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Bathing water quality analysis, management and policy: an integrated assessment for Ireland

Angelos Alamanos [a,*], Alec Rolston [b], Suzanne Linnane [a] and Triona McGrath [c]

[a] Centre for Freshwater and Environmental Studies, Dundalk Institute of Technology, Marshes Upper, Dundalk, Co. Louth A91K584, Ireland
[b] Goyder Institute for Water Research, Adelaide, South Australia
[c] National Water Forum, Civic Offices, Limerick Road, Nenagh, Co. Tipperary, Ireland
*Corresponding author. E-mail: angelos.alamanos@dkit.ie; angalamanos@gmail.com

AA, 0000-0002-3875-2449; AR, 0000-0001-7363-1928; SL, 0000-0002-5124-2996

ABSTRACT

Every bathing season in Ireland several bathing sites are closing and receiving warnings against bathing. In this report, their water quality status is assessed, and the broader picture of each case is investigated. A database is formed including location-maps, the restrictions they were/are subject to, the official justification, past and current annual water quality status, (sub)catchment where they are located, main water bodies flowing in, the closest wastewater treatment plants with their characteristics and performance based on EU treatment standards, the closest meteorological stations and the rainfall data related with stormwater overflow events (correlation analyses) and the surrounding land cover. For each case, possible causes were discussed; the actions so far and the relevant literature are analyzed to provide key policy recommendations which are useful for the review of the European Bathing Water Directive.

Key words: Bathing waters, Bathing Water Directive, Rainfall analysis, Runoff, Stormwater overflows, Water quality

HIGHLIGHTS

- Assessment of bathing sites pollution causes, actions and policy.
- Integrated databases (spatial, statistical and other data) and simple analyses using their interlinkages to assist local authorities.
- Investigation and identification of pollution causes.
- Continuous work constantly updated, encouraging monitoring and actions.
- Useful policy review and recommendations under the European Bathing Water Directive.

INTRODUCTION

Bathing waters have a major significance for ecosystems and people who derive multiple benefits from them. Bathing sites (BS) are great assets for the local, regional and national economies and development, tourism, health and wellbeing, social and cultural benefits. Their social and cultural benefits include the pleasure, aesthetic and recreational assets, sense of ownership and pride of place for local residents and communities, sports, environmental and coastal education (Vassilopoulos & Koundouri, 2017). Preserving or improving the water quality of BS is regulated with international and national legislation, usually coordinated by central government; regional or local authorities (LAs) are responsible for the relevant monitoring, sampling, actions and measures

(Skotak *et al*., 2012). This can be challenging for many authorities because of human, expertise or financial constraints (Globevnik *et al*., 2020). The integrated assessment of BS water quality with the investigation of causes and driving factors has received limited research attention compared to its considerable importance for health, ecosystems and wellbeing (Buer *et al*., 2018; Malcangio *et al*., 2018). Even rarer are the studies that integrate multiple datasets to analyze the changing status of BS to improve their management and provide policy recommendations (Plana *et al*., 2018; Quilliam *et al*., 2019). This article presents such an assessment for the BS of Ireland and contributes to their improved regulatory management. The presented approach can be generalized and is expected to be useful for many countries, especially during the consultation period for the 2006 Bathing Water Directive (BWD). The roadmap of the BWD was developed in the spring of 2021, the public consultation is from 28 October 2021 until 20 January 2022 and the European Commission (EC) adoption is planned for the first quarter of 2023. In this work, various relevant data to BS water quality were collated and integrated into a database, simple statistical analyses were carried out to investigate potential causes, and the current regulations, responsible authorities and progress are discussed to provide useful policy recommendations. The study represents an ongoing and continuous effort for integrated monitoring of the Irish BS water quality, updated after each bathing season. The context and the combination of such elements give an added value beyond the BWD, in terms of local-scale initiatives and simple analyses that can be performed to better manage BS water quality.

LEGISLATIVE FRAMEWORK

The EC with the BWD/2006 requires Member States to monitor and assess the bathing water for at least *E. coli* and intestinal Enterococci (microbiological), to inform the public about BS quality and to beach management, pollution and its possible sources (EC, 2006). Member States classify bathing water as 'poor, sufficient, good, or excellent' depending on the concentrations of these parameters. 'Poor' BS are closing for the public (for the entire season or temporarily), and the reasons for the failure to achieve 'sufficient' status must be identified. If a BS is classified as 'poor' for five consecutive years, bathing is prohibited permanently. The BWD requires a sampling shortly before the start of each bathing season, and no fewer than four samples are considered to be taken and analyzed during the bathing season (max interval between samples is one month). In the event of short-term pollution, one additional sample is required to confirm that the incident has ended, and these samples may be disregarded (replaced by a sample taken 7 days after the end of the incident). The BWD is applied by the Statutory Instrument No. 79/2008-Bathing Water Quality Regulations 2008 in Ireland (148 identified BS). LAs have the primary responsibility for the monitoring of BS, the assessment of pollution impacts and the implementation of management measures designed to minimize pollution. The Environmental Protection Agency (EPA) ensures that LAs carry out their functions under the BWD. Irish Water (IW) is the utility responsible for water supply, sewage and wastewater treatment. The water quality status of each BS based on microbiological measurements is publicly available via www.beaches.ie which summarizes measurements, annual classifications, water quality reports and other information (e.g. amenities, etc.). Information is regularly updated during each bathing season, which runs from 01/06 to 05/09. In June of 2021, the European Environment Agency (EEA) and the EC published the European bathing water quality assessment (2020 data), including reports and maps per Member State (EEA, 2021). A similar managerial structure (hierarchy, coordination and responsibilities) applies in most EU Member States. Having harmonized detection methods and the same requirements for active BS management in Europe were among the main objectives of the BWD (Szewzyk & Knobling, 2007). The importance of transparency, more accurate and frequent monitoring, and the role of LAs have been crucial points for the BWD's implementation (Dizer *et al*., 2005; Schernewski *et al*., 2012) and are internationally recognized as fundamental elements for a reasonable BS management (Torres-Bejarano *et al*., 2018).

