Global environmental changes and the impact on ecosystems and human health

Global environmental changes caused by human activities can modify, sometimes permanently, the structure and the composition of ecosystems (aquatic, land, air). The socio-economic evolution of recent decades has caused the release and emissions into ecosystems of multiple contaminants (chemical and microbiological). Their diffusion, interaction and effects on human health can be sometimes ignored. These changes have caused the progressive loss of biodiversity, the accumulation of contaminants in biota and a deterioration of the chemical and microbiological quality status of environmental matrices. In order to prevent future damage to ecosystems it is urgent to apply innovative, rapid, sensitive monitoring tools that can allow to identify the hazards and prevent risks to human health via appropriate management measures. In this paper, we provide an overview of some European and international approaches to deal with the certain challenges raised by global environmental changes

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Environmental changes and human activities can affect the state of ecosystems and constitute a potential risk to human health and wellbeing. [1]. During recent decades, the increase of water supplies for industrial, irrigation and drinking uses, excessive land use and deforestation, hydro-morphological alterations, emissions of chemical contaminants in the environment (more than 100,000 registered by REACH in Europe) have changed, often permanently, the structure and the composition of ecosystems (aquatic, land, air) reducing biodiversity, accumulating contaminants in biota and resulting in a deterioration of chemical and microbiological quality of environmental matrices. WHO states that (http://www.who.int/globalchange/environment/en/) a new perspective is required which focuses on ecosystems and on the recognition that long-term good health in human populations rely mostly on the continued stability and functioning of the biosphere's life-supporting systems.

Ecosystems are closely connected with the wellbeing and health status of the populations. And signals of ecosystem alteration or deterioration must be considered as an alarm by the policy makers to apply prevention measures to protect human health. There are several examples of ecosystem-human health connection. For instance, an enhanced accumulation of a bioaccumulative chemicals in aquatic organisms is a signal of a current or future impact on seafood, a change of bacteria composition in a lake can be an indicator of a current or future deteriorated quality status of a bathing water area, the reduction of biodiversity in a certain area can generate a future decline of fishing activities and 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. Moreover, equilibrium status of the natural and artificial aquatic ecosystems can be impaired by climate changes. An example are the effects of climate change on weather parameters such as temperature and rain that can cause changes of their distributions giving rise to extreme events such as floods, heat or cold waves [2].

In this paper we describe some examples of monitoring and adaptation approaches in relation to specific challenges caused by the global environmental changes to the ecosystems in a European and international perspective.

The European Approach

The European Water Framework Directive (WFD) [3] is an example of an ecosystem approach for the protection of aquatic ecosystems and human health. The EU WFD is possibly the most significant European legislative instrument in the water field. It is based on an ecosystem approach, aiming to protect the whole aquatic ecosystem including environment and human health. This Directive aims to achieve and ensure the "good ecological and chemical status" of all waterbodies (surface and ground) throughout Europe by 2026 through the updating and implementation of management plans at the river basin level and with the use of a science-policy strategy (Common Implementation Strategy), involving governments, policy makers, researchers, various stakeholders, industrial enterprises, and NGOs. The chemical status assessment and classification are based on the compliance with legally binding European environmental quality standards (EQSs) for selected chemical pollutants (priority substances) of EU-wide concern. EQSs for priority substances are set in the Directive 2008/105/EC, recently amended by the Directive 2013/39/EU [4]. EQSs are designed to protect the environment and human health. In the last years the WFD has also foreseen a mechanism (watch-list) to deal with the emerging chemical substances through the use of a monitoring system in selected monitoring stations at European level. The current watch-list [5] includes some emerging substances such as pharmaceuticals (e.g. diclofenac, E2, EE2) and antibiotics. The assessment of the ecological status takes into account the effects at population and community level, based on the use of specific indices and ecological quality ratios. Good ecological status of the WFD is defined in terms of the values of the biological quality elements (phytoplankton, macroalgae, angiosperms, benthic invertebrate fauna and fish), the hydrological and morphological conditions and physic-chemical elements. Good ecological status (or potential) requires also that the concentrations of the specific chemical pollutants (also called river basin specific pollutants) do not exceed the EQSs set at member state level.

The WFD requires three monitoring programmes:

- Surveillance monitoring: to supplement and validate the impacts analysis, to support the efficient and effective design of future monitoring programs and to assess long-term changes in natural conditions and changes resulting from anthropogenic activity. Monitoring is performed at least once every management cycle (usually every 6 years).

- Operational monitoring: to establish the status of those waterbodies identified as being at risk of failing to meet the WFD environmental objectives and to assess any change in the status resulting from the programs of measures.

