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# Aquatic Ecosystems and Climate Changes: Data Gaps in Relation to Flooding Events

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**Abstract**

At European level the strategy on adaptation to climate changes promoted adaptation plans at all levels and has recommended the need to bridge the gaps through applications of actions at local level. In the paper has been remarked that there are some gaps in the European legislation that should be solved through the funding of more research projects and pilot studies; for example the use of microbiological monitoring, not foreseen by the water framework directive, can help to identify and prevent effect adverse on human health. In this study we propose an operative methodology to be applied at local level with the aim to support the institutional requirements for risk management before and after flooding events, based on a multi-criteria approach. This integrated monitoring plan could represent a shared methodology with the aim to give a contribution for the management of the risks of extreme weather events such as flooding for human health and ecosystem protection.

**Keywords:** Aquatic ecosystem; Flooding; Microbiology; Ecotoxicology; Human health; Investigative monitoring

## Introduction

During the past centuries, anthropogenic pressure, urbanization and, climate changes got worst the aquatic ecosystem quality [1]. The effects of climate changes on meteorological parameters give rise to extreme events such as floods, heat or cold waves [2]. Flooding is a major disturbance that impacts aquatic ecosystems and the ecosystem services that they provide and all populations living in the area affected suffer theirs impacts [3-5]. They can damage the environment, infrastructures, properties as well as human health and cultural heritages [6,7]. These impacts can be due to direct contact with floodwaters detritus causing damage to infrastructure, health facilities and deaths due to drowning; also physical trauma, heart attacks, electrocution, carbon monoxide poisoning can occur. Instead, the longer-term effects can appear days, weeks or months later and they are less easily identified, and can they include infectious diseases, vector-borne diseases burn and mental health effects [8]. Several are the factors that enhanced the negative effects of flood events: as the presence of artificialized banks, hydro- morphological alteration, the presence of infrastructures, deforesting, use of agricultural practices harmful for the environment; excessive extraction of groundwater and the soil impermeabilisation that prevents infiltration of water. The flooding and flash flood produce immediate runoff from agricultural, zootechnical areas, water treatment facilities and sewage systems with a progressive mobilization of microbiological, physical and chemical contaminants ensues [9-17]. Further, the spread of any contaminants such as micropollutants can be enhanced also by a range of other climate variables, such as wind patterns snowfall [18].

The spread of bioaccumulative chemical substances (e.g. mercury, dioxins, Polycyclic Aromatic Hydrocarbons (PAH)) enhanced by flooding events, is a signal of a current or future impact on aquatic ecosystems, considering the value of goods like seafood. They affect all levels of aquatic trophic chain causing: changing of bacteria composition, alteration in morphology (teratogenic forms) and in community composition of diatoms as well as the appearance of skeletal abnormalities in fish fauna, and an overall reduction of biodiversity [19,20]. In a certain areas it can generate a future decline of fishing activities, added to other impacts, for instance the decrease of the water level of a lake, used for the abstraction of drinking water, can impact the future water uses and the abundance of aquatic organisms [21].

Further, changes on temperature parameter can affect the biological community causing growth of green algae and diatoms, with the occurrence of harmful algal blooms, as well as fish communities can be altered in terms of size-structures, composition and abundances, in fish fauna [22-24].

Over the last 20 years flood events have been recorded in 49 of the 53 Member States of WHO Region and data indicate that approximately 400 floods have caused the deaths of more than 2000 people [25,26]. At global level many actions and activities have been developed for the prevention and risk management to human health. For example in Europe the aquatic ecosystems assessment is based on the obligations that derive from the laws recommend parameters and criteria used to assess the surface water quality through operational and surveillance monitoring based on biological, microbiological and chemical parameters but no indication is provided on emergency monitoring closely linked to flooding events [27-29]. The Floods Directive 2007/60/EC provides a framework for adaptation and establishes a legal framework for the assessment and management of flood risks across Member States, aiming at reducing the adverse consequences of floods to the human health, the environment, cultural heritage and economic activity and the flood risk management can be summarized in the four phases of emergency management: prevention, preparedness, response and recovery [30]. A survey of countries in the WHO Region highlighted the gaps in the prevention




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of health effects of floods and the availability of timely flood–health response strategies or established action plans [10].