BATHING SITES IN IRELAND

Figure 1 shows all BS which received reports and warnings during the summer of 2020. The orange-colored ones were closed for the entire season (Table 2), while the white-colored ones (summarized in the Supplementary material) closed temporarily or received warnings for certain periods. From these orange-colored BS, Merrion was classified as poor for the fifth consecutive year, leading to its permanent closure (declassification), and Clifden will be declassified by the end of 2021, for the same reason. The quality status of most BS is fragile and prone to deterioration or warnings after heavy rainfall events or unexpected discharges and other contamination. The need for more systematic monitoring and tracking of the actions has been noted from the EPA (2020, 2021). The problems' causes are complex and often difficult to be identified with certainty, mostly because of insufficient monitoring. Discharges from urban land use and sewage, wastewater treatment plants (WWTPs), farming activities, overflows after heavy rainfalls, combined with poor infrastructure (pipelines, treatment, misconnections) and combinations of these factors are the usual causes (EPA, 2021).

Scholars have studied the BS quality in Ireland and provided useful insights, and potential solutions to tackle water quality issues. Table 1 provides an overview of the most relevant publications and documents, with their focus, objectives and possible implications for consideration. The international literature has studied similar problems and has tried to improve policy around management of BS: Tiwari *et al.* (2021) assessed and compared Bathing Water Quality Monitoring Practices in Europe and the United States. The cost burden of the BS management for small communities is relatively high, and also monitoring the quality of BS can result in significant costs for countries with extensive coastlines, so Bonamano *et al.* (2021) introduced a predictive index based on *E. coli*

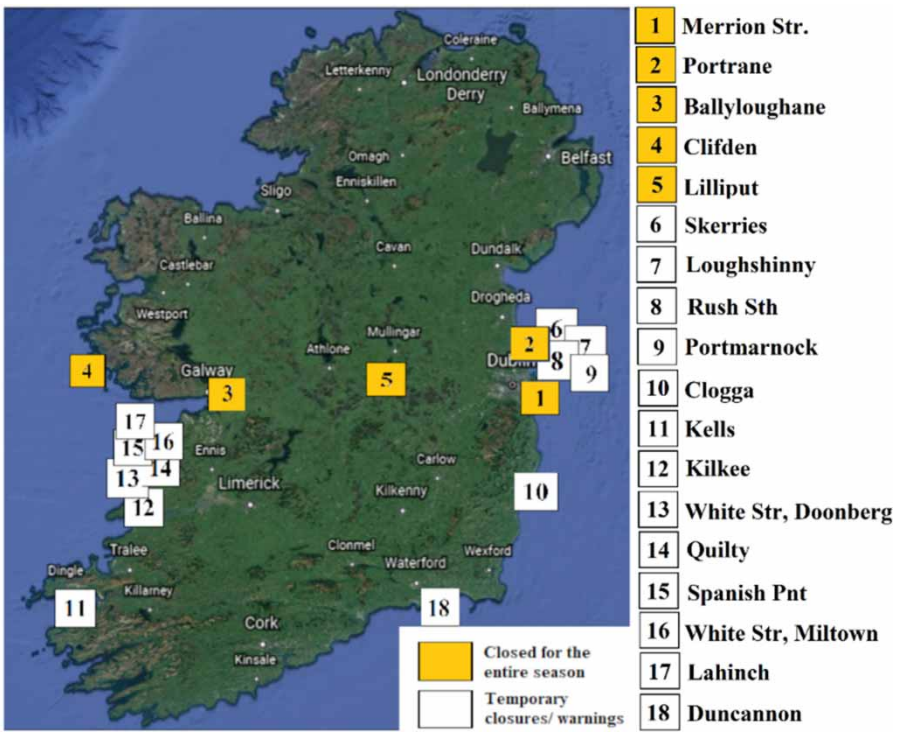


Fig. 1. | Bathing sites with swimming restrictions in 2020.

Table 1. | Brief literature review of Irish cases.

