegible]; [illegible]; Vieira et al., 2021). Removal of EDCs in the environment has received international attention due to the long-term health risks to humans and wildlife ([illegible]; [illegible]). The long-term consequences include impairment of neurodevelopment in children such as autism, breast and prostrate cancer, obesity and diabetes type 2, alteration of sperm quality and fertility to mention a few ([illegible]; [illegible]; WHO, [illegible]). Low public awareness, low evidence on human exposure risks, incompetent existing regulations and political responsibility makes EDC removal challenging (Wee and Aris, 2019). In addition, removal of EDCs in wastewater is difficult due to the complex structures of EDCs, inefficient removal by conventional WWT and their pervasiveness in the environment ([illegible]; Schug et al., 2016; [illegible]; Vieira et al., 2021). Discharge of SO and poorly treated wastewater effluents from WWTPs that are rich in EDCs undermine the safety of drinking water and access to safe public water supply (Wee and Aris, 2019). Therefore, biodegradation, multi-stage/combined WWT processes and advanced WWT with nanofiltration are recommended for enhanced removal or reduction of EDCs in wastewater treatment ([illegible]; [illegible], 2016; Kasonga et al., 2021; Vieira et al., 2021) ([illegible]; Kasonga et al., 2021; [illegible] et al., 2016; [illegible]). In addition, replacement of pesticides, herbicides and industrial chemicals in agriculture and manufacturing of pharmaceutical and personal care products with ecofriendly alternatives is also recommended to avoid dietary and lifestyle exposures to EDCs (Autrup et al., 2020; He et al., 2015; Li et al., 2021b; [illegible] et al., 2012).

Policy and social interventions are necessary to reduce/eliminate infections during disease outbreaks and pandemics. Since such interventions are made by government, combination of insights from policy makers and scientists are important to come up with cost-effective interventions (Haushofer and Metcalf, 2020; Manipis et al., 2021). Recent studies revealed that aggressive social interventions were more effective in saving both human lives and the economy compared to lenient infection control measures (Silva et al., 2020; Ueda et al., 2021) (Silva et al., 2020; Ueda et al., 2021). The most effective infection control measures to suppress disease transmissions involved multiple strategies such as school and university closures, home quarantine, case isolation, enhanced personal hygiene, beach closure and social distancing before vaccination is available and distributed ([illegible]; [illegible]; [illegible]; [illegible]; [illegible]). While suppression is favourably recommended, it causes severe economic hardships which need to be mitigated ([illegible]). Therefore, welfare policies need to be put in place to take care of the vulnerable populace such as low-income households, informal workers, slum dwellers, low-skilled workers and self employed ([illegible]; [illegible]; [illegible]).

Covid-19 pandemic present peculiar challenges and opportunities for solid waste management. The challenges include intensification of single-use plastics such as face masks, food containers and gloves, safety protection of waste handlers due poor waste handling, reduction of waste collection due to fear of infection, pathogen transmission during waste treatment/processing, reduction in demand for recycled waste materials and recycling of contaminated bottles ([illegible]; [illegible]; [illegible]; [illegible]; [illegible]; [illegible]). The opportunities presented for efficient solid waste management include automated waste management, internet of things, automated waste separation, development of non-incineration disposal technologies, improved guidelines for waste collection, storage and treatment, regular maintenance of stormwater systems, decentralized waste management and investment in recycling technologies ([illegible] et al., 2021; [illegible] et al., 2020; Kulkarni and Anantharaman, 2020; [illegible] et al., 2021; Ragazzi et al., 2020; Sharma et al., 2020; Singh et al., 2020; Zhao et al., 2021). Therefore, solid waste management should be seen as essential public health service which should be integrated with public health emergencies ([illegible]; Kulkarni and Anantharaman, 2020).

Furthermore, vector transmission of pathogens poses a global threat to human health due to their presence mostly in tropical and subtropical regions of the world and transmission through companion and farm animals (Schorderet-Weber et al., 2017; Shaw and Catteruccia, 2019; [illegible], 2020). For instance, mosquito species such as Aedes aegypti and *Aedes albopictus* poses threat of spreading viruses such as yellow fever, dengue, chikungunya, Zika, West Nile, Chikunguya viruses as well as encephalitis (Whiteman et al., 2019). Favourable conditions for such transmission are tree covers, micro-climatic conditions, high impervious surfaces, unmaintained drains and socio-economic conditions (Whiteman et al., 2019; Wimberly et al., 2020). In order to curb vector pathogen transmission to humans in urban and rural environments, integrated vector surveillance and pathogen prevention/intervention campaigns have been recommended alongside bio-chemical control measures, lethal traps and improved water and sanitation systems ([illegible] et al., 2021; [illegible] et al., 2017; Schorderet-Weber et al., 2017; Sharma and Lal, 2017; Shaw and Catteruccia, 2019; Singh et al., 2019; Whiteman et al., 2019). Also, optimization of combination of various intervention measures, co-ordinated development of local capacity and development of effective vaccines are also recommended to prevent vector-borne diseases (de la Fuente and Estrada-Peña, 2019; Peterson et al., 2019; [illegible], 2020).

4.3. Modelling-based studies

Four modelling approaches are identified from previous studies and are summarized in Table 5. The top modelling aproach utilized is categorized under multiple techniques (63%), followed by AI approaches (19%), while the least deployed approaches are numerical and statistical modelling techniques (9% each), as shown in Fig. 10 (a). Multi-techniques involve combination of different complementary techniques, as shown in Fig. 10 (b). This approach has the capability to model and reveal sewer network-WWTP-receiving water spatio-temporal complex interactions. Also, multi-technique approach helps to improve both the robustness of the modelling as well as data

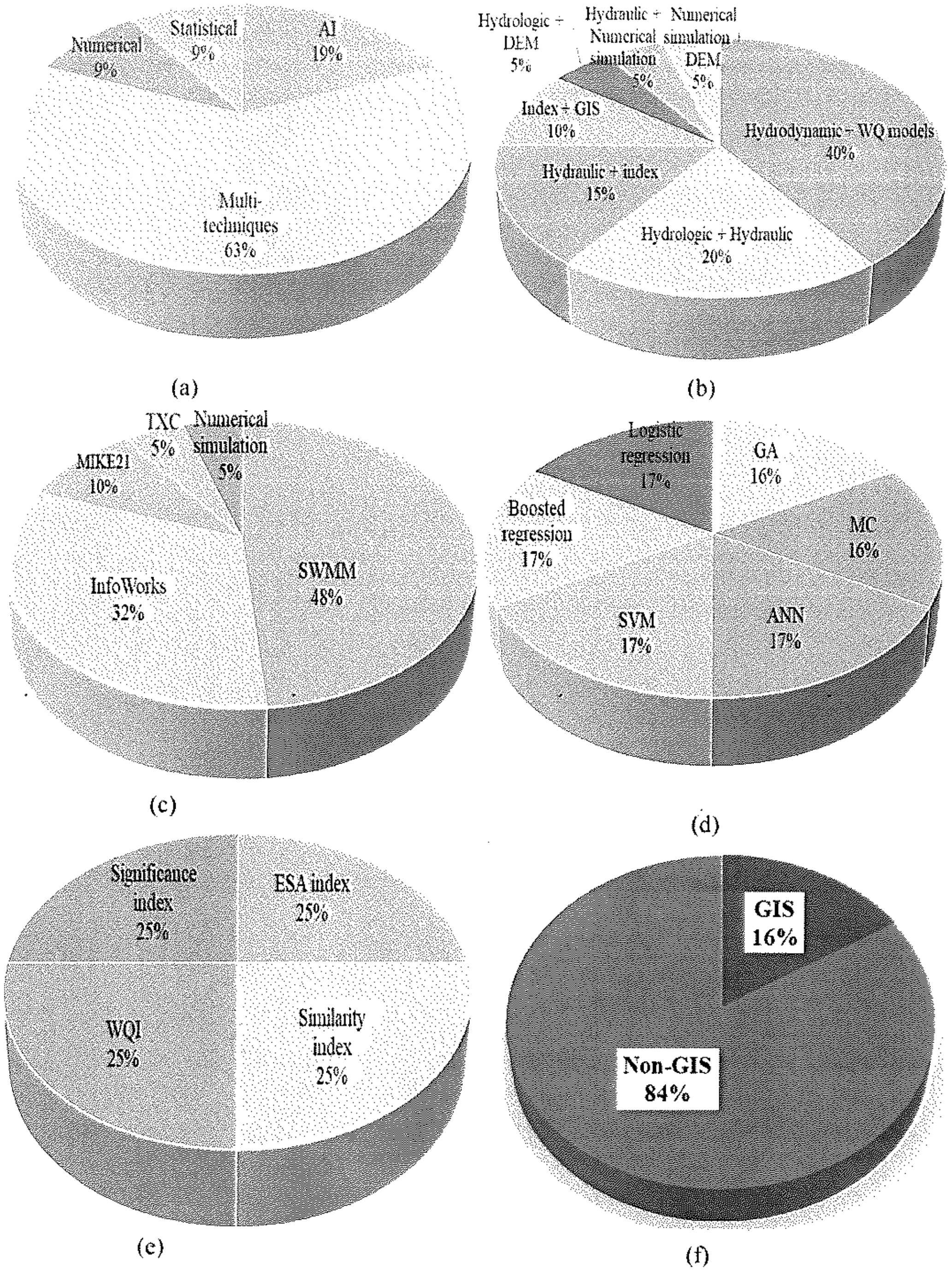

Fig. 10. (a) Modelling-based approaches (b) Multi-technique approaches (c) Hydrodynamic modelling approaches (d) AI modelling approaches (e) Index classification approaches (f) GIS utilization.

interpretation. As shown in Fig. 10 (c), stormwater management model (SWMM), developed by the United States Environmental Protection Agency (USEPA), is the most common model utilized for hydrodynamic modelling (48%). Next in popularity is InforWorks (32%) owned by Infors and Mike 21 developed by Danish Hydraulic Institute (DHI).

In addition, artificial intelligence (AI) approaches have been utilized in modelling. The AI methods include genetic algorithm (GA), monte carlo (MC), artificial neural network (ANN), support vector machine (SVM), and boosted regression, as shown in Fig. 10 (d).

ANN is suitable for complex, non-linear physical systems which vary in time and space (Aziz et al., 2013). Applications of ANN include prediction of CSO depth using rainfall data and water level of CSO chamber, forecast dry weather and wet weather SO level, detection of potential SO and infiltration, automation of storage and screening devices, risk and hazard identification and mitigation and multi-objective optimization (Abbasi et al., 2021; Abdellatif et al., 2015; Aziz et al., 2013; Darsono and Labadie, 2007; Jang et al., 2021; Mounce et al., 2014; Rathnayake, 2021; Rosin et al., 2021; Sumer et al., 2007). Disadvantages of ANN include requires accurate calibration and data pre-processing requirements, susceptible to overfitting and overtraining and lack of transparency to aid analysis and performance interpretation ([illegible]; [illegible]; [illegible]). The advantages of ANN include suitable for complex problems, adaptive learning, high execution speed and fault tolerance ([illegible]; [illegible]). Suggested methods to overcome the shortcomings of ANN and improve its accuracy include reduction/restriction of network size, limiting the magnitude of the weights applied, selection of suitable architecture and appropriate training, booststrapping and hybridization ([illegible]; [illegible]; [illegible]; [illegible]).

On the other hand, support vector machine (SVM) has strong adaptability, global optimization, and a good generalization performance because it include aspects and techniques from machine learning, statistics, mathematical analysis and convex optimization and has been applied in storm runoff and flood forecasting ([illegible]). The main advantages of SVM is simultaneous reduction of model complexity and prediction error, good performance in classification and regression task ([illegible]; [illegible]). Also, SVM has higher classification accuracy compared to ANN, can be utilized with small data sets and high-dimensional data ([illegible] 2005). Also, SVM performed better than logistic regression in monitoring land use changes and has been applied in flood forecasting and flood mapping when combined with GIS ([illegible]; [illegible] 2018; [illegible] 2015). Disadvantages of SVM include may require large amount of data, time-consuming, susceptible to error from utilization of past data and difficulty in model interpretation ([illegible] 2015; [illegible] 2014; [illegible] 2018). Recent studies reported that SVM performed better than logistic regression and ANN ([illegible] 2018; Pal and Mather, 2005).

Monte Carlo is a statistical/mathematical technique used to predict possible outcome of output based on the distribution of the input parameters. Monte Carlo analysis can provide better information to decision makers about the potential risk of failures and alternative treatments of SO (Verhuelsdonk et al., 2021). Examples include assess risk of WWTP effluent exceeding regulatory requirements and potential savings in comprehensive plant optimization ([illegible]; [illegible]). Advantages of Monte Carlo include relatively easy to understand, assessment of the uncertainty in model output via sensitivity analysis and identification of major input factor responsible for most of the model output variability ([illegible] 2002; [illegible] 2018; [illegible] 2019; [illegible] 2020). Disadvantages of Monte Carlo include output accuracy depends on utilization of reasonable/fair assumptions, tendency to underestimate risk events, computational requirements, time-consuming and susceptible to overfitting ([illegible] 1992; Han et al., 2007; [illegible] 2008).

Genetic algorithm (GA) is an efficient algorithm/tool inspired by nature for real-time optimization of the sewer network system for effective decision making to control SO ([illegible]; [illegible]). GA has advantages of flexibility, prompt adaptation to changing conditions and reliability and limited CPU requirements ([illegible]). However, recent studies recommended combination of model predictive control and GA as well as GA and ANN for real-time control of urban sewer systems and to improve performance of GA and reduce network load without sacrificing quality ([illegible] 2021; Rauch and Harremoës, 1999). Advantages of GA include suitable for large, complex and poorly understood problems, robust, stochastic and supports multi-objective optimization within a short computation time (Rao et al., 2008) (Rao et al., 2008). Disadvantages of GA include difficult to design and represent the problem, computationally expensive, time-consuming and premature convergence ([illegible] 2021).