  Investigative monitoring: to determine the reasons for exceedances or predicted failure to achieve environmental objectives if the reasons are not already known and to determine the magnitude and impacts of accidental pollution.

Innovative European approaches recommended for monitoring ecosystems

Various projects related to aquatic ecosystems monitoring have been funded by the European Commission (https://ec.europa.eu/programmes/horizon2020/). The tools for a rapid identification (http://publications.jrc.ec.europa.eu/repository/bitstream/JRC92395/lbna26881enn.pdf) of contaminants (chemical and microbiological) represent a great opportunity to implement preventive measures during the emergencies. An example is the European Project Horizon 2020 INTCATCH (*Development and application of Novel, Integrated Tools for monitoring and managing Catchments* http://intcatch.eu/ that has a main goal to recommend and deliver new innovative tools for the monitoring of surface waterbodies in Europe. The tools foreseen by INTCATCH include, *inter alia*, sensors related to heavy metals, nutrients, pH, temperature, pesticides, *Escherichia coli* and metagenomics. The innovative approach that goes beyond the WFD current monitoring programs is based on the connection and integration of the sensors on autonomous and radio-controlled boat platforms. In the context of INTCATCH the use of Next generation sequencing (NGS) metagenomics has the potential to investigate any perturbation of the chemical and ecological status by rapidly determining the microbiome present in a specific waterbody. This genomic tool can give rapid responses in the case of emergencies increasing in frequency due to the effects of climate change. INTCATCH will be tested and validated with the support of stakeholders and citizens in Lago di Garda (Italy), the great Ouse and urban rivers London (UK), Ilyki lake (Greece) and Ter River (Spain).

The most important requirements for a reliable analysis of the ecosystems are: specificity, sensitivity, reproducibility of results, speed, automation and low cost. In addition, the low concentration of contaminants (e.g. pathogenic agents, emerging chemical contaminants such as pharmaceuticals) in aquatic ecosystems require preliminary steps for the collection of large volumes of water and enrichment and concentration of the sample for their detection [6]. Microbiological parameters should deal with the fact that many microorganisms cannot be cultured or can enter in a vital but non-culturally-state (VBNC). Current microbiological monitoring methods are based on culture techniques that measure the growth or the metabolic status of a microorganism after an incubation period. The use of methods focused on the immunological or genetic characteristics of the microorganism would allow a rapid identification of specific microorganisms within a few hours instead of the days required by traditional methods [7]. Molecular biological tools have now greatly enhanced the ability to investigate biodiversity by identifying species and estimating gene flow and distribution of species in time and space. The development of a universal microchip for simultaneous detection of a large number of pathogens in aquatic ecosystem is the main objective of the European project μAQUA—Universal microarrays for the evaluation of fresh-water quality based on detection of pathogens and their toxins THEME [KBBE.2010.3.2-04] [Innovative aquatic biosensors—Call: FP7-KBBE-2010-4] funded by the 7th Framework Programme for Research & Technological Development http://cordis.europa.eu/project/rcn/99122_en.html.

This universal microchip is designed to detect various pathogenic agents (cyanobacteria, bacteria, viruses and parasitic protozoa) and their toxins in the waters. In addition, the project includes the identification of certain species of diatoms, which represent reliable bio-indicators to assess the overall water quality [8]. The molecular methods are developed by the MicroAQUA consortium mainly through the rational use of specific molecular probes combined into a universal microarray chip.

In relation to the chemical monitoring programmes the classical single-chemical risk assessment approach for the management of chemical pollution of waterbodies has some limitations highlighted by recent European projects (e.g. EU EDA-Emerge ITN-FP 7, EU Project Solutions www.solutions-project.eu) because it is not possible to analyze, detect and quantify all substances that are present in the aquatic environment. [9, 11]. Currently, more than 700 emerging pollutants, their metabolites and transformation products, are listed as present in the European aquatic environments by the Norman (Network of reference laboratories, research centres and related organizations for monitoring of emerging environmental substances) network www.norman-network.net. Emerging pollutants (EPs) are defined as synthetic or naturally occurring chemicals that are not commonly monitored in the environment but which have the potential to enter the environment and cause known or suspected adverse ecological and (or) human health effects. It is important to know which are the real effects [12] 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 management objectives. Furthermore, the substances present in the aquatic environment can form mixtures whose effects may not be predictable on the basis of chemical analyses alone. In the context of the WFD, a specific task was foreseen for the elaboration of a technical report [13] on aquatic effect-based tools (e.g. bioassays, biomarkers). The activity was chaired by Sweden and co-chaired by Italy and progressively involved several member states and stakeholders in an EU-wide drafting group of 47 experts. The report has been endorsed by the Strategic Coordination Group of the WFD and by the Water Director Meeting in Vilnius, Lithuania (December 2013) and aims to present the state of the art of aquatic effect-based monitoring tools and to describe in which way these tools can help EU member states to make more efficient monitoring programs (including reduction of monitoring costs). The tools described in the report are categorised into four main groups:

- Bioassays, in vitro and in vivo, which measure the toxicity of environmental samples under defined laboratory conditions, at cellular or organism levels, respectively
- Biomarkers, i.e. biological responses at the cellular or individual levels, measured in field exposed organisms
- Ecological indicators, measuring changes observed at higher biological organization levels, i.e. at population and/or community level
- OMICs (including metagenomics approaches). As mentioned in the WFD report, these effect-based tools can be used:
    - as screening tools to aid in the prioritisation of analysis of waterbodies,
    - to establish early warning systems,
    - to take into account the effects of chemical mixtures or chemicals that are not analysed (e.g. to support investigative monitoring where causes of a decline of specific species are unknown)
    - to provide additional support in water and sediment quality assessment

Approaches recommended for the adaptation to climate changes

The potential role and benefits of treated wastewater reuse as an alternative source of water supply is well acknowledged within international and European strategies [14], in particular in the areas where water scarcity and droughts are likely to be severe and intense due to climate change. Water reuse is a priority area in the strategic legislative agenda of the European Commission and there is need to elaborate quality criteria that can guarantee the protection of human health and environment.

The use of treated wastewater (TWW) can cause negative effects on human health and environment [15]. TWW may contain hazards such as physical, chemical, radiological and microbial agents that can be a risk to human health and therefore, there is a need to define quality criteria and a control system for this type of water.

The EU Project FRAME http://www.frame-project.eu/ (a novel framework to assess and manage contaminants of emerging concern in indirect potable reuse) is funded by the European research initiative "Water JPI (Joint Programming Initiative, Water Challenges for a Changing World). The FRAME project aims towards novel approaches to assess and manage IPR (indirect potable reuse) by: i) the development of an overarching evaluation and monitoring scheme for IPR processes including sound analytical and modelling approaches, toxicological assessment and public health-relevant microbiological parameters; ii) design and testing of reliable and cost-effective treatment strategies and novel treatment approaches; iii) providing water utilities and agencies, as well as regional, national and EU authorities, with a meaningful and reliable decision support tool for future investments and implementations. To apply comprehensive monitoring strategies, analytical methods for a suite of chemical, biological and toxicological parameters have been developed. For the analysis of CECs

(Contaminants of Emerging Concern) these include several multi-residue, sensitive mass-spectrometry-based analytical methods for the determination of several individual CECs as well as methods for the detection/identification of unknown contaminants (non-target methods). The application of advanced treatment options in a multiple-barrier approach is applied at laboratory- and full-scale to test novel and effective treatment options, specifically to improve the removal of CECs, inactivation of pathogens and improvement of other health-related parameters. Detailed fate studies into CECs during water treatment processes are used to unravel the transformation to previously unknown transformation products (TPs). Antibiotic-resistance evaluation will be also included. Bioassays and Biomarkers in course of development will assess the toxicity of the chemical mixtures and unknown compounds. Modelling tools are implemented in the context of Frame to test the performance of novel treatment combinations and are coupled with transport modelling tools to describe the fate of CECs and pathogens in different IPR scenarios. The information gained from experiments and modelling is made accessible via Decision Support Tools, which allow decision makers to estimate IPR performance based on modelling results. The Decision Support Tools are part of a wider communication and decision support strategy to provide guidance for regulation and compliance needs. An assessment and management guidance and a specific handbook for the stakeholders will be also delivered in the context of the project.

Related, the COST-ACTION Nereus ES1403 (New and Emerging Challenges and Opportunities in Wastewater Reuse) http://www.nereus-cost.eu/ is a multi-disciplinary network that intended to determine which of the current challenges related to wastewater reuse are the most concerning for public health and environmental protection, and how these can be overcome. Nereus it is the largest Cost-Action of European Union, it has 31 COST Countries, four neighbours countries and five international partner countries and a Total Number of 371 members and is coordinated by the University of Cyprus. The WG include different arguments: Microbiome and mobile antibiotic resistome, uptake and translocations of microcontaminants, effect-based bioassays, wastewater treatment technologies, risk assessment, and policy development.