Study	Type	Study area	Objective – description	Alternatives – insights
Reynolds *et al.* (2021)	Peer-reviewed paper	Dublin Bay	Contamination by unidentified sources at Elm Park stream (Dublin), and the effect of severe weather events on water quality	Effectiveness of pairing microbial source tracking, fecal indicators and ammonium monitoring to identify 'sentinel' stations that could be more rapidly assessed using real-time ammonium readouts to assess remediation efforts
Alamanos *et al.* (2021a)	Conference paper	Ireland-wide	Precipitation analysis and forecast, extremes analysis, comparison with climate change projections	Combination of water parameter monitoring with rainfall forecasts to provide early warning systems
Reynolds *et al.* (2020)	Peer-reviewed paper	Dublin Bay	For 1 year, bi-monthly water samples were collected from two urban streams and Dublin city's three designated bathing waters	Microbiological levels were determined and the source of fecal pollution (human, dog, gull) quantified by microbial source tracking
Hawtree *et al.* (2020)	Conference paper	Ireland (9 BS)	Implementing EU System for bathing Water quality Modeling (SWIM)	Statistical/machine-learning predictive models for water quality parameters, at high spatial and temporal resolution scales
Anton *et al.* (2020)	Peer-reviewed paper	Galway	Socio-economic aspects of environmental protection issues	Useful for information and educational feedback
EEA (2017)	Report	Europe-wide	EU SWIM project	Short-term pollution prediction models using '*pre-existing microbiological quality data, other relevant environmental data, citizen engagement, predictive modeling with multivariate and other models, and intelligent orchestrated sensing*'
Bedri *et al.* (2015a)	Peer-reviewed paper	Dublin Bay	5-day forecast models of *E. coli*	The approach of using a deterministic and integrated catchment-coastal model for such purposes is easily transferable
Bedri *et al.* (2015b)	Peer-reviewed paper	Bray and Killiney bathing sites	Simulation of *E. coli* distributions under WWTP upgrade scenarios	Upgraded WWTPs remarkably improve the water quality. However, stormwater overflows are still a problem
Briciu-Burghina *et al.* (2014)	Peer-reviewed paper	Dublin Bay	Potential of sensor technologies and continuous monitoring, to act as a decision support tool in both environmental and port management	*E. coli* and Enterococci samplings related to detected turbidity events were up to nine times higher after vessel arrival than prior to disturbance
Lucey (2006)	EPA Report	Ireland-wide	11 indicators for water quality	More parameters than *E. coli* and Enterococci are suggested to address more impacts (e.g. eutrophication, shellfish waters, etc.)

to facilitate monitoring, while Palazón *et al.* (2017) proved how numerical models could reduce the microbiological analyses during bathing seasons.

Irish studies (Table 1) reflect the country's efforts towards a better understanding of the water quality of coastal systems and ways to preserve/improve it. Most studies are examining cases around Dublin Bay, which is reasonable, given the recent urban expansion of the greater area. The importance of monitoring, modeling (and forecasting parameters' behavior) and consideration of more sampling parameters is highlighted by most studies. The research focus has been on the detailed assessment of specific factors, and there are very few cases that aimed to provide insights for regulations based on original research. In the present study, this systematic assessment is supported from a complete database for the deteriorated BS (starting from the bathing season of 2020), investigating potential contamination sources, drivers and actions, and identifying knowledge and informational gaps. Together with the policy review and recommendations, this approach can be useful for practitioners and decision-makers.

MATERIALS AND METHODS

To assess the factors that deteriorate bathing water quality, the first step was to form a database with as complete information as possible to describe the situation and 'map' each BS (Figure 2), to facilitate the identification of the potential pressures to the BS water quality.

The potential causes for each BS's water quality status that were added to the database following the classification used by most LAs and beaches.ie, and were grouped as:

- *Urban & sewage*: runoff from urban land cover, runoff from roads and raw sewage discharges.
- *Poor network condition*: misconnections, leaks, spills and damaged wastewater collection systems.
- *Agriculture*: runoff from agricultural and pasture activities.
- *Stormwater overflow*: existing storm events that caused water quality deterioration or expected events.

The above categories are useful for targeting relevant measures (urban or rural drainage, infrastructure works, etc.). For most cases, multiple causes are combined, and it is difficult to distinguish with certainty each cause's