Boosted regression is a framework that aims to reduce the bias and variance in a supervised learning technique. Its advantages include does not require data pre-processing, handles missing data, highly flexible, high predictive performance, easy implementation of complex interactions while its disadvantages include prone to overfitting, computationally expensive and its high flexibility results in multiple parameters directly affecting the model behavior ([illegible]; [illegible]; [illegible]). Boosted regression has been applied in predicting occurrence of chemicals of emerging concern in surface water and bottom sediment, prediction of sewer pipe sediment as well as flow prediction in sewer and drainage systems ([illegible]; [illegible]; [illegible]).

Logistic regression his a statistical method for predicting the outcome of a binary variable from one or more input variables. Logistic regression has been applied in predicting the influence of rainfall and imperviousness on storm overflow, predicting overflow discharges and annual number of overflow discharges, modelling the risk of SO triggered by sea level rise and design of hydraulic structures for SO ([illegible]; [illegible]; [illegible]). Advantages of logistic regression include easier to implement compared to most machine learning techniques, suitable for dataset that can be linearly separated, provides additional insight on the relationship between dependent and independent variables ([illegible]). The disadvantages include unsuitable for non-linear problems with complex relationships, requires fairly large dataset for improved accuracy, cannot provide continuous outcome and susceptible to overfitting.

Though computationally intensive, the AI modelling approaches are suitable for modeling complex interactions of sewer network-WWTP-receiving water nexus. In addition, AI approaches are effective for carrying out multi-objective optimization problems to minimize environmental impact of SO.

Several indices that are utilized to simplify management decision making are displayed in Fig. 10 (e) and are often combined with geographic information system (GIS). ESA (environmental sensitive areas) index combines several indices, which cover vegetation, climate, soil quality, and management quality (De Paola et al., 2013). Similarity index is useful for rainfall classification to identify extreme rainfall that can induce sewer overflow (SO) and their distribution pattern ([illegible]). Water quality index (WQI) is useful in portraying spatio-temporal deterioration changes in receiving waters to prioritize intervention schedule. Similarly, significance index takes into consideration population served by sewer network, available dilution, type of receiving water, and their environmental services. Though subjective, the index is useful in prioritizing SO monitoring sites and reveals areas with potential high risk of SO impact (Morgan et al., 2017). Of the assessed studies, only 16% utilize the GIS system, as shown in Fig. 10 (f). This implies that there is ample opportunity to improve GIS applications in monitoring SO. GIS has been utilized to demonstrate the impact of land cover changes ([illegible] 2020), display environmentally sensitive areas (De Paola et al., 2013), and areas of high ecological risk ([illegible]).

4.4. Hybrid method-based studies

Studies reporting hybrid modelling are summarized in Table 6. The hybrid modelling approach combines field sampling/laboratory studies with modelling techniques, which include hydrodynamic, numerical, ANN or statistical, as shown in Fig. 11 (a) and (b). Various types of analyses carried out in the field sampling part are shown in Fig. 1 (a). It is observed that more attention has been paid to both physical and physico-chemical analyses than biological and microbiological analyses. More attention is required to showcase the impact of organic pollution (from physico-chemical pollutants) on aquatic organisms. In addition, more research is needed to show the microbiological impact of virus and bacteria that are transported to the receiving waters during SO.

The four modelling approaches that have been employed under the hybrid method are shown in Fig. 11 (b). Most of the studies (53%) utilize hydrodynamic models, followed by numerical modelling, while the least employed methods are ANN modelling (8%) and statistical modelling (8%). Hybrid method displays spatial-temporal contaminant transport and simulate impact of urban effluent/SOs on receiving waters. It is also useful in evaluating different (SO) management strategies to select the

Table 6
Summary of hybrid method-based studies.

Category	Summary/Remark	References
Physico-chemical	SO causes permanent short and long-term impacts on rivers, such as oxygen depletion, increased BOD, and turbidity, which affect the suitability of those habitats for fishes and other aquatic lives. DO impact is caused by the degradation of organic matter by heterotrophic bacteria and reduced phytoplankton activity. 30–70% of the impacts can be reduced with different mitigation strategies. ANN and SWMM can accurately predict water quality in sewers and stormwater systems.	([illegible])
Physico-chemical & microbiological	Organic loading and sediment resuspension from SO cause serious chemical and biological degradation of river and beach water quality, thus reducing aquatic biodiversity. Major contaminants include COD, BOD_5 and *E. coli*. Besides, *E. coli* 500 times over the regulation threshold has been observed during SO. Mitigations studies recommend microbial pollution monitoring at beaches and repositioning marine outfalls.	([illegible])
Physical analysis	This approach recommends optimizing the design of various processes of WWTP to improve WWT efficiency and hence, minimize residence time and dredging costs.	[illegible]
Microbiological analysis	This technique recommends source-water protection against SO impacts on public health. Highest *E. coli* concentration has been found in drinking water during SO events.	[illegible]
Biological & Index	This method recommends estuarine fish assessment index to monitor the impact of different environmental stressors on fishes.	[illegible]
Physico-biological	Urban, industrial, and agricultural activities serve as important sources of chemical pollutants and nutrients, which cause oxidative stress with genotoxic effects in aquatic organisms. The pollutants include PCB, PAH, herbicides, personal care products, pharmaceuticals, and trace metals. Protection of watercourses from these toxic pollutants is crucial to protect aquatic organisms and public health.	[illegible]

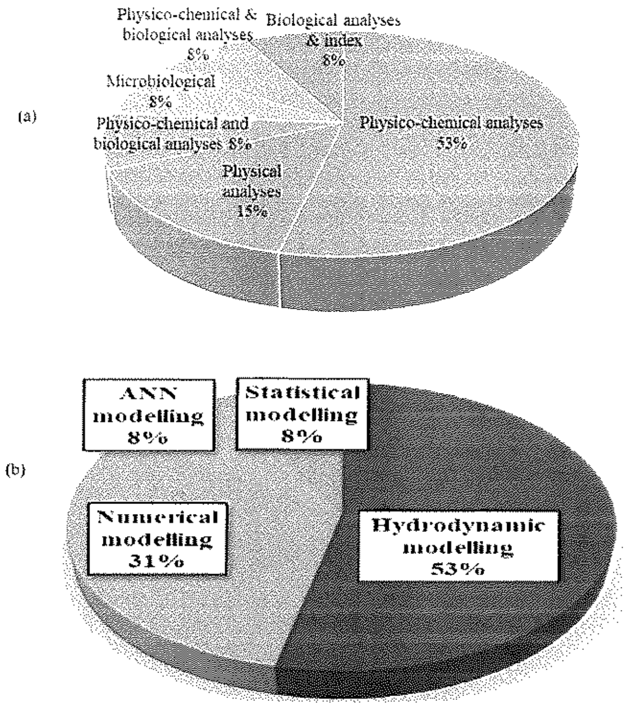

Fig. 11. (a) Distribution of types of field/laboratory analyses (b) Modelling approaches for hybrid method.

best design and management option to mitigate the impact of SO on aquatic organisms (e.g. fishes). It can also be used to reduce public health risks to end users who use such rivers and beaches for recreation and sources of drinking water.

To mitigate biodegradation caused by sewer overflow, a recent study suggests combined application of sedimentation tank and multi-stage treatment with plants ([illegible]). Based on this combined set-up, the authors achieved TP (total phosphorus) and COD (chemical oxygen demand) removal of 23.9% and 45.9%, respectively during SO event. With the aid of GIS, a recent research maps out a study area and finds that seven lakes out of nine are unsuitable for fishes in terms of BOD and DO. Pollution in those lakes is attributed to anthropogenic pollution from agricultural activities, fish farming, and poor domestic waste disposal ([illegible]). Groundwater infiltration, through joints and sewer leakage, has also been reported to affect WWTP efficiency. A field study showed that SO events can also result from low delivery capacity and blockage of branch sewer pipes ([illegible]).

In order to diagnose and mitigate SO impact on the environment, a study recommended a sewer system-treatment plant-receiving natural environment approach ([illegible]). Also, the low treatment efficiency and poor cost-effectiveness of WWTP are due to a lack of optimization of the various processes of WWTP ([illegible]). Therefore, CFD (computational fluid dynamic) modelling of the WWTP processes is encouraged before constructing future WWTPs to improve treatment efficiency, avoid redesigning costs, and reduce dredging/maintenance costs.

4.5. *Studies based on laboratory/field experiments*

Studies focusing solely on laboratory/field experiments only are displayed in Table 7. The research focus distribution of studies concentrating on only laboratory experiments is also displayed in Fig. 12. Almost half of the studies focuses on degradation and settling treatments of wastewater. Both adsorption and degradation techniques are focused on the elimination of emerging contaminants/micropollutants, such as acetaminophen, naproxen, trinizadole, and benzotriazole ([illegible]; [illegible]; [illegible]). These contaminants are difficult to remove using conventional wastewater treatment protocols. Activated biochar and UV, solar radiation, and chlorination have been utilized to remove them at different removal efficiency of between 50 and 100%. Furthermore, settling methods exploit polyacrylamide and sand to remove iron nanoparticles and suspended solids. Polyacrylamide is a cost-effective method for improving WWTP effluent through the removal of iron nanoparticles by dynamic gravity settling ([illegible]). The dynamic gravity process is compatible with conventional WWTP process.

Table 7
Summary of studies based solely on laboratory and field experiments only.

Category	Summary	References
Laboratory experiments		
Adsorption	Activated biochar removes 94.1% and 97.7% of acetaminophen and naproxen, respectively through adsorption. Therefore, optimized combination of adsorption and other methods, such as coagulation, is recommended.	[illegible]
Degradation	Recommends photo-Fenton systems comprising UVC and solar radiation for removal of antibiotics from contaminated water and wastewater. Also, UV-A/chlorination process is recommended for effective removal of emerging contaminants in WWTPs and reduction of their toxicity.	([illegible]; [illegible])
Settling	Recommends dynamic gravity settling with polyacrylamide and ballasted settling with sand for fast and efficient wastewater treatment for removal of nanoparticles and suspended solids from coagulation/flocculation process	([illegible] et al., 2018; [illegible])
Filtration	Proposes the use of either tubular or spiral membranes to improve wastewater treatment. While tubular has a very high removal of turbidity, COD, and colour, it requires pre-treatment owing to its high fouling resistance and low permeates. On the other hand, spiral membrane has a lower COD and colour removal and requires additional treatment for colour removal.	[illegible]
Sediment transport	Flume test is utilized to study in-sewer sediments deposition, erosion and transport. The test reveals sediment deposition cohesion during long dry weather and biodegradation of sediments due to their organic content, which improves sediment bed resistance. Test also shows that 74% of pollutants attached to sediments decrease to 56%, while 75% of the pollutants attached to biofilms remains constant. Screening-out sediments from wastewater before entering the sewers is recommended to reduce biodegradation of sewers, organic load transmission, and improve WWTP efficiency.	[illegible]
Anaerobic digestion	Proposes anaerobic co-digestion of food waste (FW) and Covid-19 infected sewage sludge (SS) to eliminate Covid-19 to undetectable levels. Combined control of operational temperature and organic loading (OL) is crucial to eliminate Covid-19. At 20 °C + OL of 3.5 gVS/L, 35 °C + OL of 3.5 gVS/L and 50 °C + OL of 1.5 gVS/L, Covid-19 RNA is not detected.	[illegible]
Field experiment		
Rain garden	Recommends vegetated rain gardens for stormwater control.	[illegible] et al. ([illegible])

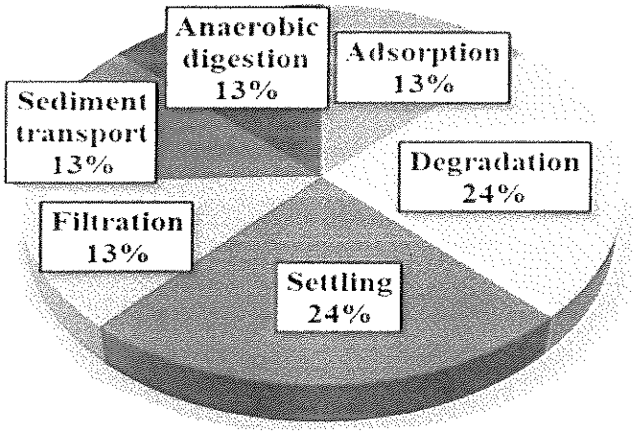

Fig. 12. Research focus distribution of studies focusing on laboratory experiments.

A recent study also reported that suspended solids in wastewater can be removed faster (<4 s) by dosing with ballasted sand ([illegible] et al., 2020). Turbidity removal efficiency of 90% has been achieved at 2 mg/L of flocculants to 1 g/L of sand. Future studies should investigate the best combination of sand and flocculants and application intervals to improve the efficiency of ballasted flocculation method. It is also observed that different filtration membranes require different design criteria, operation, and maintenance to achieve similar performances ([illegible] et al., 2011). In order to improve the longevity and efficiency of filtration membranes, pretreatment of wastewater is required to reduce membrane fouling caused by pore blockage and cake formation.

Some studies have also focused on sediment transport study by examining sediment erosion and deposition in sewer pipe. Sediments and biofilms have been reported to play crucial roles in the biodegradation processes taking place in sewer networks ([illegible] et al. 2020). Therefore, screening out the sediments from entering the sewer network and regular flushing maintenance are required to improve WWTP efficiency. Such practices will reduce both sediments and biofilms in sewer networks and significantly reduce microbial and organic pollution of receiving downstream waters during SO. Co-digestion of WWTP sludge with food waste at elevated temperature of 50 °C has also been recommended to reduce the viability of Covid-19 in WWTP sludge by up to 99.7% ([illegible] and [illegible], 2021). Such high efficiency is attributed to the synergistic effects of volatile fatty acid (VFA) accumulation, long operation condition (45 h), and temperature.

Studies focusing on field experiment are also displayed in Table 7. It is observed that rain gardens can be used to dissipate urban storm runoffs and 50% dissipation can be achieved within two days ([illegible] et al., 2015). Rain gardens are green infrastructure which promote infiltration of storm runoffs into the groundwater, evapotranspiration, and capture of stormwater for reuse. The system requires construction of several wells. The efficiency of the rain garden is determined by the infiltration capacity of the soil, the surface area of the rain garden, and the number of connections to the rain garden. The optimal number of rain gardens depends on the type of drainage areas and SO control targets (Shamsi, 2012). Rain gardens with between 10 and 20% of impervious surface area are recommended and are cost-effective alternative to the large-scale centralized stormwater sewers and detention tunnels (Aad et al., 2010; Dussaillant et al., 2004).