In this study we propose an operative methodology to be applied at local level with the aim to support the institutional requirements for risk management before and after flooding events, based on a multi-criteria approach.

## Identification of Data Gaps

The main gaps that need to be improved to right management of the risks for human health linked by flooding are the following:

- Identification of potential risk area.
- Identification of microbiological, biological and chemical hazards.
- Setting criteria and methods for emergency monitoring programme.
- Risk communication.

## Operative Plan Proposal

In this study we propose an operative methodology to be applied at local level with the aim to support the institutional requirements for risk management before and after flooding events, based on a multi-criteria approach (Figure 1).

The integrative character of the presented methodology is featured by the combination of information on land use, microbiological and chemical risks for human health due to direct and indirect consumption of contaminated water. Considering the identified gaps describe in the last paragraph, the approach to be adopted, to manage the risk linked to aquatic ecosystems caused by the occurrence of flooding events should be built on a combination of microbiological, biological, chemical and ecotoxicological data, land use and hydrological information.

Furthermore it is essential the use of the Geographic Information Systems (GIS) for the identification of risk areas, as foreseen by the mentioned European Flooding Directive [30]. The control should be based on different temporal phase/scales. For the ”pre event” critical areas should be defined together with a control of the priority and emerging sources of risk and the data should be collected on the basis of the current legislation. During the “post event” the monitoring plan should be implemented through the use of parameters linked to the evaluation of the effects and impacts and not necessarily present in the current European legislative framework.

### Identification of potential risk areas

This step includes the individualization and mapping of relevant areas for surveillance programme of waterborne diseases, biological and chemical risks through the use of GIS. Critical areas in floods events are the coastal marine waters, the hydrographic basins with high anthropogenic impacts, the aquaculture areas and also the river mouths. Marine coastal areas are vulnerable to extreme events: the impact of them on these areas depends on the presence of recreational uses as bathing waters, aquaculture and fishing activities. Most of the Italian coastlines for example are characterized by beaches located in the proximity of river mouths. Being these areas a link between coastal and land they represent a strategic point for


**Figure 1**: Overview of implementing action plan proposed.

the surveillance and primary preventions of waterborne disease. Environmental information, such as land use and physical–chemical parameters including nutrients should be collected. Microbiological, biological and chemical data should be gathered from the monitoring programme performed on aquatic ecosystem in compliance with the legislative obligations. Thanks to GIS tool it will be possible integrate environmental and health data/information.

The mapping of critical areas shall take also into account the presence of high population density and major pressures as industrial enterprises (small, medium and large) in order to identify the potential microbiological, biological and chemical hazards. They register several impacts from the contamination of nutrients to hydromorphological alteration. Furthermore, as regards to human health protection, it is useful to know the probability of an increasing of water related diseases that are normally present in these areas and a collaboration with local sanitary units is fundamental for this purpose.

### Hazard identifications

Microbiological risks related to the consumption of contaminated water can occur directly through the ingestion of contaminated water and/or indirectly consuming of fishes, molluscs, vegetables and fruits contaminated, recreational activities [31-33]. There are not enough studies that show a significant statistical correlation between the increasing of infectious disease incidence and flooding events, but only a relationship seems to exist between these infectious diseases and floods in Italy, although further analyses should be carried out to confirm this correlation. [16]. In this context pathogens occurring in the critical areas should be preventively identified. According to One Health perspective we suggest to improve the current obligatory notifications records used in clinical sector of microorganisms of epidemiological relevance with environmental information (i.e. route of transmission in environmental matrices like surface water).