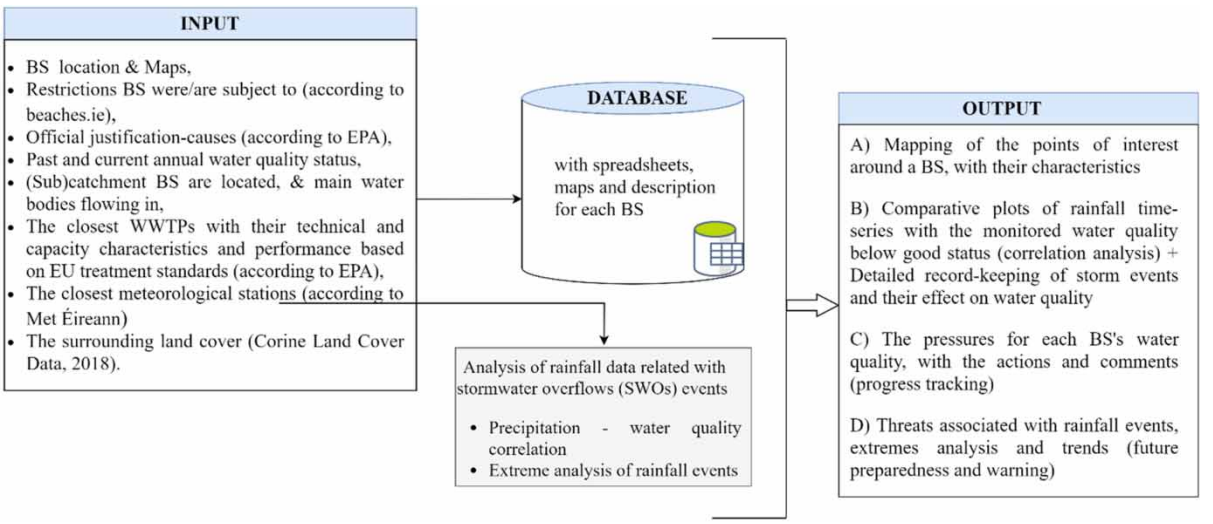


Fig. 2. | The conceptual diagram (flowchart) of the procedure followed to analyze the BS water quality drivers.

Table 2. | Summary of the main database characteristics for BS closed for the entire bathing season of 2020.

Beach – location	Restriction (EPA/beaches.ie)	Justification (EPA/beaches.ie)	Close to WWTP/EU treatment standards 2018	Main causes	Main land use (CORINE 2018)
Merrion Strand, Dublin	Declassification, according to the Bathing Water Regulations	Classified as having 'Poor' water quality following the 2015–2019 assessment period	Ringsend/Fail/Raw sewage	Urban & sewage + Poor network condition + Stormwater overflow	Discontinuous urban fabric
Portrane, the Brook beach, Dublin	Bathing restriction for the entire 2020 bathing water season	Classified as having poor water quality following the 2019 bathing season	Portrane-Donabate/Pass	Urban & sewage + Poor network condition	Discontinuous urban fabric
Ballyloughane Beach, Galway	Bathing restriction for the entire 2020 bathing water season	Poor classification for bathing water historically	No (just a stormwater overflow)/–	Poor network condition + Stormwater overflow + Agriculture	Pastures
Clifden beach, Galway	Declassification, according to the Bathing Water Regulations	Classified as having 'Poor' water quality following the 2016–2020 assessment period	Clifden/Pass	Urban & sewage + Stormwater overflow + Agriculture	Land principally occupied by agriculture, with significant areas of natural vegetation
Lilliput, Lough Ennell, Westmeath	Bathing restriction for the entire 2020 bathing water season	Water quality deteriorated due to suspected agricultural activities/runoff	No/–	Agriculture + Septic tanks	Pastures

magnitude or contribution to the overall pollution. Thus, in each BS we often have at least one entry. According to EPA and beaches.ie., the problems' outline-actions-comments were listed for each BS, collated and will be updated annually.

Following the analyses of Figure 2, the time-series of rainfall were plotted with the monitored water quality below good status, i.e., sufficient and poor status. If the water quality status changed after a rainfall peak, then it is safe to assume that the heavy rainfall caused overflows or runoff from the surrounding land uses, with a direct impact on the water quality. This relation is explored with a simple Pearson correlation coefficient, using a binary variable for the water quality measurements: Poor = 3, Sufficient = 2, Good = 1, Excellent = 0. Thus, the correlation is estimated, for certain dates-events, when the amount (and frequency) of quality measurements was adequate and allowed that estimation. This is an indicative and simplified measure, however useful for the LAs. In general, stormwater overflows (SWOs) are often reported as an issue of concern for many BS, so an extra analysis on the rainfall from their nearest meteorological stations was followed (e.g. trends for daily, monthly, seasonal and annual time steps) (Alamanos *et al.*, 2021a).

RESULTS AND KEY ISSUES

The process described in the previous section is an ongoing work, aimed to provide an integrated database useful for monitoring the situation of each BS of interest. It is expected to be expanded and updated in the future. Table 2 is an indicative example of the main features collated in the database.

The BS that were closed for the entire bathing season of 2020 (Table 2) have historically poor water quality status over the last 3–5 years mainly because of raw sewage and poor infrastructure issues, while the contamination of the other BS (Table S.1 – supplementary material) was mostly attributed to SWOs and a combination of other causes. This is an interesting observation on the duration of the water quality problems and their causes. Figure 3 is an example of the process followed for every BS, according to the approach explained in the previous section, and the outputs of Figure 2.