Benefits of rain gardens include 38% total runoff volume reduction, 33% peak reduction and 76% stormwater reduction ([illegible]; [illegible]). Another study reported draining time of 1.5 min–8 h with an average drain time of 1.3 h ([illegible]). Another study showed runoff reduction of 12.7%–19.4%, volume reduction of 13–62%, and peak flow reduction of 7–56% depending on the SO event ([illegible]). Beside peak flow reduction and delay in peak flow arrival time, rain gardens are useful in pollution reduction through natural attenuation of contaminants during infiltration ([illegible]; [illegible]). However, the major drawbacks of rain gardens are unsuitability for large runoff events and costly maintenance requirements ([illegible]; [illegible]). Owing to overlapping of jurisdictional boundaries in conservation and disposal of SO, public buy-ins, institutional co-operation, and appropriate location are required ([illegible]). Potential cost savings of US$ 35 million over a 50-year period has been reported for combined green/gray infrastructure ([illegible]). Therefore, future studies are required to assess and design cost-effective rain gardens.

5. Sewer overflow impact on public health

Sewer overflow negatively influences drinking water, surface waters and recreational beaches, groundwater, and irrigated foods as shown in Table 8. Consumption of such infected foods/water and direct contact with infected foods/water and animals have facilitated disease outbreaks in several countries (Campos and Lees, 2014; Caplin et al., 2008; Elmahdy et al., 2019; Farkas et al., 2018; Han and He, 2021; Hassard et al., 2017; Lee et al., 2012; O'Reilly et al., 2007). The gastrointestinal outbreak on South Bass Island, which affected both residents and tourists, was caused by consumption of contaminated drinking water sourced from fecally-contaminated public and private wells (O'Reilly et al., 2007). Reported symptoms of infected patients include diarrhea, abdominal cramps, nausea, vomiting, fever and bloody diarrhea and were attributed to fecal-indicator pathogens such as *Arcobacter, E.coli, C. Jejuni, Salmonella. Giardia spps.* found during investigations (O'Reilly et al., 2007). Both environmental and epidemiological investigations linked the contamination to disposal of untreated sewage and infiltration of contaminants from septic tanks through the fragile karst aquifer (O'Reilly et al., 2007).

Furthermore, another study reported that highly contaminated beaches pose health risk to beachgoers (Lee et al., 2012). The most prevalent pathogen found in Lake Erie beach water namely *Arcobacter* spp was significantly correlated with human bacteroides (*Prevotella*), which is a fecal contamination marker. Fecal and microbial contamination of the beach was attributed to a large population of birds bathing in the beach waters and sanitary/sewer overflows and the contamination is often high during the swimming season (Lee et al., 2012). Likewise, another study reported outbreak of gastroenteritis in children which was linked to fecal-oral transmission of human adenovirus via contaminated water and food (HAdV) (Elmahdy et al., 2019). The inadequate removal of HAdV in treated effluents at the WWTP facilitates release of pathogens into the water environment and utilization of such water for irrigation, shellfish cultivation and any industrial process engender pathogen transmission (Elmahdy et al., 2019; Katayama et al., 2002).

Food-chain transmission of pathogens was confirmed in gastrointestinal outbreaks caused by norovirus in some studies and was attributed to consumption of fish, shellfish and oysters harvested from sewage-polluted rivers and estuarine waters (Campos and Lees, 2014; Farkas et al., 2018; Hassard et al., 2017). In addition, epidemic outbreak of antibiotic-resistant enterococci was linked to food-chain transmission via infected dairy cattle, sheep and poultry (Caplin et al., 2008). A recent study also reported that communities served by combined sewer systems are prone to higher risks of Covid-19 transmission due to their frequent exposure to sewer overflow which contains infected human urine and feces (Han and He, 2021). These results imply pathogen transmission occur via several routes.

Table 8
Public health impact of sewer overflow.

Reference	Pathogens	Causes	Diseases	Locations
[illegible]	Multi-pathogens (*Arcobacter, E.coli, C. Jejuni, Salmonella. Giardia spps.*)	Drinking sewage-contaminated groundwater	Outbreak of gastrointestinal diseases (1450 persons infected)	South Bass Island
[illegible]	*Arcobacter* sp.	Swimming in contaminated beach waters	Gastrointestinal diseases	Lake Erie beach, Ohio
[illegible]	Human hepatitis A Virus (HAdV)	Discharge of poorly-treated WW effluent	Inflamed liver, fever, dark urine, jaundice	Eastern Cape, South Africa
[illegible]	Human Adenovirus (HAdV)	Disposal of poorly treated WW & sewage sludge	Outbreak of grastroenteritis in children (60 children)	Egypt
[illegible]	Norovirus (NoV)	Consumption of shellfish harvested from sewage-polluted estuarine waters	Epidemic gastroenteritis	UK
Hassard et al. 2017	Norovirus (NoV)	Person-person contact & consumption of infected fish, shellfish & oysters	Gastrointestinal outbreaks in restaurants, etc.	Australia, USA, Netherlands, France, UK
Farkas et al. 2018	Norovirus (NoVGI)	Consumption of shellfish harvested from sewage-polluted rivers	Gastroenteritis outbreak (36 persons infected)	North Wales
Han and He, 2021	Covid-19	Sewer overflow of untreated wastewater or sewage	Community outbreak of Covid-19	USA & China
Caplin et al. 2008	Enterococci	Food chain transmission via infected dairy cattle, sheep and poultry	Epidemic outbreak of antibiotic-resistant enterococci	UK, Netherlands, USA & Australia

Therefore, multi-barrier approach is required to protect public health and prevent pathogen transmission. In summary, pathogenic persistence and transmission is highly dependent on water and wastewater infrastructure, agricultural practices, health infrastructure, environmental surveillance, and public awareness. The public health impact is enormous when adequate attention is not given to these crucial factors.

6. Health risk assessment of wastewater treatment plant

Quantitative microbial risk assessment (QMRA) is a tool for evaluating and quantifying exposure risks to pathogens, communicate associated health risks and facilitate risk management (Beaudequin et al., 2015; USEPA, 1989; Whelan et al., 2014; Yan et al., 2021). The health risks associated with Covid-19 and various pathogens in WWTP are shown in Table 9. The reported health risks range from 0.0003 to 8.01. The highest health risk was recorded for children and the least risk was recorded for male adults and the total health risks is higher than reported risks from various studies since several pathogens such as bacteria, virus and protozoans are present in wastewater (Li et al., 2021a; Rodrigues et al., 2016; Yang et al., 2019b). Therefore, children must have restricted access to WWTP. Children are the most vulnerable to pathogen exposure due to their lower rate of immunity and higher

Table 9
Health risk assessment of various pathogens in WWTP.

Pathogens	Annual risk of infection	Source of contamination	Exposure location/activities	Reference
Covid-19	0.0001–0.013	Working in WWTP	Splashing, ingestion, Hand-to-mouth and fomite contacts	[illegible]
Covid-19	0.011–0.023	Working in WWTP	Inhalation of bioaerosols	
Covid-19	0.0003–0.03	Working in WWTP	Inhalation of bioaerosols	
Enterobacteria, Staphylococcus, Pseudomonas	1.90–2.09	Working in WWTP	Inhalation, dermal contact	[illegible]
Integrated bacteria	6.85 (adults) 8.01 (children)	Working in WWTP Around or within WWTP	Inhalation	([illegible])
Staphylococcus	0.0002–0.064	Working in WWTP	Inhalation of bioaerosols	[illegible]
Rotavirus	0.00525–0.5 0.00022–0.23	Working in WWTP Living 300–1000 m from WWTP	Inhalation of bioaerosols	([illegible])
Norovirus	0.177–0.5 0.004–0.25	Working in WWTP Living 300–1000 m from WWTP		
E.coli	0.012–1	Working in WWTP	Accidental ingestion	[illegible]
E.coli	0.011–0.016	Working in WWTP	Bioaerosol ingestion	[illegible]
S.Aureus	0.0005–0.025	Working in WWTP		
Bacteria	0.36 (children), 0.089 (male adult), 0.077 (female adult)	Living close to WWTP	Inhalation and skin contact	[illegible]

[a] Probability of risk of infection for a single event.

ingestion rate (De Man et al., 2014; Wade et al., 2006). The health risks arise from exposure activities such as splashing of contaminated water/wastewater during recreation/work, accidental ingestion, hand-to-mouth, fomite and dermal contacts, inhalation of bioaerosols and skin contacts ([illegible], 2021; Gholipour et al., 2021; Li et al., 2021a; Mbanga et al., 2020; Pasalari et al., 2019; Yan et al., 2021; Yang et al., 2019a, 2019b; Zaneti et al., 2021). For Covid-19, the daily health risks of WWTP workers was 5.5–23.6 times higher than annual tolerable risk of 0.00055 ([illegible]). This implies Covid-19 poses serious occupational hazard to WWTP workers. Besides Covid-19, several health risks are also posed by other pathogens such as enterobacteria, staphylococcus, pseudomonas, rotavirus, norovirus and E.coli found in wastewater at the WWTP and surrounding environment (Li et al., 2021a; Mbanga et al., 2020; Pasalari et al., 2019; Yan et al., 2021; Yang et al., 2019a). The main risk of infection for WWTP workers are aerosolization of pathogens during pretreatments of wastewater/sewage, operation of aerobic moving bed biofilm reactor, aeration units and sludge dehydration and treatments (Carducci et al., 2018; Sanchez-Monedero et al., 2008; Yan et al., 2021; Yang et al., 2019b).

In addition, significant health risks is posed to surrounding communities where the WWTP is located and was higher than the tolerable health risks of 0.0001 (USEPA, 1989) by 40–2500 times for norovirus and 2.2–2300 for rotavirus, 1–10,000 for E.coli and 3600 for bacteria. This implies residents leaving close to WWTPs were at risk of exposure to aerosolized pathogens similar to WWTP workers and the disease burden depends on the dose, disease burden per case and viral concentration (Pasalari et al., 2019) (Pasalari et al., 2019). Therefore, WWTP should be located far away from residential apartments to reduce infection risks to the local communities via inhalation of bioaerosols. While generation of bioaerosols is influenced by aeration rate, source and concentration of pathogens in the wastewater and type of diffuser utilized, the distribution of the bioaerosols is determined by wind speed, relative humidity, scale of the WWTP, total suspended particulates, temperature and solar illumination (Carducci et al., 2018; Sanchez-Monedero et al., 2008; Wang et al., 2018; Yang et al., 2019a).

To reduce the risks, several studies have recommended several measures. Recent studies reported that infection risk and disease burden can be reduced by 86.1–100% through the use of personal protective equipment (PPEs) and training while bioaerosol generation can be reduced by > 60% through installation of UV (ultraviolet lamp) and air diffusers (Li et al., 2021a; Munoz-Palazon et al., 2021; Yan et al., 2021).

In support of the use of PPE, a recent study reported significant risk reduction of 97.6% for E.coli and 97.96% for S. Aureus and significant reduction of disease burden by 97.32% for E.coli and 97.47% for S. Aureus (Chen et al., 2021b).

Though no link has been established between Covid-19 shedding in WW and risk of infection, the risk of infection has been reported to decrease with treatment and the highest exposure risk is untreated feces and untreated sludge ([illegible] et al., 2021). Also, a recent study reported that fecal aerosols transmission of Covid-19 via wastewater through building plumbings is possible and lower than person-to-person transmission via respiratory droplets/aerosols (Ahmed et al., 2021). However, several studies have reported infection risks from Covid-19 and several pathogens during sewer overflow (Ahmed et al., 2021; [illegible] et al., 2015; [illegible] et al., 2019; De Man et al., 2014; [illegible] et al., 2008; [illegible] et al., 2016; [illegible] et al., 2016; [illegible] et al., 2021; [illegible], 2020; [illegible] et al., 2019; Shi et al., 2021; Soller et al., 2017; ten Veldhuis et al., 2010) as shown in Table 10. The health risk exposure occurred during bathing/swimming in beaches/recreational waters, swimming/playing in urban flood waters and sewage-impacted estuarine water, cleaning of SO floodwater from residences, food-bioaccumulation and inhalation of bioaerosols during flushing and from faulty drainages in residential apartments (Ahmed et al., 2021; [illegible] et al., 2021; Shi et al., 2021; ten Veldhuis et al., 2010). Potential for aerosolization of pathogens is increased when untreated wastewater and stormwater is released during heavy rains, thereby transporting the pathogens to downstreams and upstream communities.

Microbial risks increases during sewer overflow and children and pedestrians have 3–10 times more microbial risks than swimmers due to higher dosage of pathogens from different sources during heavy rains (Stapleton et al., 2011; Sterk et al., 2008). Illness rate of 24–226 gastrointestinal illness per 1000 have been reported for norovirus during beach surfing after SO (Soller et al., 2017). The elevated concentrations of enterovirus, norovirus, Campylobacter in both groundwater and beach water is due to the release of untreated SO and inadequately treated WWTP effluent (Schijven et al., 2015). SO also occurs due to septic fecal leaching which contaminates drinking water well and recreational waters and a recent study reported norovirus outbreak which affected 179 individuals (Mattioli et al., 2021).

Recent study reported that flooding constitute highest risk for disease burden through export of pathogen to downstream communities (Foster et al., 2021) and constitute an annual risk of 8% which is

Table 10
Health risk assessment for contact with different pathogens during SO.

