VI-136 - METHODOLOGICAL APPROACHES FOR ENVIRONMENTAL RISK PREVENTION IN WATER AND WASTE MANAGEMENT: ANALYSIS OF CASE STUDIES

Sabrina Sorlini
Full Professor at the Department of Civil, Environmental, Architectural Engineering and Mathematics, University of Brescia and Coordinator of the CeTAmb LAB (Laboratory of Documentation and Research in Appropriate Technologies for Environmental Management in Developing Countries), Brescia, Italy. PhD in Sanitary and Environmental Engineering at Milan Polytechnic (Italy). MSc in Civil Engineering at University of Brescia (Italy)
Giorgio Bertanza
Full Professor at the Department of Civil, Environmental, Architectural Engineering and Mathematics, University of Brescia, Brescia, Italy. PhD in Sanitary and Environmental Engineering at Milan Polytechnic (Italy). MSc in Mechanical Engineering at University of Brescia (Italy)
Mentore Vaccari
Assistant Professor at the Department of Civil, Environmental, Architectural Engineering and Mathematics, University of Brescia, Brescia, Italy. PhD in Sanitary and Environmental Engineering at Milan Polytechnic (Italy). MSc in Civil Engineering at University of Brescia (Italy)
Alessandro Abbà
Assistant Professor (fixed term) at the Department of Civil, Environmental, Architectural Engineering and Mathematics, University of Brescia, Brescia (Italy). PhD in Civil Engineering at University of Pavia (Italy). MSc in Civil Engineering
Giovanni Vinti
PhD Student at University of Brescia, Brescia (Italy). MSc in Environmental Engineering at University of Palermo (Italy)

Address[(1)]: Via Branze 43, Università degli Studi di Brescia, Itália - Tel: (39) 030-3711299 - e-mail: sabrina.sorlini@unibs.it

ABSTRACT

Environmental risks account for a large fraction of the global disease burden. The link between environmental risks and Sustainable Development Goals (SDGs) shows that improving environmental conditions is an important element in progressing towards SDGs concerning the health-based targets. The aim of this paper is to present and discuss methodological approaches that can be useful for planning safe water and sanitation systems addressed to reduce the environmental and health risks. Three different case studies has been presented and discussed related to drinking water, wastewater and solid waste. The first case study concerns the Water Safety Plan development for the Drinking Water Supply Systems (DWSS) of a town in northern Italy. The second case study concerns a Wastewater Treatment Plant where bioassays have been conducted on the influent and effluent so as to compare the water cleaning potential of the activated sludge process and additional ozonation, compared to the pollution load to the atmosphere due to energy consumption. The last case study focuses on dumpsites in developing countries and the related potential health risks. In the first case study, the team has studied the DWSS to identify the hazardous events, hazards and risks by means of the application of a semi-quantitative risk matrix approach, proposing new control measures with the aim to reduce the risks. The second case study found the use of tertiary ozonation improves the human health status by reducing the overall impact of about 20-25%, compared to the reference situation. In the last case study has been evaluated groundwater contamination caused by the escape of leachate from dumpsites in developing countries, considering different boundary conditions and finding the area of risk was always very large.

KEY WORDS: Environmental risk, health risk, wastewater, drinking water, solid waste.

INTRODUCTION

Environmental risks account for a large fraction of the global disease burden. Across the total population, 12.6 million deaths globally, representing 23% of all deaths worldwide, are attributable to the environment (PRÜSS-USTÜN *et al.*, 2016). In children under five years, up to 26% of all deaths could be prevented, if environmental risks were removed. Environmental risks to health are all the physical, chemical and biological factors external to a person, and all related behaviors, excluding those natural environments that cannot reasonably be modified. Reducing environmental exposures would greatly reduce the global burden of disease. Environment directly influences health in many ways, including through harmful exposures, inadequate infrastructure and services for water and waste management, degraded ecosystems, environmental risks due to climate change, exposure to air pollution etc. Limited access to appropriate and safe environmental services and infrastructure, such as safe water-sanitation and safe waste management, can affect people health conditions and, consequently, reduce their access to education and job, leading them to poorer conditions. The link between environmental risks and Sustainable Development Goals (SDGs) shows that improving environmental conditions is an important element in progressing towards SDGs concerning the health-based targets. Many strategies can be promoted in order to reduce the environmental risks strictly related to health impacts, e.g. providing safe services for drinking water, sanitation, solid waste collection and management, access to clean fuels and appropriate transportations, etc. Specific methodologies are available and can be applied in order to define safe solutions towards lower environmental risks related to health based targets.

In the past, the basic access to safe water was based exclusively on the use of improved water sources (e.g, piped water, deep well, etc.) but this indicator was considered inappropriate, therefore new approaches and methods have been introduced in order to minimize the health risks related to drinking water consumption. The Water Safety Plan (WSP) is an innovative risk assessment and management approach aimed at ensuring the safety of water for human consumption in the entire drinking water supply system (DWSS), from catchment to consumer (WHO, 2004; BARTRAM *et al.*, 2009). Recently, the WSP has been included in European Directive 2015/1787 (EU, 2015) concerning water quality intended for human consumption. This approach is aimed at identifying and drastically reducing water contamination in the entire drinking water system.