The correlation table-plot of the BS' precipitation data is shown in Figure 4(a), where the station names are shown along the diagonal boxes; the bottom-left part displays a scatterplot of the relationship between each pairwise combination of stations' rainfall (a 1:1 line would be a perfect correlation) and the top-right corner of the matrix displays the Pearson correlation coefficients, as a 'mirror' of the bottom-left part.

As mentioned, the rainfall was further analyzed to explore the trends of extreme events, as SWOs often are reported as the main (unexpected) cause for water contamination. Here, a brief extreme analysis is presented, indicatively for the Malahide station, as it can be considered representative of the beaches of Loughshinny, Rush, Portmarnock and Merrion, while it also applies to the Greater Dublin Area (GDA), as Dublin and Dun Laoghaire stations are highly correlated (Alamanos *et al.*, 2021a). Water quality deterioration due to SWOs (Malahide station) came after continuous rainfall events (longer than 1-day storms) or isolated events (1-day storms >10–15 mm in certain cases). Here, the 95th percentile of precipitation on wet days (>10 mm) was 16, while the total precipitation on the days with more than 15 mm rainfall was 2050.5 mm, indicating that the heavy rainfall events can actually cause significant discharges that may degrade the BS' water quality. The maximum annual values of the 5-day total precipitation (Figure 4(b)) show a clear, almost constant increasing trend, which is indicative of the increasing seriousness of the SWO issues. Even this brief analysis, and a more detailed one (Alamanos *et al.*, 2021a), clearly indicated that addressing overflows would not be seen as a rare-occasional issue, but as an increasingly serious phenomenon. This suggestion is in line with EPA's finding on the permanent character of SWOs affecting bathing waters (EPA, 2021).

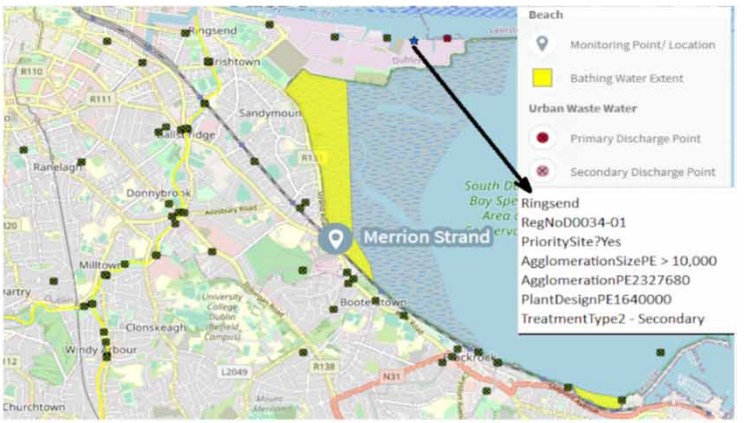
The main outcome of this process is a detailed description of the situation, the main issues, the actions and their impact so far on the BS' water quality. This is expected to enhance integrated approaches and future analyses, as well as to support the key recommendations for the improvement of each BS' quality status. Table 3 reflects this indicatively for the five BS with permanent warnings, while the findings for the rest of the BS are in the supplementary file.

Although putting this information together is a simple and basic task, it is a fundamental message for many countries' LAs towards the development of databases with as much information as possible, to support the investigation of complex pollution problems and the identification of suitable measures.

POLICY RECOMMENDATIONS

Integrated analyses such as the one presented in this work per BS, the consideration of the international and national literature, and the critical evaluation of the causal effect relations for each BS, is a recommended approach for most countries (and especially useful for the LAs). During the process of creating a single database, collating different datasets and findings from the literature, analyzing the situation, progress and providing specific recommendations for each BS, several points for consideration have occurred. These are generalized

(a)



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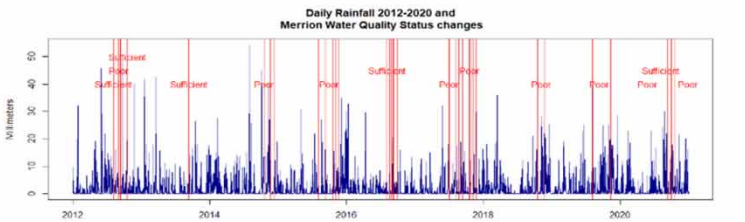

(c)