The relationship between climate, other environmental changes and citizens well-being has been acknowledged in the Horizon 2020 Project "BlueHealth" https://bluehealth2020.eu/ linking Environment, Health and Climate for Inter-sector Health Promotion and Disease Prevention in a Rapidly Changing Environment" (Call Horizon 2020 research and innovation programme Grant agreement No 666773- Duration: 2016-2020). This project is coordinated by University of Exeter with the collaboration of 9 Partners; BlueHealth aims to understand the effects on health and well-being of exposure to urban blue space in various geographical, climatic, socioeconomic and cultural contexts across Europe, through a multidisciplinary approach based on environmental psychology, ecosystems management, epidemiology, toxicology, landscape and urban planning and design, climate change modelling, social geography, virtual reality, microbiology, health and environmental economics. BlueHealth will also develop key inputs into policymaking and land/water-use planning towards a sustainable use of the blue space.

The International approach

International financing institutions and intergovernmental agencies also play an important role in supporting research on environment, ecosystems, and health. The World Health Organization, Convention on Biological Diversity, World Organization for Animal Health, Food and Agriculture Organization, and World Bank each have discrete programs that address environmental health, climate change and health, One Health, or Ecohealth. The connections are sometimes even included in international frameworks and conventions. For example, health was formally included in the Paris Climate Agreement of 2016. The UN Convention on Biological Diversity formally established a joint work program on biodiversity and health with the World Health Organization in 2012 leading to two comprehensive decisions on biodiversity and health in 2014 and 2016. The World Health Assembly presented a resolution on climate change and health in 2008. And the Montreal Protocol to protect the ozone layer (and human health) came into effect in 1989. Diving more deeply into one organization gives a sense of the nuanced approach needed to address this constellation of related issues within a bureaucracy.

Taking the World Bank as an exemplar, the three 'fields' of climate change and health, environmental health, and one health have been segregated to fit within the structure of the institution, so that subtopics within each field can most closely align with the hosting department's agenda. Environmental health is embedded within the Environment department and tends to focus on (though is not exclusive to) pollution and waste management and ecosystems and health; One Health is based in the Agriculture department has an emerging focus on disease threats at the animal-human health interface; and climate change and health is embedded within the Climate department, focusing on the population health risks and opportunities associated with climate change. The Health department is central to each effort as well, though (in)formal coordinating efforts lie with the each of the other sectors. Specialized work is unique to each silo, yet understanding the interactions amongst each is important for work-planning and optimizing shared knowledge. For example, many of the air pollutants that cause climate change also result in negative respiratory health impacts; as climate change is hastened, various vectors of disease, such as mosquitoes and tsetse flies may shift, thus increasing the risk of certain diseases to both humans and animals. The environmental health dimension of this work may focus on air pollution, one health would focus on animal-human disease transmission, and climate health may consider either or both together to develop strategic policy interventions. And so, it becomes clear that while one group or department must take the lead for purposes of efficiency and delivery, the issues and approach are necessarily multisectoral.

Diving down even further, focusing from one institution to one department reveals the breadth of work that can be accomplished with this siloed, yet inclusive and considerate approach. Over the past three years, the World Bank Climate department (http://www.worldbank.org/en/topic/climatechange) has established the first major program at any international financing institution, addressing climate change and health. The program was built with intentions that specifically addressed World Bank lending, but also serve the broader international environmental health community. The first step was to identify those with the greatest degree of climate change-associated health impact, drawing upon established indices of climate impact and vulnerability to reveal countries at high risk- both in terms of health impacts associated with carbon co-pollutants, such as cardiovascular and respiratory disease, as well as health impacts caused by climate change, like infectious disease, malnutrition, and heat stress. Findings are presented in *Geographic Hotspots for World Bank Action on Climate Change and Health* and point to critical areas in South-East Asia and sub-Saharan Africa. Next it was necessary to undertake a new analysis of climate connections to the health sector, uncovering an enormous opportunity both for the World Bank portfolio and for others designing and operating health systems. This new report [16], *Climate-Smart Healthcare: Low Carbon and Resilience Opportunities for the Health Sector*, links climate change, the health investment, and development. It describes in-depth approaches for building and sustaining health systems that are prepared for climate change and provides tools and resources to help practitioners turn this knowledge into action.

Conclusions

There is considerable need to improve the protection of human health through the investigation, analysis and assessment of the alterations of the ecosystems. The development of efficient, sensitive, rapid and inexpensive tools for monitoring the ecosystems and the detection and assessment of emerging issues should facilitate the control and prevention of diseases caused by pathogens, toxins, or the chemical substances. This approach is strongly recommended by the EU strategic research agenda (e.g. Horizon 2020) and by the UNEP Sustainable Development Goals. The research and policy international experiences described in this paper are examples of science-policies good practices that should be spread at national and local level to better understand and to fight the effects of the global environmental changes. International financing institutions and intergovernmental agencies, also will have a role to play if more sustainable and inclusive solutions are to be achieved that integrate environment, ecosystems and health.

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