Pathogens	Annual risk of infection	Source of contamination	Exposure location/activities	Reference
Cryptosporidium	5 x 10-6 – 0.004	Urban flooding of streets/roads by SO	Pedestrian and playing child	[illegible]
Giardia	0.001–0.03			
Campylobacter	0.02–0.3			
Fecal Streptococcus	0.14–0.68	Release of untreated SO into river	Beach recreation and visitors	
Enterococcus	0.14–0.67			
Norovirus	0.024–0.23		Beach surfing	[illegible]
E.coli	0.007–0.1	Release of partially treated sewage into ocean	Bathing in sewage-impacted recreational beaches	[illegible]
Norovirus	0.159–0.206	Release of untreated sewage and sewer leakage	Bathing in recreational beaches	[illegible]
Campylobacter	0.84–68	Contaminated storm sewer with sewage	Swimming/playing in urban flood waters	[illegible]
Cryptosporidium	0.00007–0.12			
Giardia	0.0014–0.04			
Norovirus	15–52			
Enterovirus	1–24			
Enterococcus & PMMoV	0.01–0.1	Release of diluted sewage due to infiltration of stormwater into sewers	Swimming in sewage-impacted estuarine water	[illegible]
Poliovirus	1.4 x 10–9 -0.86	Release of diluted poliovirus-infected wastewater	Swimming in infected water bodies	[illegible]
Norovirus	0.004–0.03	Release of raw sewage	Swimming in recreational waters	[illegible]
PMMoV	0.0005–1	Soil contamination during SO	Soil ingestion during outdoor recreation	[illegible]
Campylobacter	0.015–0.016	SO from overloaded sewers	Cleaning of SO floodwater from residences	[illegible]
Covid-19	1×10^{-7}-5.2×10^{-5}	Swimming in infected rivers	Ingestion	([illegible]
	1×10^{-7}- 1.7×10^{-5}	Fishing	Ingestion during fishing & fish consumption	[illegible])
	0.0015	Shallow aquifer	Ingestion	
Covid-19	1.11×10^{-10} -0.00058	Toilet flushing	Inhalation of indoor bioaerosols	[illegible]
	3.53×10^{-11}	Faulty drainage		

[a] Probability of risk of infection for a single event.

expected to increase with increased urban flooding due to heavy rain caused by climate change (De Man et al., 2014). Covid-19 RNA has been found in 21.4–81% in feces of Covid-19 cases and removal of the virus load depends on the treatment system adopted by the WWTP ([illegible] 2021). While tertiary system achieve 100% complete removal, secondary treatment has residual content of 5.4 log 10 copies/L(Randazzo et al., 2020; [illegible] 2021). However, Covid-19 transmission by aerosols via faulty sewage pipelines and inadequate ventilation systems have been reported in literature ([illegible] et al., 2021).

Some studies reported that reduction of pathogen concentration in effluents discharged from WWTP and abatement of sewer overflow frequency is more effective in significantly reducing infection risk compared to increasing WWTP/sewer system capacity and restricting access to waterways/beaches (Goulding, 2011; Goulding et al., 2012). Therefore, mitigating pathogen transmission from WWTP during SO is important for meeting UN sustainable development goal (SDG) of safely managed water and sanitation ([illegible] et al., 2021). Also, the use of multiple pathogens rather than few indicator micro-organisms is more helpful to ensure safe disposal of SO considering their significantly higher risk of infections compared to indicator micro-organisms ([illegible] et al., 2021).

7. Research gaps and future research directions

The identified research gaps along with the respective future research directions are shown in Fig. 13. Though significant efforts have been made to understand the impact of SO on public health, there are still rooms for improvement. The research gaps identified are highlighed below.

There is lack of standardized protocols for detecting, quantifying and inactivating microbial pathogens of bacteria, virus, phages, etc to facilitate comparison. This concern has been reported by several researchers (Ahmed et al., 2020a; Arora et al., 2020; Haramoto et al., 2020; Kitamura et al., 2021). Utilization of different procedures and experimental conditions make data comparison and benchmarking difficult. In addition, cost-effective inactivation mechanisms in different media are required ([illegible] et al., 2021; [illegible] et al., 2020). Also, there is insufficient studies on the impact of WASH (water, sanitation and hygiene) and POUT (point-of-use water treatment) at household and community levels in combating pathogen transmission especially Covid-19. This concern was addressed in a recent study ([illegible] et al., 2021). With the present global Covid-19 pandemic, there is need to demonstrate the potential benefits of these methods to encourage wide public acceptance at the household and community levels. In addition, their implementation should be encouraged to drive disease prevention, which is always better and cheaper than procuring a cure.

There is inadequate studies on bioaerosol and fecal-oral transmission and infectivity of pathogens in diverse environments and cost-effective disinfection/prevention mechanisms. This gap is mentioned in some recent studies (Collivignarelli et al., 2020; Dhama et al., 2021; [illegible] et al., 2021; [illegible] et al., 2020). Awareness and mitigation of fecal-oral and aerosolized transmission routes will safeguard residential buildings, schools, public buildings, office buildings, and commercial buildings. Timely implementation of these mechanisms will fast-track our return to normal/near-normal life post covid-19.

Also, lack of cost-effective optimization of water and wastewater treatment and sludge disposal has been highlighted in some studies (Eganhouse and Sherblom, 2001; Ji et al., 2020; Kumar et al., 2020a; Mohapatra et al., 2021; Ryu et al., 2014; [illegible] et al., 2020). Cost-effective optimization of water and wastewater treatment as well as sludge disposal is crucial to reduce operational costs and time, improve efficiency of WWTPs, and increase resilience to pathogen transmission. Also, there is lack of multi-objective optimization of sewer network maintenance to minimize sediments, pollution load, and pathogen transmission. This concern has been raised in a recent study (Rathnayake and Anwar, 2019). Sewer network maitenance is crucial to reduce environmental pollution/transmission during SO event. Inadequate water quality modelling and real-time monitoring of SO-sewer-WWTP-receiving water continuum and lack of quantified impacts and contributions from runoff, WW, and in-sewer processes. The importance of water quality modelling has been highlighted in some

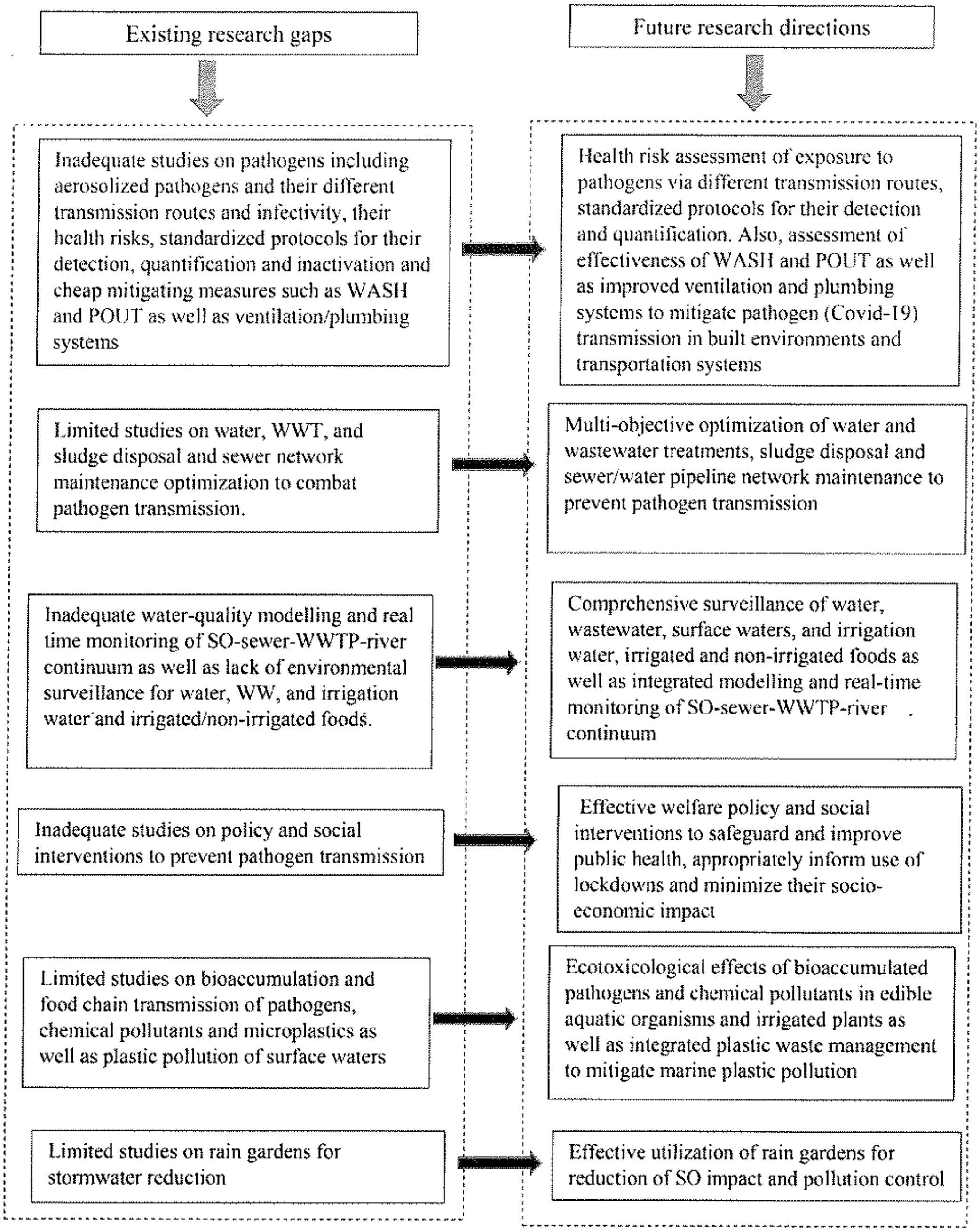

Fig. 13. Existing research gaps and future research directions to reduce SO event and safeguard public health.

studies ([illegible] et al., 2020; Gaspari et al., 2020). Also, the importance of real-time monitoring has been emphasized in a recent study (Lesimple et al., 2020). Likewise, lack of comprehensive surveillance of WW, irrigation, public tap water, surface waters, and irrigated and non-irrigated foods was noted. While importance of WW surveillance has been highlighted in several studies (Mandal et al., 2020; Medema et al., 2020; Saawarn and Hait, 2021), surveillance of other transmission media are also required.

Likewise, inadequate health risk assessments of different pathogens via different transmission routes including aerolized pathogens was also observed. The importance of health risk assessment has been reiterated in several studies (Cohen and Cooter, 2002; Jeon et al., 2017; Ortega et al., 2009; Siddiqee et al., 2020). Health risk assessment is important to establish the range and occurrence of contamination and infections, and adopt appropriate mitigative measures to protect public health. Results from health risk assessments will guide appropriate policy making to reduce pathogen transmission. Also, lack of well-informed targeted, impartful policy, and social interventions to reduce pathogen transmission, safeguard public health, and improve public welfare was also noted. This concern has been highlighted in few recent studies (Adelodun et al., 2020; Sunkari et al., 2021). Proactive policies and social interventions are crucial in curbing pandemic and more scientific studies are required to provide/guide effective evidence-based policy interventions to minimize pandemics. In addition, appropriate welfare mechanisms are required to minimize the negative effects of such policy and social interventions on the low-income households.

Likewise, this study revealed inadequate studies on bioaccumulation of pathogens and chemical pollutants in edible aquatic organisms as well as food chain transmision of pathogens and chemical pollutants in irrigated foods. Some disease outbreaks have been attributed to ready-to-eat foods such as salads ([illegible]). In addition, there is inadequate studies to effecively mitigate plastic and litter pollution of beaches and surface waters during SO. This environmental challenge has been highlighted in recent studies ([illegible]; [illegible]; [illegible]). Mitigating plastic pollution is important to avoid food-chain transmission of microplastics to humans through ingestion of fish. Furthermore, there is limited studies on effective utilization of rain gardens to reduce storm runoff to sewer networks during SO event. Limited studies have shown the benefits of green infrastructure, such as rain gardens in storm runoff and pollution reduction (Aad et al., 2010; [illegible]; [illegible]; [illegible]; [illegible]). However, their practical application in urban environments is limited.

8. Conclusion

SO poses serious threat to global public health and the environment and requires urgent concerted attention. The existing underlying threats have been aggravated by the present Covid-19 pandemic and requires a multidisciplinary approach to find urgent solutions to the identified gaps. Despite progress made, several gaps still exist to be plugged to safeguard public health and improve urban resilience towards pandemics and pathogen transmission. The main findings of this study are:

Based on scientometric analyses, the top six most-active countries in terms of SO and public health are the USA, China, Spain, Australia, Japan, and Canada. Surprisingly, they have also been highly collaborative. The top seven keywords are non-human, sewage, wastewater treatment, water quality, human, and Covid-19. The top five journals are *Science of the Total Environment, Marine Pollution Bulletin, Chemical Engineering Journal,* and *Water Science and Technology*. Based on systematic review, five methodologies were identified. The methods include combined field sampling and laboratory experiments-based studies, review-based studies, and modelling-based studies. Others are hybrid method-based studies and studies based on laboratory/field experiments.

SO impacts surface waters, irrigation water and food crops, drinking water quality, and air quality in built environments. Therefore, comprehensive surveillance of water, wastewater, surface waters, irrigation water, irrigated and non-irrigated foods is required to improve resilience to pathogens. Also, integrated modelling and real-time monitoring of SO-sewer-WWTP-river continuum is crucial in communities exposed to sewer overflow. Multi-objective optimization of water and wastewater treatments, sludge disposal and sewer/water pipeline network maintenance to prevent pathogen transmission is critical to minimize pathogen transmission. In addition, improved ventilation and plumbing systems are required in buildings and transportation systems to curb local pathogen transmission in residential buildings, hospitals, commercial buildings and transportation systems. Increased public awareness on cheap measures such as WASH (water, safety and hygiene) and POUT (point-of-use-water-treatment) such as boiling will also go a long way to safeguard public health. Health risk assessment of exposure to pathogens via different transmission routes is required to appropriately inform the use of lockdowns, minimize their socio-economic impact and guide evidence-based welfare/social policy intervention.

Furthermore, ecotoxicolocal studies on food-chain transmission of pathogens, chemical pollutants and microplastics is important to reveal the effects of these contaminants on aquatic organims and humans and their possible interactions. Also, integrated plastic waste management solutions are needed to curtail global marine pollution and associated consequences. Pre-screening of SO is recommended to minimize transport of plastic litters to marine waters while appropriate disposal systems should be provided in coastal/urban areas experiencing sewer overflow. In addition, soft infrastructure such as raingardens should be exploited and optimized to reduce stormwater burden on existing WWTP during SO. Also, literature revealed elevated health risk exposures to different pathogens for WWTP workers and surrounding communities due to bioaerosols, during swimming in polluted recreational beaches, during urban flooding, toilet flushing and faulty drainage in residential apartments as well as consumption of fishes harvested from polluted waters and polluted drinking water.