Date	Quality Status	Description
Jun2012	Sufficient	02-Jun: 45.7mm of rain, 05-Jun: Sufficient water quality.
Jun2012	Poor	27-Jun: 10.5mm of rain and Poor water quality. Correl = 0.816
Jul2012	Sufficient	16-Jul: 10.3mm of rain, 17-Jul: Sufficient water quality. Correl = 0.801
Aug2012	Sufficient	continuous rain (<10mm), 27-Aug: Sufficient water quality. Correl = 0.651
Jul2013	Sufficient	continuous rain (<11mm), Sufficient water quality (two samplings). Correl = 0.682
Aug2013	Sufficient	No rain, Sufficient water quality
Aug2014	Poor	1-4-Aug: heavy rain (>50mm), 6-Aug: Poor water quality
Aug2014	Poor	No rain, continuously Poor water quality
Sep2014	Poor	No rain, continuously Poor water quality
Jun/Jul2015	Poor	Poor water quality after two rainfall events < 15mm (27-Jun and 3-6-Jul)
Aug2015	Poor	Rain < 5mm, continuously Poor water quality
Jun/Jul2016	Sufficient/ Poor	Rain < 5mm, samplings 1 day after rainfall event, 2 times Sufficient and 2 times Poor water quality. Correl =0.517
May/Jun2017	Poor	Rain < 5-9mm, continuously Poor water quality
Jun/Jul2017	Poor	Rain varying daily from 0-12mm, samplings close to rainfall events, continuously Poor water quality. Correl =0.634
Jul/Aug2017	Poor	Rain < 5-7mm between 29-Jul-3-Aug, Poor water quality. Correl =0.617
Aug/Sep2017	Poor/ Sufficient	Rain varying daily from 0-20mm, samplings close to rainfall events, 2 times Poor and 1 time (Sept) Sufficient water quality
Aug/Sep2018	Poor	Rain < 3mm, continuously Poor water quality
Jun2019	Poor	04-Jun: 14.5mm of rain (and milder events before), Poor water quality. Correl=0.84
Jun2019	Poor/ Sufficient	Rain varying daily from 0-12mm, samplings referred 2 times to Poor and 1 time to Sufficient water quality
Aug2019	Poor	Rain < 10mm, only one event of 39.2mm, continuously Poor water quality
Jul2020	Poor/ Sufficient	Rain varying daily from 0-16mm, samplings slightly between Sufficient and Poor status
Aug2020	Poor	Higher concentrations of E.Coli and Enterococci samples than July, even with no rainfall. The highest concentrations (higher than the Poor status thresholds) were observed right after the rainfall events (>15-20mm) of the 16th, 17th, 24th of August. Correl=0.87

(d)

Merrion Strand, Dublin – Problem description	Actions	Comments
According to Dublin City Council, one of the main problems at Merrion Strand is the impact from two polluted streams which flow onto the beach. These are the Elm Park and Trimleston streams which flow through both Dun Laoghaire-Rathdown and Dublin City Council areas. These streams are polluted by a combination of misconnections, where domestic plumbing goes into the wrong pipe and goes directly into the stream; leaks, spills and overflows from wastewater collection systems; and run-off from roads. Other potential sources of pollution, that need more investigation, include urban wastewater discharges, birds and dogs. A new task force was set up by Dublin City Council in 2019 to specifically focus on improving the bathing water quality at Merrion Strand and Sandymount Strand.	1) Representatives from Dun Laoghaire-Rathdown County Council and others will identify actions and measures to be implemented	https://www.acclimatize.eu/ Acclimatize project for identification of main pollution sources in the Dublin Bay area, including at Merrion Strand
	2) Actions already underway = increase in water quality sampling to help identify the sources of pollution.	No measurements in the site
	3) Dublin City Council is also working with Dun Laoghaire-Rathdown County Council and Irish Water to address pollution sources related to the wastewater network including misconnections, combined sewer overflows and pumping station overflows.	A number of areas have been identified for further investigation, including significant misconnections
	4) Dublin City Council is investigating the potential for creating wetlands to improve the water quality of the Elm Park stream.	It needs to be carefully designed to achieve desirable filtering in competitive costs

Fig. 3. | The database building and analysis process, indicatively for Merrion Strand: (a) mapping the points of interest, (b) plotting rainfall–water quality status, (c) listing their (cor)relations, (d) problem-actions-comments outline and updates to track future progress.