In relation to chemical hazards for surveillance and operational monitoring programmes the European Member States should select the list of chemical parameters for which monitoring should be put in place; the selection should be based mainly on the analysis of the pressures and impacts. The priority European chemical substances discharged in the river basin [34] should be monitored in column water, sediment or biota on a monthly (in case of water column) or yearly basis (in case of sediment and biota); besides the priority substances also river basin specific pollutants discharged in significant quantities should be monitored. For the chemical substances relevant for the areas interested by possible flooding phenomena it is relevant to establish an inventory of the potential sources of pollution both point and diffuses; this knowledge can be useful in the days following the flooding because it can address in an appropriate way the control of chemical substances post-event.

### Implementing monitoring programme strategy

To have a full vision of potential risks carried out from aquatic ecosystem for human health when flood or flash flood occur it is essential setting criteria and methods for investigative/emergency monitoring programme. In the context of Water Framework Directive WFD [28] there are 3 types of monitoring: surveillance, operational and investigative. All these types of monitoring are relevant in the areas at risk of flooding but the methods and criteria for investigative one, must be implemented for its application in flood events. We suggest the following integrated parameters and method to implementing the monitoring in relation of flood events.

### Biological component

The aquatic ecosystem health after floods should be assessed through the analysis of biological community alteration using ecotoxicological assays too. The use of effect based- ecotoxicological tools in the assessment of water quality should be reinforced because these methods have the capacity to detect for example early warning effects caused by mixture of pollutants or emerging pollutants not analyzed by routine chemical monitoring. We suggest to investigate the presence of skeletal abnormalities of fish fauna and the teratological forms of diatoms in biological samples collected in critical area. Their presence must be considered as an early warning by the policy makers to apply prevention measures to protect human health. These communities are already included in surveillance and operative monitoring [28].

### Microbiology component

The knowledge of pathogens present in the risk area represents the basis for emergency procedures in order to protect the health of people that living in the critical area. Moreover, studies have highlighted the value of sediments as indicators of microbiological pollution able to provide information on past pollution events no longer detectable in raw water [16,35,36]. Indeed, they are potential reservoirs for pathogenic bacteria and viruses that can be release into aquatic ecosystem during floods posing a threat to human health. River sediment is an ideal habitat of *Clostridium perfringens* and of others species because in this matrix coexist the main factors, as low oxygen concentration that enhance their survival capability. After floods and appropriate monitoring should be based on set of microbiological indicator able to give full spectrum of pathogens present in water [37]. This set should include not only *Escherichia coli*, and intestinal *Enterococci* according to legislative framework [29,38,39] but also *Coliphages* indicators of enteric virus and the *C. perfringens*, an obligate anaerobe, that indicates the presence of parasitic protozoan and enteric viruses in the water column as *Cryptosporidium sp*., *Aeromonas sp e Giardia* [40,41].

We suggest to apply the use of a microbiological indicators set both to analyses the water column and sediment of risk area after event.

The use of the microbiological indicators set mentioned above is able to provide a full vision of pathogens present in the risk area and also represents the basis for planning emergency and prevention procedures. Further, we suggest according to One Health perspective to improve the current obligatory notifications records of microorganisms of epidemiological relevance used in clinical sector with environmental information (i.e. route of transmission = environmental matrices).

### Chemical component

The obligation of trend monitoring of sediment and biota for some priority substances that has been included in the European directive 2008/105/EC [42] should improve the knowledge of the effects of climate change on the bioavailability of the compounds. For the chemical aspects we suggest to focus on the following aspects:

- Analysis of physico-chemical parameters: it will be necessary to evaluate accurately the changes and the modifications of physico-chemical parameters (e.g., temperature, dissolved oxygen, acidification, conductivity and nutrient enrichment in water columns and sediment) that are the first indicators of changes of the fate of dangerous chemicals substances.
- Analysis of biota in different trophic levels in relation to the local trophic chains.
- Analysis of emerging pollutants. A first list of substances is included in the watch-list of EU [43].
- Use of bioavailability approaches for the metals.
- Detection of ecotoxicological effects.