Existing research gaps alongside future research directions are highlighted. The major limitation of the existing body of knowledge is lack of integration of modelling and real-time monitoring of sewer oveflow-sewer-WWTP-river continuum. Another limitation is inadequate knowledge on pathogen transmission routes in the built environment.

Besides vaccination and isolation, environmental surveillance should be complementarily funded. To avoid common pitfalls of vaccine development, combination of conventional western medicine and natural medicine in vaccine trials should be carefully designed for optimization with AI, clinical imaging and other cutting edge technologies to achieve optimized, efficient and sustainable vaccine development.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at [illegible].

Abbreviations

ANN	Artificial neural network
Covid-19	Coronavirus disease of 2019
DWTP	Drinking water treatment plant
E.coli	*Escherichia coli*
EDC	Endocrine disrupting compounds
GIS	Geographic information system
HAdV	Human adenovirus
HPV	Human papillomavirus
HPyV	Human polyomavirus
ICP-MS	Inductively coupled plasma mass spectrometry
ICP-OE	SInductively coupled optical emission spectrometry
LC-MS	Liquid chromatography mass spectrometry
MERS-COV	Eastern respiratory syndrome coronavirus
MPN	Most probable number
NoV	Norovirus
NoVG1	Norovirus genogroup 1
PAH	Polycyclic aromatic hydrocarbons
PCA	Principal component analysis
POUT	Point-of-use-treatment
PPCP	Pharmaceuticals & personal care products
PPE	Personal protective equipment
RNA	Ribonucleic acid
RT-PCR	Real time-reverse transcription polymerase chain reaction
RT-qPCR	Quantitative reverse transcription polymerase chain reaction
SARS	Severe acute respiratory syndrome
SO	Sewer overflow
WASH	Water, sanitation & hygiene
WBE	Wastewater-based epidemiology

WQI	Water quality index
WWT	Wastewater treatment
WWTP	Wastewater treatment plant

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FILED WITH LRC
TIME: 10am
DEC 12 1996
Susan C. Wunderlich
REGULATIONS COMPILER

STATEMENT OF CONSIDERATION RELATING TO:

401 KAR 5:001 (Amended After Hearing)
401 KAR 5:005 (Amended After Hearing)
401 KAR 5:006 (Amended After Hearing)

pg 43

Letter to Greg
Letter to Karen

401 KAR 5037 Groundwater

Public Hearing Conducted
October 28, 1996
1:30 p.m., Auditorium
Capital Plaza Tower
Frankfort, Kentucky

by the

Kentucky Natural Resources and Environmental Protection Cabinet
Department for Environmental Protection
Division of Water
14 Reilly Road
Frankfort, Kentucky

(58) (a) *<u>Comment:</u> Jerry Deaton* *Kentucky League of Cities*
The word "can" in the last sentence should not be deleted.

(b) <u>Response:</u> The Cabinet intended to replace the word "can" with "may". Section 7(1)(a) is being amended to add "<u>may</u>" in the last sentence after "references to current engineering practice".

Section 7(3)

(59) (a) *<u>Comment:</u> Tom FitzGerald* *Kentucky Resources Council, Inc.*
This subsection should be modified to clarify that the design goal for a WWTP should be compliance with all effluent standards and water quality limitations, not just minimum standards, particularly if the discharge is into a high quality stream, where compliance with minimum standards for the stream classification is insufficient.

(b) <u>Response:</u> The Cabinet agrees with the concept and Section 7(3) already requires the applicant to demonstrate that the effluent from a proposed facility will not cause the receiving waters to violate a water quality standard, or in the case of a "high quality" stream, additional criteria that the Cabinet determines. Specifically, Section 7(3)(b) as proposed, includes references to the regulations that include the additional protective measures for "high quality" waters (401 KAR 5:030 and 5:031). See also the response to Comment #68.

Section 7(4)

(60) (a) *<u>Comment:</u> (Unsigned)* *Bowling Green Municipal Utilities*
The flow measuring device should be located at the influent of the WWTP.

(b) <u>Response:</u> Section 7(4) specifies that the WWTP have a flow measuring device that is capable of measuring the anticipated flow. The use of the phrase "all flow discharged by the WWTP" was not intended to specify the location. The flow measuring device can be located either at the influent point or the discharge point, as long as all the anticipated flow is measured, therefore no change in response to this comment is necessary. See also the response to Comment #90.

Section 8

(61) (a) *<u>Comment:</u> Jerry Deaton* *Kentucky League of Cities*
The regulation proposes that sewer line extension applications will be denied if the sewer system in question is subject to excessive infiltration or excessive inflow; the owner of the system would be required to first implement a plan for remediation.

See # [illegible]

(b) Response: The Cabinet disagrees; Section 8(3) and (4) state that the Cabinet may deny sewer line extensions . . . unless a plan. . . which addresses those conditions has been approved and is being implemented, not has been implemented. The plan does not have to be fully implemented before sewer line extensions will be approved. The intent is to prevent an already unacceptable situation from getting worse. It is not the Cabinet's aim, goal, or intent to approve projects that will exacerbate an existing pollution problem, especially if the owner is not willing to correct the problem. See also the responses to Comments #62-67, 85, and 109.

(62) (a) *Comment: Jerry Deaton* *Kentucky League of Cities*
The concept of remedial sizing of sewer systems statewide will be an unreasonable task due to the complexity of each system and the variables involved. This will result in unequal enforcement and the benefit received will not justify the cost expended.

(b) Response: The initial and remedial sizing of sewer systems must be accomplished, and the Cabinet will work with the system to accomplish it. The bypassing of untreated sewage is a violation of the Clean Water Act. The Cabinet cannot accept bypasses of untreated or improperly treated sewage because the sizing of the system is complex and variable. Such bypasses create health problems and affect the quality of life for the system's customers who are paying for a properly operational system. If the size of the system becomes too small due to infiltration/inflow (I/I) problems, either the I/I can be removed or the system can be sized to properly transport and treat the wastewater, whichever is more cost-effective.

The regulation is applicable to all sewer systems and the Cabinet intends on enforcing the requirements equally. The Cabinet also believes the benefits received from protecting the public's health and improving the quality of life of the system's customers will justify the cost expended to correct inadequate systems and illegal discharges.

Finally, it is important that existing customers not have to contend with inadequate systems that result from additional growth. If there are already problems or potential problems, then the existing customers need to be adequately served before new growth is undertaken and new customers are added. The changes to this regulation will assure that the facility owners balance these obligations. See also the responses to Comments #61, 63 - 67, 85, and 109.

(63) (a) *Comment: Jerry Deaton* *Kentucky League of Cities*
Virtually every wastewater system in the state experiences the problem of sanitary sewer overflows during intense rainfall. Many of our cities will incur enormous expense to pay for this type of improvement. City governments currently face many other unfunded mandates and are severely limited in their ability to raise additional revenues. These cities will be faced with tax increases, cutbacks, or increased debt service payments to meet the requirements of this regulation.

(b) <u>Response:</u> The Cabinet does not believe the problem is as widespread as is indicated. The Cabinet is merely requiring some assurance from the owner of the sewer system that the wastewater flow from the sewer line extension will reach the WWTP and that the additional flow will not cause permit violations or overflows of untreated sewage. The Cabinet believes the cities have a legal and fiscal responsibility to their citizens to build and maintain an adequate sewer system which delivers the wastewater to the treatment plant, and does not allow overflow to basements, backyards, or streets even during intense rainfall.

The Cabinet recognizes that correcting inadequate systems may be expensive and may take years to fully accomplish. The intent is to prevent an already unacceptable situation from getting worse. It is important that existing customers not have to contend with inadequate systems that result from additional growth and they should be adequately served before new growth is undertaken and new customers are added. What is proposed will not completely ban all sewer line extensions until the overflow condition is eliminated; rather, the proposed regulation would allow sewer line extension approvals to resume once a plan for investigation and remediation has been approved and is being implemented. See also the responses to Comments #61, 62, 64-67, 85, and 109.

(64) (a) *<u>Comment:</u>*

Jimmie L. Campbell	*Lexington-Fayette UCG*
Jeff Eger	*Sanitation District No. 1*
Gordon Garner	*Louisville & Jefferson County MSD*
David Hawes	*Owensboro Regional Resource Agency*
Larry V. Miller	*Bowling Green Municipal Utilities*

The wastewater flow apparently is the only point of interest when assessing if a system is capable of accepting new customers. Flow is a major concern if there are known, active sanitary sewer overflows in the system being extended. However, in most sanitary sewer systems, the presence of excessive infiltration or excessive inflow may not impair the treatment plant's ability to meet KPDES discharge limits. The presence or absence of KPDES permit violations and their frequencies should be considered.

(b) <u>Response:</u> The Cabinet requires a demonstration that both the sewer system and the WWTP have adequate capacity to transport and treat the current and the anticipated flow from the new connection. If there are known active sanitary sewer overflows in the system, the Cabinet would deny the sewer line extension, even if the WWTP had adequate capacity to treat the additional flow, unless the owner of the sewer system is addressing the condition by implementing an approved plan for investigation and remediation. Discharges from sanitary sewer overflows are illegal discharges and indicate that the system does not have adequate capacity to <u>transport</u> the existing flow. It is unwise and irresponsible to add additional flow to a sewer system that does not have the capacity to transport the existing flow. Similarly, the Cabinet would deny a sewer line extension to a sewer system with adequate capacity to transport the flow if the WWTP did not have adequate capacity to treat the additional flow, unless the WWTP owner was addressing the condition by implementing an approved plan for investigation and remediation. When a plan to address the condition and an associated schedule are approved and being implemented, sewer line extensions could be approved. See also the responses to Comments #61-63, 65-67, 85, and 109.

(65) (a) *Comment:*

Jimmie L. Campbell	*Lexington-Fayette UCG*
Jeff Eger	*Sanitation District No. 1*
Gordon Garner	*Louisville & Jefferson County MSD*
David Hawes	*Owensboro Regional Resource Agency*
Larry V. Miller	*Bowling Green Municipal Utilities*

Infiltration and inflow water quality impact should be looked at with all other potential water quality degradation sources.

(b) Response: The Cabinet already considered the human health risks and the water quality impacts in the development of these regulations. Sanitary sewer overflows (SSOs) can contain high levels of pathogenic microorganisms, suspended solids, toxic pollutants, floatables, nutrients, oxygen demanding organic compounds, oil and grease, and other pollutants. SSOs can discharge into areas where they present high risks of human exposure such as basements, private property, streets, and receiving waters used as a drinking water source, for fishing, or for contact recreation. SSOs can also contribute to impairment of aquatic life and exceedances of water quality standards. The Cabinet considers these illegal discharges to be a high priority when comparing a raw sewage discharge with even a discharge receiving primary or secondary treatment and disinfection. Allowing additional load to a sewer system or WWTP without the capacity to transport and treat the existing flow or load is unwise and irresponsible. See also the responses to Comments #61-64, 66, 67, 85, and 109.

(66) (a) *Comment:*

Jimmie L. Campbell	*Lexington-Fayette UCG*
Jeff Eger	*Sanitation District No. 1*
Gordon Garner	*Louisville & Jefferson County MSD*
David Hawes	*Owensboro Regional Resource Agency*
Larry V. Miller	*Bowling Green Municipal Utilities*

The regulation should be revised to clarify the condition for the grounds for the denial of sewer line extensions. The condition would require the actual dry weather flow, organic load, or the solids load to be considered in the context of plant performance.

(b) Response: The Cabinet would only deny sewer line extensions under this section if there were recurring overflows or permit violations at the WWTP due to infiltration/inflow. The Cabinet considers it to be inappropriate to consider only dry weather flows and loads in the context of plant performance, since the WWTP still has to meet the permit limits in wet weather. An additional problem would be in finding

St Germain, Dante

From: Clarence Hixson <budhix@iglou.com>
Sent: Tuesday, January 10, 2023 4:35 PM
To: St Germain, Dante
Cc: Cassie Armstrong; McCraney, Paula
Subject: Bull Run Townhomes SLE Comments
Attachments: Sewer Lateral Bull Run Townhomes.pdf; 1996 SSO policy.pdf

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Re: Case No: 22-ZONE-0073

and case No. 22-ZONEPA-0054

Owners: Bull Run Town Homes LLC

and KABA Select Sires Inc.

Please file the attached .pdf documents in the record and share with Planning Commission.

Thank You.

Clarence Hixson
budhix@iglou.com

Clarence H. Hixson, Esq.
1336 Hepburn Avenue
Louisville, KY 40204 (502)758-0936

"If only it were all so simple! If only there were evil people somewhere insidiously committing evil deeds, and it were necessary only to seperate them from the rest of us and destroy them. But the line dividing good and evil cuts through the heart of every human being. And who is willing to destroy a piece of his own heart?

Aleksandr Solzhenitsyn, The Gulag Archipelago, 1918 - 56.

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District and Circuit

United States District Court,
Western District of Kentucky

United States Court of Appeals
for the Sixth Circuit

January 10, 2023

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Frankfort KY 40601

Re: Case No: 22-ZONE-0073
and case No. 22-ZONEPA-0054
Owners: Bull Run Town Homes LLC
and KABA Select Sires Inc.

Project Name: **Bull Run Townhomes**

Dear Planning Commissioners,

Thirty years ago, rapid sprawl growth of Metro Louisville had outpaced the development of the sewer pipe network and main treatment plant. The pipe system included more than 118 Combined Sewer Overflows (CSOs), and numerous Sanitary Sewer Overflows (SSOs) that, in wet weather, dumped annually, billions of gallons of untreated municipal sewage into Beargrass Creek, and the Ohio River. This system failure continues today, with many wet weather overflows, despite MSD's schedule of capital engineering projects costing more than a billion dollars.[1]

One reason for the failure of MSD's thirty years struggle to protect Louisville's urban streams from sewer overflows, is the removal of critical information from planning commission hearings on new development. There is no requirement of full disclosure by the applicant and MSD, of the location and overflow frequency and volume of CSOs and SSOs affected by the

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[1] See attached. March 22, 2018, Angela Akridge, PE, Minor modification to Middle Fork Interceptor and Storage Project, submitted to KYDEP Energy and Environment and EPA listing dates and volumes of sanitary sewer overflows since 2008 dumped into Middle Fork Beargrass Creek.

proposed project. Approving significant new sewage flows to MSD sewer pipes that are already surcharging in wet weather, exacerbates an already unacceptable condition. Plan 2040's vision for healthy community development[2], Chapter 4.8.1 of the Land Development Code states:

> "This part is intended: (i) to promote, preserve, and enhance the important hydrologic, biological, ecological, aesthetic, recreational, and educational functions that river and stream corridors, lakes and other critical waterways, wetlands, and their associated riparian areas provide in Jefferson County."