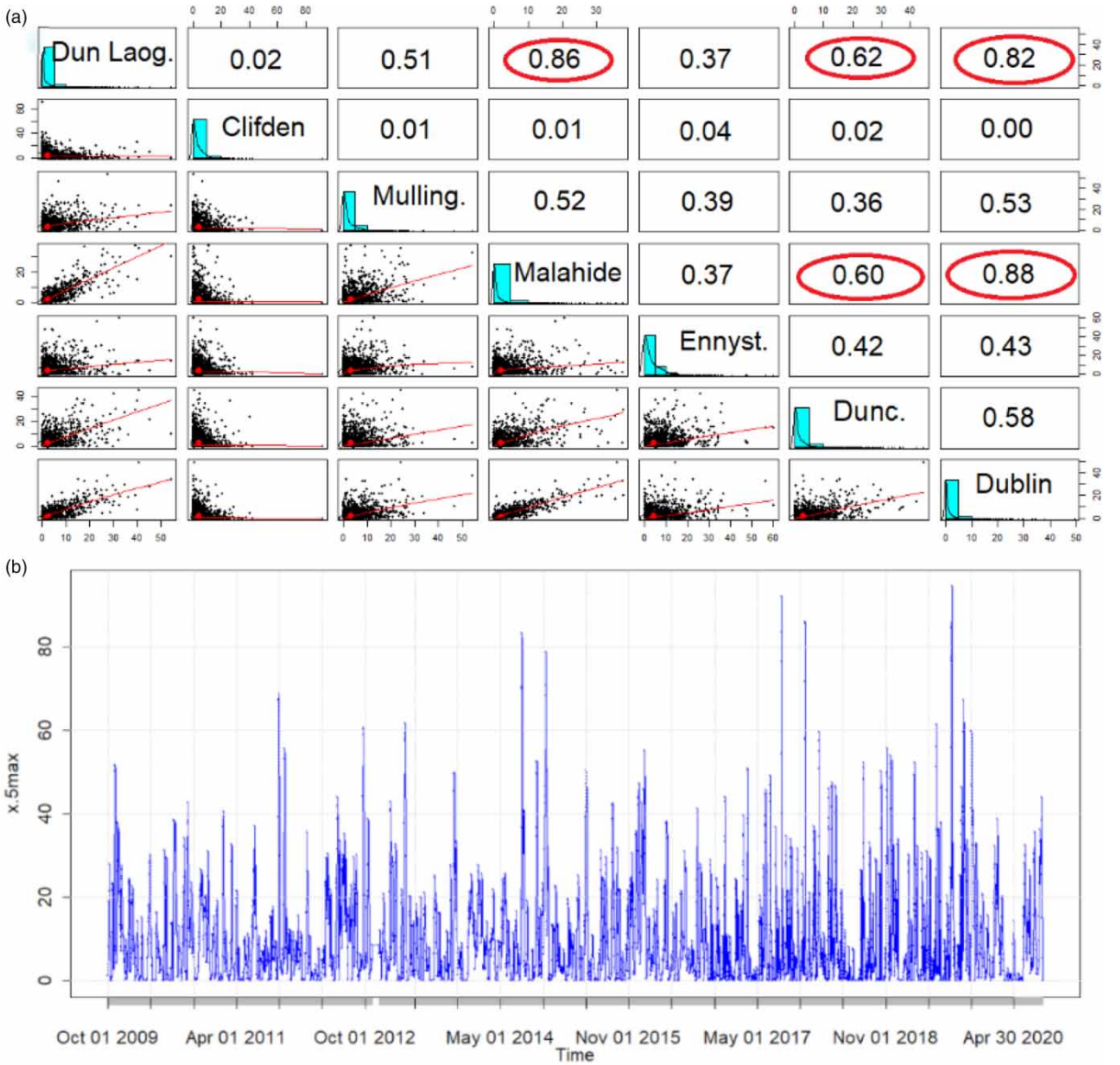

Fig. 4. | (a) Correlation among the studied stations. (b) Maximum annual rainfall of 5-day events (x.5max = the 5-day total-accumulated precipitation) for Malahide station (GDA).

and are listed below as policy recommendations to improve the regulatory management of the bathing water quality:

1. *Data transparency*: It would be good to publish all data (beaches.ie), not only the compliance data to the minimum BWD requirements. These could be enriched by adding also operational/monitoring data from EPA, LAs and IW having thus more transparency:

Table 3. | The summary of the main findings for each BS closed for the entire bathing season of 2020.

Beach – location	Main findings
Merrion Strand, Dublin	The situation is outlined in Figure 2; the Ringsend WWTP located close to the beach seems to be a significant pollution source, poor network condition and occasional stormwater overflows, and polluted streams further contribute to the deterioration of the coastal water quality. Merrion Strand was declassified after the summer of 2020 for being at Poor status for five consecutive years.
Portrane, the Brook beach, Dublin	Multiple and complex causes combined (WWTP, urban and sewage discharges, poor network condition, possible animal contamination) and inadequate data caused problems and doubts in the past. IW investigated closely the case, several actions have been taken and for the next bathing season this beach is reported to be safe. After the bathing season of 2020, Portane's status became Good (it was Poor for the last three years).
Ballyloughane Beach, Galway	Urban-sewage and WWTP seem to be the primary causes, supported occasionally by rainfall events. After the necessary measures, now the beach is reported as a safe BS. To better understand the pressures on bathing water quality, additional higher frequency monitoring should be carried out which can capture water quality during and after rainfall events. After the bathing season of 2020, Ballyloughane's status became sufficient (it has been Poor for four years so far).
Clifden beach, Galway	WWTP discharges, stormwater overflows and agriculture runoff need to be addressed and further investigated. There are no publicly available resources on the updates and outcomes of the progress on Leakage Reduction Program and water supply network improvements. Clifden has been classified as 'Poor' for five years in a row, so it will be declassified as a BS.
Lilliput, Lough Ennell, Westmeath	This BS is surrounded by pastures, agricultural lands and vegetation, where also forest and wetland areas exist. Diffuse agricultural runoff flowing from multiple streams and rivers into the lake, while local (small) WWTPs and any septic tanks need further investigation.

   a. Adding data about the dates of releases and discharge loads from WWTPs, to encourage IW to continue improving the operation and management of WWTPs and networks.
   b. Once a BS is declassified, water quality data are still reported; however, a bi-monthly year-long sampling with genome sequencing is suggested to identify sources and ways to tackle them by LAs (i.e. septic tanks, farms and animal contamination) or IW (WWTPs). This can give more accurate evidence to EPA for identifying sources of contamination.