Chemical analysis of biota, for a set of parameters relevant for the specific areas, should be performed 2-4 times a year on different trophic levels. Translocation procedures using filter-feeder organisms can assess the potential for bioaccumulation of dangerous substances [44] in a water body and should be recommended to improve evaluation of the potential risk of bioaccumulation of a specific substance. Furthermore the monitoring of the new emerging compounds such [45] as pharmaceuticals or personal care products that have been introduced in the environment in the last decades should be enhanced because many of these substances are not destroyed by the depuration plants and after flooding events their concentration can increase. For the metals methods such as the use of biotic ligand models that respond to the chemical variations of the waterbodies caused by climate changes should be implemented.

The European Reach (Registration, Evaluation, Authorization and Restriction of Chemicals) regulation has registered more than 100,000 chemical substances [46]. The effects from the mixture of substances present in the aquatic environment may not be predictable on the basis of chemical analyses alone [47]. To reach the protection goal we also must understand the potential for effects caused by the sum of the chemical substances in the aquatic environment (including emerging pollutants, metabolites and transformation products) and to link the observed effects with cost-effective measures. Chemical analysis should be strictly related to the ecotoxicological evaluations, in this context we think that ecotoxicological techniques can support the monitoring plans pre and post-events in several ways, for example:

- Establishing early warning systems through the detection of biochemical changes (e.g. biomarkers, *in vitro* assays).

- Supporting the selection of monitoring variables, in particular to identify relevant specific pollutants with specific mode of actions.

- Detecting the effects from mixtures of pollutants.

### Risk communication

It is essential to promote preventive action for human health among population living in critical areas. We suggest Educational campaigns according to citizen science approach in order to raise the awareness of potential exposure to contaminants through aquatic ecosystem and the resulting risk of diseases after floods events. We recommend also to promote the importance of good basic hygiene practices to be taken in order to avoid the negative effects on human health after floods. Hence, public health authorities should target their advice accordingly.

## Conclusions

The aim of this study has been to summarize the main data gaps related to the assessment of biological, microbiological and chemical water quality in relation to extreme weather events such as flooding and to propose a pilot study that can become a shared methodology to support the institutional requirements for risk management before and after extreme events, based on a multi-criteria approach. The chosen set of indicators could give useful information for example on microbiological and chemical risks for the population that lives in critical areas and also has the aim to improve emergency and prevention plans when extreme weather events occur. In the paper has been remarked that there are some gaps in the European legislation that should be solved through the funding of more research projects and pilot studies; for example the use of microbiological monitoring, not foreseen by the water framework directive, can help to identify and prevent effect adverse on human health. For the chemical aspects the use of ecotoxicological tools, taken only partially in consideration by the current legislative framework, can support to prevent the chemical risks for the aquatic ecosystems caused by extreme weather events such as flooding. At European level the strategy on adaptation to climate changes promoted adaptation plans at all levels and has recommended the need to bridge the gaps through applications of actions at local level [48]. The methodology of this paper can also be proposed in the context of the future revision of the river basin management plans foreseen by the EU Water Framework Directive as an adaptation measure to climate change issues, in particular flooding.

In conclusion in this paper we suggest:

- To understand and anticipate as far as possible increased exposure, vulnerability, and flood risk the critical area must be mapped.

- To implement the local monitoring strategy pre and post-event with fit for purpose analysis of microbiological, biological, chemical and ecotoxicological parameters.

- Improve the use of innovative tools for the detection of biological and microbiological parameters [49,50].

- To improve the risk-communication in relation to flooding events.

## Authors' Contributions

Conceived and designed the paper SM, LM, MC. Writing of the manuscript SM, MC, LM. Critically revised the manuscript and participated in the discussion of results CP, LT, IL, FC. All authors read and approved the final manuscript.

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