But the 4.8.1 Code only contains rules about buffer areas and surface runoff. Code Section 7.4.30 - Sanitary Sewage, provides no requirement for sharing the facts of sewer overflows and line capacity issues with the affected neighbors at any hearing:

> " The method of disposal of sanitary sewage shall be the requirements of the Louisville and Jefferson County Board of Health in coordination with the Metropolitan Sewer District and the Kentucky Department for Natural Resources and Environmental Protection. When a subdivider constructs a sewage disposal plant, he shall provide for maintenance thereof until taken over by a public agency."

Code Section 7.9.92 Certificate of Sewer Extension, fails to include any requirement to share sewer capacity impacts with the Planning Commission and hearing participants.

> "This is to certify that the undersigned is the owner(s) of the land shown on this plat and hereby acknowledges that this plat is being approved with the condition that prior to any construction activity (including but not limited to clearing, grading, excavation or issuance of building permits) on any of the lots created hereby, a contract for extension of the sanitary sewer collection system (also known as a "lateral extension contract") shall be executed with the Metropolitan Sewer District."

Code Section 11.1.2. provides for the establishment of a Technical Review Committee with MSD as a member, but does not mandate disclosure of sewer overflow impacts of any project to the Planning Commission, nor provide any guidance for when such information must be included in the staff review or public hearing materials.

Code Section 11.4.3. provides rules for notification of proximate land owners, but ignores chronic sewer overflow pollution affecting neighbors downstream and causing regional pollution. The requirements for a submitted development plan LDC 11.4.4. (B) are broad and vague:

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[2] Plan 2040, Chapter 4.5 Livability, Goal 1, "Protect and Enhance the Natural Environment" Goal 1 (b.) Protect waterways and enhance water quality. However, the 41 Land Use and Development Policies have been stripped of any mention of sewer capacity or overflows.

> "A development plan of sufficient detail to demonstrate to the Planning Commission the character and objectives of the proposed development and the potential impacts of the development on the community and its environs."

LDC 11.4.4 (C.) does not require any party submit any technical report where the project will be built in areas with chronic sewer overflows and sewer polluted water. This despite the Plan 2040 identifying water quality as a livability standard to be protected. LDC 11.4.5 (B.) is also devoid of any recognition of chronic sewer pollution, and does not require submission of any technical report about sewer impacts.

LDC Sections defining the scope of Planning Commission review are devoid of any recognition of the impact of significant development on overloaded, surcharging sewer lines and regional water pollution. See, LDC 11.4.5 (F)(2):

> "The Planning Commission shall consider, but not be limited to, the following factors in review of a detailed district development plan:
>
> a. The conservation of natural resources on the property proposed for development, including: trees and other living vegetation, steep slopes, water courses, flood plains, soils, air quality, scenic views, and historic site."

More specific rules are needed to assure a fair and equitable review process that actually implements the Plan 2040 goals to make a livable community. The public's due process right to make meaningful comment at a meaningful time is violated when MSD and the developer conceal material facts of pollution impacts to tilt the scales toward approval.

> " The Planning Commission is authorized to use its staff to conduct a preliminary investigation of an application and such use does not violate due process so long as the staff report produced from such investigation "is composed of competent evidence, all interested parties are given an opportunity to study and respond to the report, and the party preparing the report is available for examination[.]"

Warren County Citizens for Managed Growth, Inc. v. Board of Commissioners of Bowling Green, 207 S.W.3d 7, 18 (Ky.App. 2006).

> "Unless action taken by an administrative agency is supported by substantial evidence it is arbitrary."

Thurman v. Meridian Mut. Ins. Co., Ky., 345 S.W.2d 635 [1961].

> "The fundamental requirement of procedural due process is simply that all affected parties be given 'the opportunity to be heard at a meaningful time and in a meaningful manner.' Mathews v. Eldridge, 424 U.S. 319, 333, 96 S.Ct. 893, 902, 47 L.Ed.2d 18 (1976)..."

Hilltop Basic Resources v. County of Boone, 180 S.W.3d 464, 469 (Ky. 2005).

Affected neighbors are denied due process in Planning Commission hearings, if they are not given the facts that affect the community - like chronic sewer overflows, sewer plant failures, and resulting water pollution. Orders issued without disclosing or considering material information about sewage, that falls within the livability goals of Plan 2040, cannot be based on substantial evidence and are arbitrary and subject to judicial appeal.

Lateral Sewer Extensions Policy

In the late 1990s, EPA engaged in federal rule-making for controlling sewer overflows, since they were deemed violations of the Clean Water Act (CWA) prohibition against discharging untreated sewage into creeks and rivers. Then, and now, many urban pipe systems were combined sewer systems (CSS). Both sanitary sewage and storm water used the same pipes. They pre-dated the CWA and were designed to overflow to surface waters in wet weather without treatment. This older engineering design remains in service in Louisville and many street catch basins and roof drains connect directly to the pipe system conveying the cities' municipal sewage.

SSOs or sanitary sewer overflows occur in newer parts of the sewer system that were built 'separate' and not part of the storm water sewers. Separate sanitary pipe surcharging in wet weather, results from illegal storm water inflow and infiltration due to sump pump connections, roof drains, area drains and improper connections. SSOs are violations of the CWA prohibition against discharge of untreated sewage, whereas, CSOs are 'grandfathered in' as permitted, numbered outfalls under the Kentucky Pollution Discharge Elimination Permit (KPDES).

In 1994, EPA eventually adopted a CSO Control Policy that purports to enforce the CWA by requiring sewer agencies to construct a Longterm Control Plan, a schedule of capital system improvement projects intended to eventually eliminate combined sewer overflows. MSD's recently completed Water Quality Tunnel is one such capital project that will reduce polluted overflows from CSOs to Beargrass Creek in the Lexington - Grinstead road area.

In 1996, the Kentucky Natural Resources and Environmental Protection Cabinet began a rulemaking process to formulate state policy on Sewer Lateral Extensions (SLE) for new development and SSOs. Sprawl growth in the Louisville suburbs resulted in new SLE applications causing significant wet weather sewer overflow volumes.

Metro politicians, private developers, and the Cabinet politicians wanted to enable private development in the suburbs without imposing a sewer moratorium to enforce the CWA. Developers wanted to shift the cost of sewer overflow mitigation onto the public.

The policy debate was recorded in the rulemaking public hearing process held October 28, 1996, and some excerpts are attached.[3]

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[3] December 12, 1996, Statement of Consideration, 401 KAR 5:005 Kentucky Natural Resources and Environmental Protection Cabinet

Kentucky adopted a policy for SSOs similar to EPA Policy for CSOs - new SLE would not be denied--even where chronic SSOs would result--as long as MSD "created a plan for investigation and remediation of causes of inflow and infiltration." No sewer moratorium was required under the administrative rules, even for new development above major SSOs.[4]

The Second Amended Consent Decree is a Lawsuit Shield

The Clean Water Act, 33 U.S.C. 1365(b)(1)(B) allows affected residents to sue a polluting wastewater system, like Louisville's MSD, but bars the citizen action, if within the required sixty-day notice of action period, the Cabinet commences a compliance action, "in a court of the United States, or a State, and diligently prosecutes it."

On or about February 27, 2004, the Kentucky Division of Water filed a CWA action against MSD, alleging violation of its KPDES discharge permit. EPA joined the action alleging violations of federal law, and the suit was removed to the Western District of federal court. The Consent Decree ultimately issued by the Court, included admission by MSD that permit violations and illegal sewer overflows were occurring.[5] Various remedial programs were required of MSD, but they all substituted reporting, monitoring and capital project funding for actually halting sprawl development or requiring treatment of the sewage at the point of overflows.

After thirty years of chronic overflows in Louisville, the SSO policy and Consent Decree, Amended Consent Decree and Second Amended Consent Decree are properly viewed as regulators failing to actually enforce the Clean Water Act, but instead holding the door open to major sprawl development regardless of the water pollution consequences.[6] Since 2009, this has boiled down to MSD reporting sewer overflows in obscure reports to the state and feds, spending millions of dollars for full employment of engineering contractors, and approving new private developments without pause, in suburbs far from treatment plants, with surcharging lines.

MSD budgets millions for computer modeling inflow and infiltration, and has concocted a Sewer Capacity Assurance Plan (SCAP) based on dry weather capacity. Some of the same SSOs identified in 1996, still overflow today in the 2 year, 3 month storm. The Cabinet in 1996, had originally planned to use a five year frequency as the control storm.

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[4] So much new development was added to the surcharging suburban lines, that MSD set up diesel sewage pumps at locations in Hikes Point and Stonehenge Lane at Shelbyville Road to pump down the sewer lines and dump the wastewater into the Middle Fork of Beargrass Creek, creating new SSOs. As this practice continued and showed a failure to protect streams the possibility of a CWA citizen lawsuit against MSD increased.

[5] 04/15/09 Amended Consent Decree, Case # Case 3:08-cv-00608-CRS, Western District Federal Court ¶ 11, 15.

[6] MSD submitted for approval a Final SSDP (Sanitary Sewer Discharge Plan) on December 19, 2008, as Volume 3 of the IOAP (Integrated Overflow Abatement Plan). The IOAP was accepted by the Federal Court and incorporated by reference into the Amended Consent Decree by a Federal Order signed February 12, 2010, and was entered into public record on February 15, 2010. A revised SSDP was included in the 2012 IOAP Modification, submitted on June 14, 2013. On June 19, 2014, MSD received approval of the 2012 IOAP Modification from EPA/KDEP. The approved document can be viewed on the MSD. Project WIN website, available at.org www.msdprojectwin.

Bull Run Townhomes and Robley Rex VA Hospital sewage will overflow

The Bull Run Townhomes are located in what MSD calls the 'Middle Fork Catchment' area of Beargrass Creek. The pipes go east along the Watterson Expressway, then along the creek past Shelbyville Road, south through Draut Park, past Breckinridge, to Cannons Lane at Seneca Park. A 'sewer trace' map and lateral extension application records obtained through Open Records request, shows sewage must travel 17 miles to go from Herr Lane to the Algonquin Parkway location of the Morris Forman wastewater treatment plant. The SLE application for the project identified numerous downpipe SSOs, including some with large, annual, volume of overflow at Breckinridge and Cannons Lane.[7]

The Morris Forman treatment plant is dealing with multiple system failures and currently failing to meet KPDES discharge pollutant permit limits. The Discharge Monthly Reports (DMR) since 2015, report exceedances of permit limits for total suspended solids, fecal coliform bacteria and other pollutants. Morris Forman is not providing full secondary treatment as required by the Clean Water Act. Very strong waste streams from major distilleries are cited as having caused breakdown of the sewage solids handling facilities that have crippled the plant.

In wet weather many millions of gallons coming through the sewage lines are diverted around the plant main treatment batteries and dumped into the Ohio River. The recent MSD Project WIN Quarterly Report # 63, Page B20 reported a grand total of CSO overflows for the April 1, 2021 - June 30, 2021, of 265,586,741 gallons. For four quarters of that would exceed a billion gallons of urban sewer overflows annually into the Ohio River from Louisville.

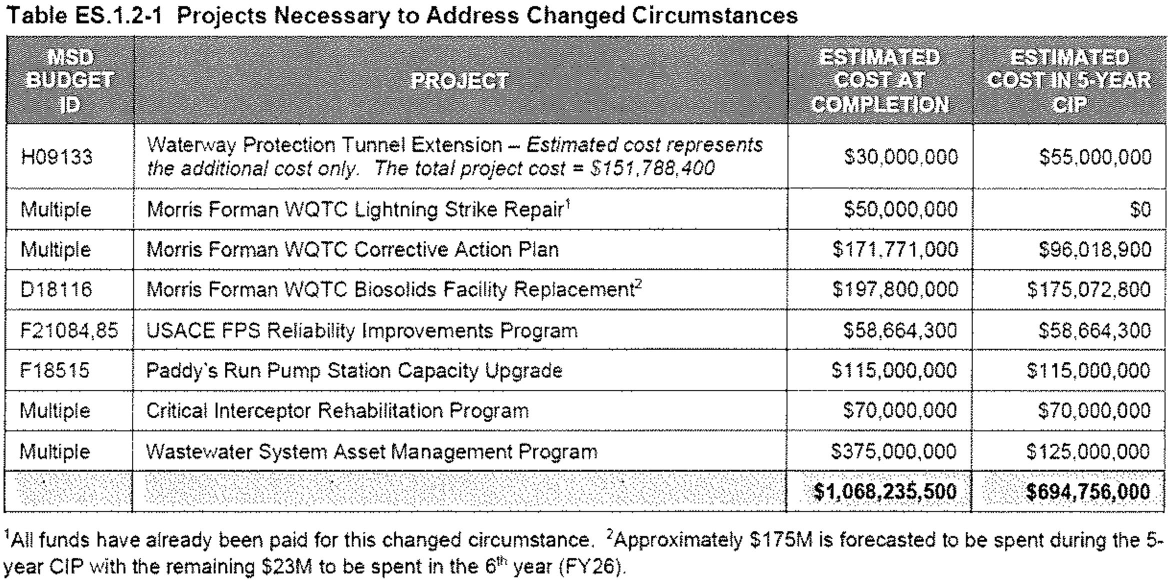

Table ES.1.2-1 Projects Necessary to Address Changed Circumstances

MSD BUDGET ID	PROJECT	ESTIMATED COST AT COMPLETION	ESTIMATED COST IN 5-YEAR CIP
H09133	Waterway Protection Tunnel Extension – *Estimated cost represents the additional cost only. The total project cost = $151,788,400*	$30,000,000	$55,000,000
Multiple	Morris Forman WQTC Lightning Strike Repair[1]	$50,000,000	$0
Multiple	Morris Forman WQTC Corrective Action Plan	$171,771,000	$96,018,900
D18116	Morris Forman WQTC Biosolids Facility Replacement[2]	$197,800,000	$175,072,800
F21084,85	USACE FPS Reliability Improvements Program	$58,664,300	$58,664,300
F18515	Paddy's Run Pump Station Capacity Upgrade	$115,000,000	$115,000,000
Multiple	Critical Interceptor Rehabilitation Program	$70,000,000	$70,000,000
Multiple	Wastewater System Asset Management Program	$375,000,000	$125,000,000
		$1,068,235,500	**$694,756,000**

[1]All funds have already been paid for this changed circumstance. [2]Approximately $175M is forecasted to be spent during the 5-year CIP with the remaining $23M to be spent in the 6th year (FY26).