2. *Identifying the causes – monitoring parameters and sampling frequency*: The determination of pollution sources must be a combinative process, examining the surrounding land uses, the discharges from WWTPs, farming, septic tanks, animal access, etc. close to the BS.
   a. The BWD/2006 requires the monitoring of at least *E. coli* and intestinal Enterococci; however, monitoring only these two parameters cannot cover all contamination causes. Especially in Ireland, the regulation must be modified to address other pollution sources (agriculture, animal contamination, sediments, pesticides, etc.), so more parameters need to be considered.
   b. A continuous review of the monitored parameters should be carried out and published, together with long-term statistical analyses to show the variation of each cause over time (also relevant with the progress tracking of measures).
   c. More frequent monitoring of water quality measurements during spring and autumn months and after rainfall events would generate a clearer picture of the system as a whole, control for seasonality and detect poor management practices. All the examined BS comply with the minimum monitoring frequency as set by the

BWD; however, once a month is not enough to analyze the pollution causes and patterns. The average interval of EU's countries sampling is 13.5 days, the BWD recommends to '*take additional unscheduled samples in anticipation of short-term pollution*', so perhaps the revised BWD must highlight such issues explicitly.

3. *Short-term pollution*: Heavy rainfall leading to runoff-pollution events and SWOs affected at some degree almost all the examined BS.
   a. Sampling data after short-term pollution events are replaced by samples taken 7 days after the end of the incident, according to the BWD. Short-term pollution because of rainfall was proved to be very common in Ireland, so the number of samples' replacement allowed per beach needs to consider that otherwise, it gives a false impression of bathing water quality at certain beaches.
   b. Although early warning systems have been proposed by researchers, there is still limited application. Studying the cause–effect relation of heavy rainfall to water quality detects the rainfall (storm) threshold that can affect a BS above the acceptable quality status. Short-term forecasts that show exceedances of this threshold could be used to warn the public in a timely manner (early warning systems).
   c. SWOs have been found to be a challenging and persistent pressure that needs to be addressed, given the precipitation distribution and trends. IW knows the locations of most SWOs; however, the level of knowledge on discharge volumes, frequencies and duration needs to be further supported and analysed, considering long-term planning (e.g. sustainable urban drainage systems).
4. *Capacity building*: LAs require support for enhanced BS monitoring and management, scientific, technological and financial support.
   a. Upgraded WWTPs can significantly improve water quality, and the SWOs must be also addressed.
   b. To achieve integrated management and knowledge for each case study, catchment-scale approaches should be examined, as all EU and national legislations propose. This will facilitate the development of efficient and targeted actions measures. Integrated catchment-coastal models would be highly valuable and easily transferable, as well as 'whole-of-environment' approaches combined with stakeholder analyses (Alamanos *et al*., 2021b).
   c. In case of data limitations, available data sources can be used for various useful datasets. For example, Alamanos & Linnane (2021) listed many free repositories and demonstrated how the user can access such relevant data.
   d. Cooperating with academic and research institutions for monitoring, analysis, or measures actions (e.g. as in Lilliput, where University College Dublin (UCD) assists the LAs with the analysis of microbial source tracking).
   e. LAs to apply measures to improve the bathing waters status, individual actions to help by bringing rubbish home, cleaning up after dogs, reporting pollution, influence others, etc.

Finally, every successful policy action requires stakeholder engagement, and to achieve that, the understanding of its purpose is essential. Cooperation among key stakeholders and the public, through the delivery of educational and informative campaigns, is crucial.

CONCLUDING REMARKS

Bathing and coastal waters are valuable ecosystems with multiple environmental and economic impacts, highly appreciated by the public (Hynes *et al*., 2014). The effort to achieve excellent water quality for BS needs close investigation for each case, identification of the problems' key factors, and cooperation between relevant authorities, researchers and the public. The BWD provides the guidelines and general recommendations; however, each Member State could best tailor them for their needs to address specific issues.

This article presented a work in progress, a continuous enrichment of a database for the monitoring of the water quality of Irish BS. The integrated character of the database is an important element for future efforts; having more (and different) data greatly support the identification of cause–effect relations and measures. Such approaches can be useful for many countries, especially for the LAs involved.

This article, unavoidably, has limitations mainly referring to its narrowed perspective (analyzing only the case of Ireland); however, most recommendations could be considered by other countries facing similar problems. In the case of Ireland, the recommendations of the previous section support the progress of protecting and improving BS water quality: LAs are expected to start enhancing the monitoring and considering more parameters to their investigations. An important point here is to move from the 'minimum action required to be compliant with the BWD', to a mindset of greater control of the BS. Moreover, many LAs – not only in Ireland – need to move from the stage of investigation to actions. Such observations, supported by evidence, can be particularly useful for the consultation period of the BWD and similar regulations, regarding their monitoring standards, frequency, samplings replacement, data transparency and simple analyses that can be done to explore data interactions and capacity building.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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