MSD's Board does not review individual development approval by the engineers. For Bull Run Townhomes, there has been no technical review report published in the record, showing the

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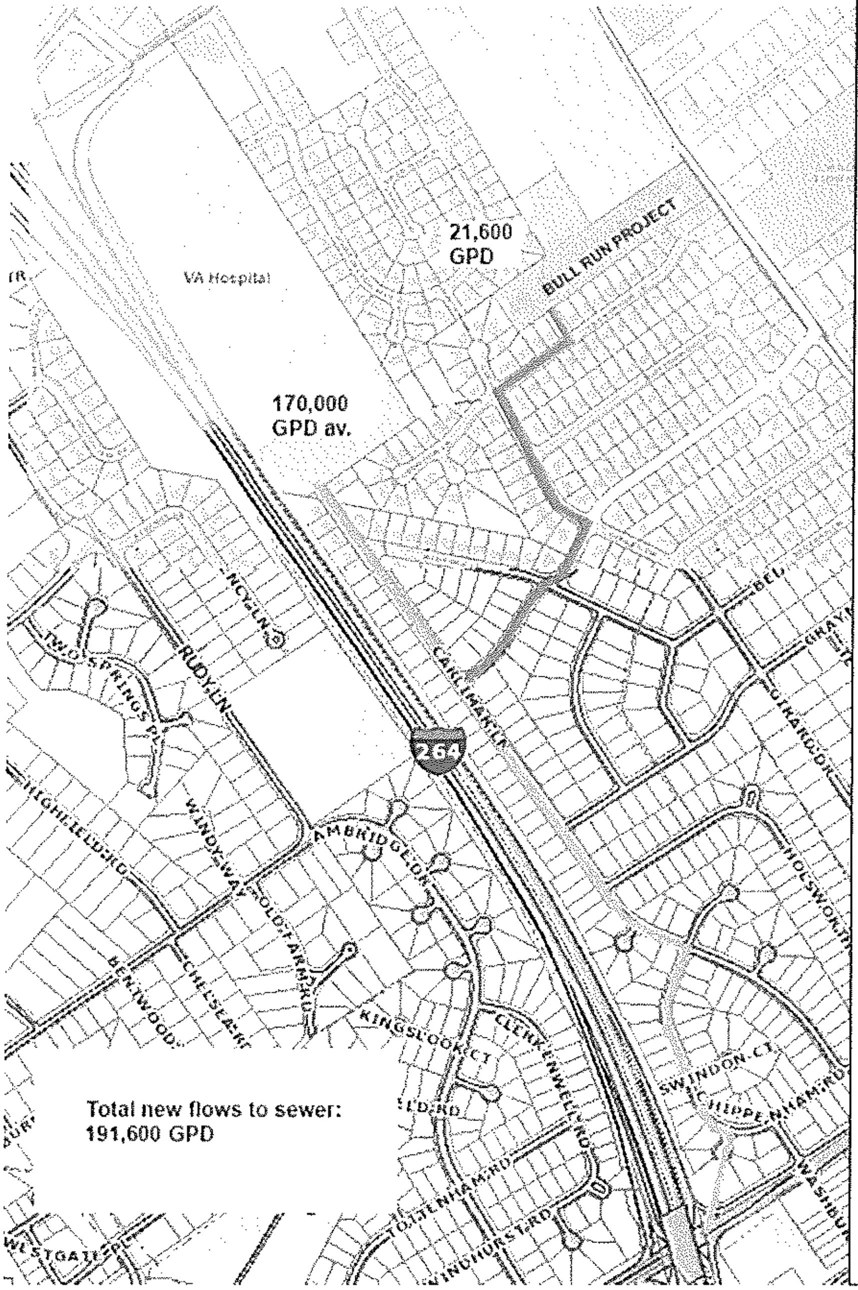
[7] Sewer Trace Map and List of SSOs attached as Exhibit.

proposed wastewater discharge impacts to the environment through SSOs. In effect, MSD and the city uses the Second Amended Consent Decree as a litigation shield from citizen lawsuits, tantamount to a CWA permit to pollute.



Land Development Code

Every new development project in Metro Louisville over which the Planning Commission or Metro Government has jurisdiction, should require the production and public distribution of a technical paper by the developer, before preliminary review, with review by MSD, identifying chronic sewer overflows, both CSOs and SSOs in the receiving pipe system and watershed. The technical paper should identify the location of each CSO, SSO and treatment facility and provide when and how much these facilities overflow, and if the treatment plant is meeting permit limits. This is not currently required, though it obviously serves and promotes Clean Water Act and Plan 2040 goals and objectives.

Plan 2040 policies and objectives do not make the connection between development decisions and sewer issues. Though the EPA and Kentucky Environment Cabinet have sued Louisville Metro MSD under the Clean Water Act and required project fixes costing hundreds of millions of dollars, Plan 2040 and the Land Development Code fail to provide critical policy tools to inform the public and decision makers.

In the Middle Fork of Beargrass Creek sewer catchment, the VA Hospital and Bull Run Townhomes add 170,00 Gallons Per Day and 21,600 GPD to already surcharging pipes. Bull Run Townhomes wastewater will go into the same pipe the VA Hospital connects to -- an existing 12 inch sewer line at Carlimar Lane. Together, the two projects will add 191,600 average gallons per day. The VA Robley Rex Environmental Impact Study, Chapter 2.2.1.13 Utilities, disclosed that peak daily flow from the hospital could be as high as 875,000 gallons per day. The EIS did not describe the impact of peak flows on the chronic SSOs. The hospital waste pathogens spilling through sewer overflows should be a serious concern.

These projects overflow sewage in small frequent storms. The sewage overflows create a noticeable odor, poison the creek ecosystem, and fill the water with human pathogens that endanger people playing downstream at Draut Park, Seneca Park, Cherokee Park and the Ohio River.[8]

> "The Cabinet already considered the human health risks and the water quality impacts in the development of these regulations. Sanitary sewer overflows (SSOs) can contain high levels of pathogenic micro-organisms, suspended solids, toxic pollutants, floatables, nutrients, oxygen demanding organic compounds, oil and grease, and other pollutants. SSOs can discharge into areas where they present high risks of human exposure such as basements, private property, streets, and receiving waters used as a drinking water source, for fishing, or for contact recreation. SSOs can also contribute to impairment of aquatic life and exceedances of water quality standards. The Cabinet considers these illegal discharges to be a high priority when comparing a raw sewage discharge with even a discharge receiving primary or secondary treatment and disinfection. Allowing additional load to a sewer.system or WWTP without the capacity to transport and treat the existing flow or load is unwise and irresponsible."[9]

For thirty years, in lieu of imposing a development moratorium, and giving the sewer system a chance to catch up, MSD instead filed reports of overflows while approving SLE applications in conformity with the System Capacity Assurance Plan (SCAP).[10] The SCAP maintained by MSD engineers, keeps a running total of the new development sewage flows as debits to dry weather system capacity, and calculates remaining dry weather pipe capacity by granting capacity credits based on removing inflow and infiltration with remedial projects like lining leaky pipes, removing sump pump inflows, or installing larger pipes.

Despite showing a positive balance of dry weather credits in the Middle Fork catchment, the sewers overflow in the 2 year 3 hour frequency storm. The SCAP balance is a measure of dry weather flow capacity, there is no remaining capacity in wet weather. Using a 2 years, 3 hours storm as the control standard, means there is little capacity in the pipes to handle inflow.

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[8] "In cities with combined sewer infrastructure, overflow events contribute to waterborne-disease outbreaks and present a risk to public health by serving as a source of pathogens and antibiotic resistant genes and bacteria." A Eramo, WRM Medina, NL Fahrenfeld - **Factors associated with elevated levels of antibiotic resistance genes in sewer sediments and wastewater**, Environmental Science: Water Research & Technology 2020 - pubs.rsc.org [8]

[9] December 12, 1996, Statement of Consideration, 401 KAR 5:005 Kentucky Natural Resources and Environmental Protection Cabinet, Cabinet's Response to Comment 65. Attached as Exhibit.

[10] See attached, Project Win Quarterly Report April 1 - June 30, 2021, pages D-7 to D-9 showing the SCAP credits and debits for the Middle Fork catchment.

Photo: Sewer Overflow location Cherokee Park January 8, 2023 with MSD warning and lime spread on ground.

The Consent Decree regulatory shield has formed an effective bar to any legal challenge of the SCAP policy.[11]

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[11] "Public participation in the development, revision, and enforcement of any regulation, standard, effluent limitation, plan, or program established by the Administrator or any State under this chapter shall be provided for, encouraged, and assisted by the Administrator and the States. The Administrator, in cooperation with the States, shall develop and publish regulations specifying minimum guidelines for public participation in such processes." 33 U.S.C. 1251(e).

[A]n interested citizen's not being permitted to so intervene can be a factor casting doubt upon the "diligence" of the state's enforcement efforts. See, e.g., Natural Resources Defense Council, Inc. v. U.S. Environmental Protection Agency, 859 F.2d 156 (D.C.Cir.1988); Frilling v. Village of Anna, 924 F.Supp. 821

Despite billions devoted to water quality protection[12], like the new 'Waterway Protection' underground tunnel, if the upstream sanitary sewers continue to overflow monthly, in the two year recurring storm, and no information is provided about sewer impacts in review of major developments, like the VA Hospital and Bull Run Townhomes, it must be concluded that MSD, the state and federal regulators, and the Planning Commission under Plan 2040, are not diligently preventing or prosecuting violations of the Clean Water Act.[13]

Under Plan 2040 and the Clean Water Act, the Land Development Code should be amended to clearly require developers and MSD to fully disclose relevant SLE information including, available sanitary sewer capacity for the connection, sewer overflow location, dates of overflows, and volume. The rules should disclose if the project wastewater will even reach treatment in wet weather, and whether the treatment plant is meeting permit conditions. Affected residents must be informed prior to the hearing, when meaningful comment can be made and evaluated, by Commissioners about the impact of new sewer flows on the environment.[14]

Sincerely,

Clarence H. Hixson
Attorney for Dennis Dolan
1336 Hepburn Avenue
Louisville, KY 40204
(502) 758-0936
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(S.D.Ohio 1996); Friends of the Earth, Inc. v. Laidlaw Environmental Services (TOC), Inc., 890 F.Supp. 470 (D.S.C.1995).
Commonwealth v. Shepherd, 366 S.W.3d 1, 3 (Ky. 2012)

[12] "The Governor's budget includes nearly $500 million over the biennium for the Better Kentucky Cleaner Water program that finances drinking water and wastewater projects, $250 million from the federal American Rescue Plan Act State Fiscal Recovery Fund and $247.7 million from the new federal Infrastructure Investment and Jobs Act."

[13]" More severe storms are already increasing sewer overflows and flooding, and it is not physically or fiscally possible to enlarge underground stormwater tunnels enough to hold it all. Experts predict that these extreme hydrologic swings will only increase with global warming." Kundzewicz, Z.W et al. ''Freshwater Resources and Their Management.'' Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry et al. Eds., Cambridge: Cambridge University Press, 2007. 173–210.

[14] *"An important motivation behind the participation of locals in public consultations is becoming part of decision-making processes governing their neighborhoods. However, it is often the case that community outreach practices do not fundamentally change anything in terms of spatial planning. Indeed, town hall meetings and the use of social media are, in fact, only "fashionable participatory techniques that are considered politically palatable forms of community engagement by the political elite" (Legacy, 2016: 3-4). In this regard, it is not apparent that these government-led participatory planning processes serve communities, but instead are often merely masking "pro-growth" logic."*[14] Zeynep Turan, Finding the "Local Green Voice"? Waterfront development, environmental justice, and participatory planning in Gowanus, NY, Urbani

Re: Case No: 22-ZONE-0073 and case No. 22-ZONEPA-0054
Owners: Bull Run Town Homes LLC and KABA Select Sires Inc.

Downstream sanitary sewer overflow locations on Middle Fork Beargrass Creek

facility #	Location
45469	Bowling Blvd Draut Park - manhole cover sanitary sewer overflow Sinking Fork Beargrass Creek interceptor surcharges in wet weather
47034	Stonehenge Drive at Shelbyville Road - into Middle Fork of Beargrass Creek
08935-SM	1001 Breckinridge Lane - 39 inch dia. Upper Middle Fork Beargrass Creek interceptor surcharges in wet weather
ISO21A-SI	1201 Old Cannons Lane - at I-64 overpass discharge to Middle Fork
48750	Manhole Between golf course and I-64 Cannons Lane - Middle Fork
40445	Manhole Middle Fork Bowman Field
45833	Manhole Alta Vista Road at Big Rock - 39 inch dia. to 48 inch dia. Middle Fork Beargrass Creek Interceptor surcharges in wet weather
45900	Manhole Cherokee Park at Big Rock
45796	Manhole Cherokee Park west of Big Rock
45829	Manhole Cherokee Park west of Big Rock
27008	Manhole Cherokee Park west of Big Rock
27007	Manhole Cherokee Park west of Big Rock
27005	Manhole Cherokee Park west of Big Rock

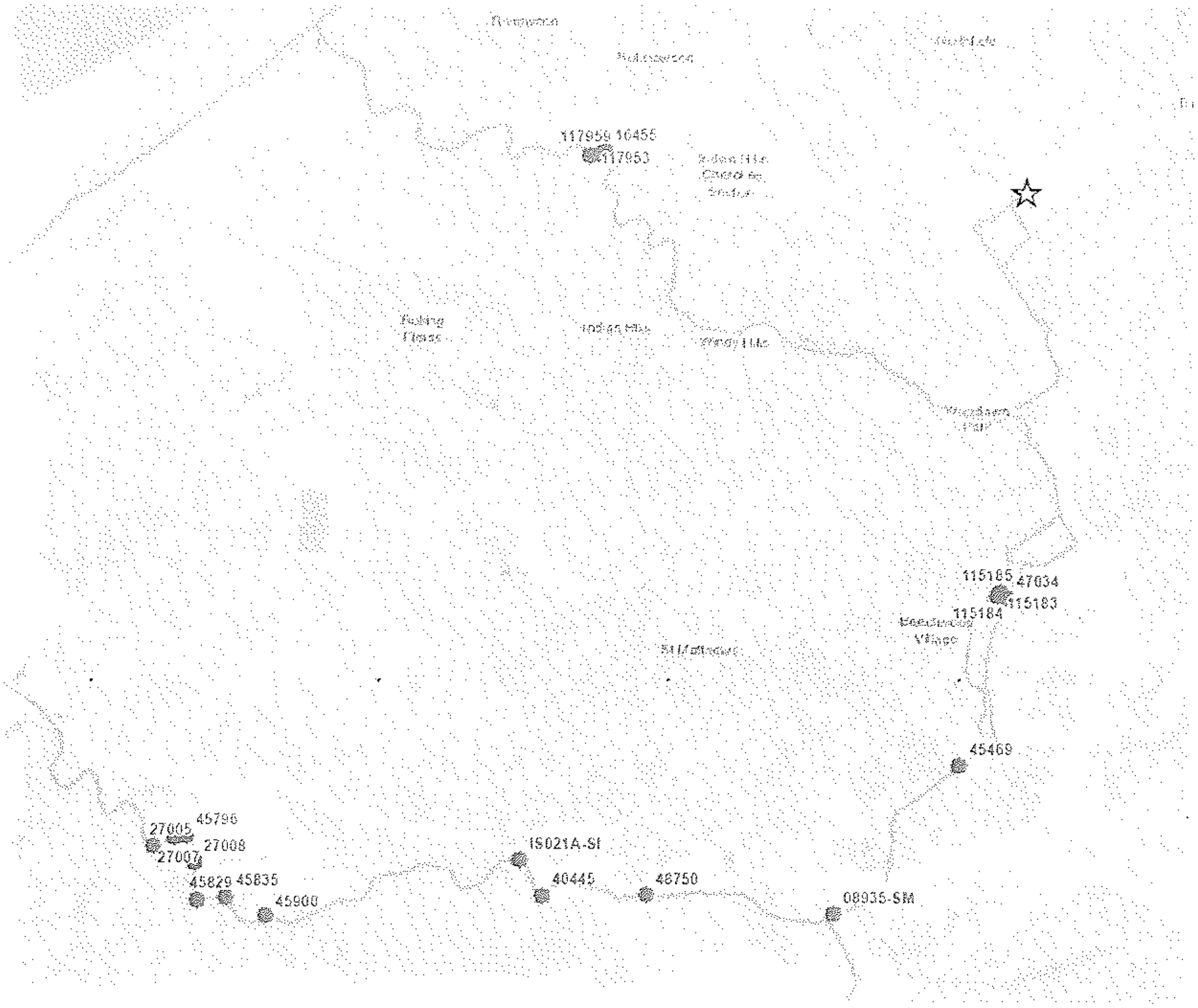
Facility ISO21A-SI —Old Cannons Lane near the I-64 overpass in Seneca Park. Discharges into Middle Fork of Beargrass Creek upstream of Big Rock. See photo below. Partial list of overflows:

08/01/2020 — 700,000 gallons
01/25/2021— 1,100,000 gallons
3/11/2021 — 3,100,000 gallons
4/28/2021 — 2,300,000 gallons
02/03/2022 — 4,900,000 gallons
4/6/2022 — 300,000 gallons
7/29/2022 - 60,000 gallons
7/31/2022 - 1,944,444 gallons

Facility 08935-SM — located at Breckinridge Lane near DuPont Square hospital zone Discharges into Middle Fork of Beargrass Creek upstream of Big Rock. See photo below. Partial list of overflows:

01/25/2021— 4,500,000 gallons
3/11/2021 — 800,000 gallons
6/03/2021 — 300,000 gallons
02/03/2022 1,900,000 gallons
4/13/2022— 1,500,000 gallons
7/31/2022 — 299,375 gallons

Data source: MSD Project WIN webpage, (Site last visited December 22, 2022).
Browse Morris Forman Discharge Monthly Reports-
https://www.msdprojectwin.org/library/#6-509-dmr_2022-1644325467



Bull Run Townhomes sewer trace detail showing location of SSOs.

FILED WITH LRC
TIME: 10am

DEC 12 1996

Susan C. Wunderlich
REGULATIONS COMPILER

STATEMENT OF CONSIDERATION RELATING TO:

401 KAR 5:001 (Amended After Hearing)
401 KAR 5:005 (Amended After Hearing)
401 KAR 5:006 (Amended After Hearing)

pg 43

Letter to Greg
Letter to Karen

401 KAR 5:037 Groundwater

Public Hearing Conducted
October 28, 1996
1:30 p.m., Auditorium
Capital Plaza Tower
Frankfort, Kentucky

by the

Kentucky Natural Resources and Environmental Protection Cabinet
Department for Environmental Protection
Division of Water
14 Reilly Road
Frankfort, Kentucky

(58) (a) *Comment: Jerry Deaton* *Kentucky League of Cities*
The word "can" in the last sentence should not be deleted.

(b) Response: The Cabinet intended to replace the word "can" with "may". Section 7(1)(a) is being amended to add "may" in the last sentence after "references to current engineering practice".

Section 7(3)

(59) (a) *Comment: Tom FitzGerald* *Kentucky Resources Council, Inc.*
This subsection should be modified to clarify that the design goal for a WWTP should be compliance with all effluent standards and water quality limitations, not just minimum standards, particularly if the discharge is into a high quality stream, where compliance with minimum standards for the stream classification is insufficient.

(b) Response: The Cabinet agrees with the concept and Section 7(3) already requires the applicant to demonstrate that the effluent from a proposed facility will not cause the receiving waters to violate a water quality standard, or in the case of a "high quality" stream, additional criteria that the Cabinet determines. Specifically, Section 7(3)(b) as proposed, includes references to the regulations that include the additional protective measures for "high quality" waters (401 KAR 5:030 and 5:031). See also the response to Comment #68.

Section 7(4)

(60) (a) *Comment: (Unsigned)* *Bowling Green Municipal Utilities*
The flow measuring device should be located at the influent of the WWTP.

(b) Response: Section 7(4) specifies that the WWTP have a flow measuring device that is capable of measuring the anticipated flow. The use of the phrase "all flow discharged by the WWTP" was not intended to specify the location. The flow measuring device can be located either at the influent point or the discharge point, as long as all the anticipated flow is measured, therefore no change in response to this comment is necessary. See also the response to Comment #90.

Section 8

(61) (a) *Comment: Jerry Deaton* *Kentucky League of Cities*
The regulation proposes that sewer line extension applications will be denied if the sewer system in question is subject to excessive infiltration or excessive inflow; the owner of the system would be required to first implement a plan for remediation.

See # .04

(b) Response: The Cabinet disagrees; Section 8(3) and (4) state that the Cabinet may deny sewer line extensions . . . unless a plan. . . which addresses those conditions has been approved and is being implemented, not has been implemented. The plan does not have to be fully implemented before sewer line extensions will be approved. The intent is to prevent an already unacceptable situation from getting worse. It is not the Cabinet's aim, goal, or intent to approve projects that will exacerbate an existing pollution problem, especially if the owner is not willing to correct the problem. See also the responses to Comments #62-67, 85, and 109.

(62) (a) *Comment: Jerry Deaton* — *Kentucky League of Cities*
The concept of remedial sizing of sewer systems statewide will be an unreasonable task due to the complexity of each system and the variables involved. This will result in unequal enforcement and the benefit received will not justify the cost expended.

(b) Response: The initial and remedial sizing of sewer systems must be accomplished, and the Cabinet will work with the system to accomplish it. The bypassing of untreated sewage is a violation of the Clean Water Act. The Cabinet cannot accept bypasses of untreated or improperly treated sewage because the sizing of the system is complex and variable. Such bypasses create health problems and affect the quality of life for the system's customers who are paying for a properly operational system. If the size of the system becomes too small due to infiltration/inflow (I/I) problems, either the I/I can be removed or the system can be sized to properly transport and treat the wastewater, whichever is more cost-effective.

The regulation is applicable to all sewer systems and the Cabinet intends on enforcing the requirements equally. The Cabinet also believes the benefits received from protecting the public's health and improving the quality of life of the system's customers will justify the cost expended to correct inadequate systems and illegal discharges.

Finally, it is important that existing customers not have to contend with inadequate systems that result from additional growth. If there are already problems or potential problems, then the existing customers need to be adequately served before new growth is undertaken and new customers are added. The changes to this regulation will assure that the facility owners balance these obligations. See also the responses to Comments #61, 63 - 67, 85, and 109.

(63) (a) *Comment: Jerry Deaton* — *Kentucky League of Cities*
Virtually every wastewater system in the state experiences the problem of sanitary sewer overflows during intense rainfall. Many of our cities will incur enormous expense to pay for this type of improvement. City governments currently face many other unfunded mandates and are severely limited in their ability to raise additional revenues. These cities will be faced with tax increases, cutbacks, or increased debt service payments to meet the requirements of this regulation.

(b) Response: The Cabinet does not believe the problem is as widespread as is indicated. The Cabinet is merely requiring some assurance from the owner of the sewer system that the wastewater flow from the sewer line extension will reach the WWTP and that the additional flow will not cause permit violations or overflows of untreated sewage. The Cabinet believes the cities have a legal and fiscal responsibility to their citizens to build and maintain an adequate sewer system which delivers the wastewater to the treatment plant, and does not allow overflow to basements, backyards, or streets even during intense rainfall.

The Cabinet recognizes that correcting inadequate systems may be expensive and may take years to fully accomplish. The intent is to prevent an already unacceptable situation from getting worse. It is important that existing customers not have to contend with inadequate systems that result from additional growth and they should be adequately served before new growth is undertaken and new customers are added. What is proposed will not completely ban all sewer line extensions until the overflow condition is eliminated; rather, the proposed regulation would allow sewer line extension approvals to resume once a plan for investigation and remediation has been approved and is being implemented. See also the responses to Comments #61, 62, 64-67, 85, and 109.

(64) (a) *Comment:*

Jimmie L. Campbell	*Lexington-Fayette UCG*
Jeff Eger	*Sanitation District No. 1*
Gordon Garner	*Louisville & Jefferson County MSD*
David Hawes	*Owensboro Regional Resource Agency*
Larry V. Miller	*Bowling Green Municipal Utilities*

The wastewater flow apparently is the only point of interest when assessing if a system is capable of accepting new customers. Flow is a major concern if there are known, active sanitary sewer overflows in the system being extended. However, in most sanitary sewer systems, the presence of excessive infiltration or excessive inflow may not impair the treatment plant's ability to meet KPDES discharge limits. The presence or absence of KPDES permit violations and their frequencies should be considered.

(b) Response: The Cabinet requires a demonstration that both the sewer system and the WWTP have adequate capacity to transport and treat the current and the anticipated flow from the new connection. If there are known active sanitary sewer overflows in the system, the Cabinet would deny the sewer line extension, even if the WWTP had adequate capacity to treat the additional flow, unless the owner of the sewer system is addressing the condition by implementing an approved plan for investigation and remediation. Discharges from sanitary sewer overflows are illegal discharges and indicate that the system does not have adequate capacity to transport the existing flow. It is unwise and irresponsible to add additional flow to a sewer system that does not have the capacity to transport the existing flow. Similarly, the Cabinet would deny a sewer line extension to a sewer system with adequate capacity to transport the flow if the WWTP did not have adequate capacity to treat the additional flow, unless the WWTP owner was addressing the condition by implementing an approved plan for investigation and remediation. When a plan to address the condition and an associated schedule are approved and being implemented, sewer line extensions could be approved. See also the responses to Comments #61-63, 65-67, 85, and 109.

(65) (a) Comment:

Jimmie L. Campbell	*Lexington-Fayette UCG*
Jeff Eger	*Sanitation District No. 1*
Gordon Garner	*Louisville & Jefferson County MSD*
David Hawes	*Owensboro Regional Resource Agency*
Larry V. Miller	*Bowling Green Municipal Utilities*

Infiltration and inflow water quality impact should be looked at with all other potential water quality degradation sources.

(b) Response: The Cabinet already considered the human health risks and the water quality impacts in the development of these regulations. Sanitary sewer overflows (SSOs) can contain high levels of pathogenic microorganisms, suspended solids, toxic pollutants, floatables, nutrients, oxygen demanding organic compounds, oil and grease, and other pollutants. SSOs can discharge into areas where they present high risks of human exposure such as basements, private property, streets, and receiving waters used as a drinking water source, for fishing, or for contact recreation. SSOs can also contribute to impairment of aquatic life and exceedances of water quality standards. The Cabinet considers these illegal discharges to be a high priority when comparing a raw sewage discharge with even a discharge receiving primary or secondary treatment and disinfection. Allowing additional load to a sewer system or WWTP without the capacity to transport and treat the existing flow or load is unwise and irresponsible. See also the responses to Comments #61-64, 66, 67, 85, and 109.

(66) (a) Comment:

Jimmie L. Campbell	*Lexington-Fayette UCG*
Jeff Eger	*Sanitation District No. 1*
Gordon Garner	*Louisville & Jefferson County MSD*
David Hawes	*Owensboro Regional Resource Agency*
Larry V. Miller	*Bowling Green Municipal Utilities*

The regulation should be revised to clarify the condition for the grounds for the denial of sewer line extensions. The condition would require the actual dry weather flow, organic load, or the solids load to be considered in the context of plant performance.

(b) Response: The Cabinet would only deny sewer line extensions under this section if there were recurring overflows or permit violations at the WWTP due to infiltration/inflow. The Cabinet considers it to be inappropriate to consider only dry weather flows and loads in the context of plant performance, since the WWTP still has to meet the permit limits in wet weather. An additional problem would be in finding