Wastewater discharge is a major source of pollution. Even if proper collection and treatment can drastically reduce the impact, the adoption of protocols for assessing the environmental footprint (and impact on human health) of WWTPs is being used in some circumstances (e.g. comparison of alternative options). Since during wastewater treatment (normally by biological process and in some cases with additional tertiary treatment) pollutants are transformed, intermediate compounds are also generated as by-products, that may be even more toxic than the parent compounds. Moreover, adding treatment stages to a conventional WWTP means also increasing chemicals and/or energy consumption. This, eventually leads to a secondary impact on the environment (and human health), for example related to increased gaseous emissions. From the one side, bioassays which are able to directly measure the combined effect of unknown pollutants in water and sludge are being proposed and, from the other hand, models for comparing the environmental impact on different environmental domains (e.g. water bodies vs atmosphere) are being developed.

Solid waste is a global issue that if not properly dealt with poses a threat to public health and the environment. While in developed countries Municipal Solid Waste (MSW) generation rates are beginning to stabilize, as economies continue to grow rapidly in developing countries per capita waste generation rates are increasing steadily. Moreover, in low and middle economies, uncontrolled open dumpsites are more widely employed than controlled and engineered landfills (ISWA, 2012). Waste disposed of in dumpsites can pose several public and environmental health risks including groundwater pollution (YAN *et al.*, 2015), heavy metals contamination in the soil (IHEDIOHA *et al.*, 2017), as well as the production of greenhouse gas emissions (GOLLAPALLI *et al.*, 2018) and volatile organic compounds (VOCs) (KUMARATHILAKA *et al.*, 2016).

OBJECTIVES

The aim of this paper is to present and discuss methodological approaches that can be useful for planning safe water and sanitation systems addressed to reduce the environmental and health risks. Three different case studies will be presented and discussed related to the water and sanitation sector.

The first case study concerns the WSP development for the Drinking Water Supply Systems (DWSS) of a town in northern Italy, that is representative of many situations of northern Italy, concerning both the type of source water contamination and the technical solutions adopted in the DWSS.

The second case study concerns a WWTP where bioassays have been conducted on the influent and effluent so as to compare the water cleaning potential of the activated sludge process and additional ozonation, compared to the pollution load to the atmosphere due to energy consumption.

The last case study (VACCARI *et al.,* 2018) focuses on dumpsites in developing countries and the related potential health risks, modeling the flow of a range of contaminants in leachate, through a conservative model, taking into account the path the pollutant makes to reach the water table and the point of exposure. Specifically, the objective of this study was to examine the contaminated plume and the variation of the area where the risk can be considered admissible.

METHODOLOGY

The environmental and heath related risks for the DWSS have been evaluated according to the Water Safety Planning approach whose objectives are to describe and analyse the drinking water supply chain; identify all the factors that can cause a risk of contamination; eliminate or mitigate these factors; prevent possible re-contamination. A detailed description of this methodology is described in BARTRAM *et al.* (2009). The case study presents the application of this approach to the DWSS of a medium-size town (16,000 inhabitants) located in northern Italy.

The investigated WWTP (150,000 p.e. nominal size) treats a mixed municipal – textile wastewater. It is an activated sludge plant (pre-denitrification configuration) equipped with coagulation-flocculation and tertiary ozonation. A monitoring campaign was conducted for the detection of some selected EDCs (Endocrine Disrupting Compounds) and for measuring toxicity by means of several bioassays: algal growth inhibition, bioluminescence inhibition and acute toxicity test (for baseline toxicity); an E-Screen-like assay (for estrogenic activity); Ames, Allium cepa and Comet tests (for mutagenic/genotoxic activity). Details are reported in PAPA *et al.* (2016a). A second step of the study consisted in the application of an innovative model for the assessment of global damage on human health related to the environmental footprint of different treatment options. The procedure is fully described in PAPA *et al.* (2016b). As for the impact due to residual pollution in the effluent, the key parameter adopted in this approach is the DALY (Disability Adjusted Life Years), as defined by World Health Organization (WHO, 2008).

Groundwater contamination caused by the escape of leachate from a landfill or a dumpsite has to take into consideration the following processes (APAT, 2005):production of leachate in the landfill; leachate flux through any holes present in the liner system or through the soil if a liner system is absent; leachate flux through the unsaturated (vadose) zone; leachate mixing with the aquifer; migration of the contaminants through the groundwater.

This last step can be evaluated the migration of contaminants via groundwater, in the study case the concentration was calculated by means of the Domenico analytical model (DOMENICO, 1987). Some conservative hypotheses were adopted: i) steady-state condition; ii) contaminants are not degraded. The Domenico model has been combined with the carcinogenic or toxic risk related to a chosen range of contaminants present in the leachate (As, Cd, Cu, Pb, Ni, Zn).

Starting from chosen risk-acceptability criteria, an inverse modelling approach was employed, fixing the maximum admissible concentration of contaminant under the accepted level of risk and defining the borders of the related area of risk for the contaminated plume beyond which the risk is acceptable. Since dumpsites in developing countries may have very different sizes and the boundary conditions may vary as well, a sensitivity analysis was performed to study the influence of the input parameters.

RESULTS

1) Case study 1: Water safety plan applied to a DWSS in the North of Italy.

The drinking water treatment plant (DWTP) receive groundwater (200 m depth) containing the following main contaminants: arsenic (10-12 µg L^{-1}), iron (70-80 µg L^{-1}), manganese (95-100 µg L^{-1}) and ammonia (0.7-1 mg L^{-1}). These pollutants are usually present in the groundwater in northern Italy and the treatment chain is often used in many DWTPs. The schematic diagram of DWTP presents a chemical pre-oxidation with oxygen, followed by $FeCl_3$ addition defore biological filtration, activated carbon absorption and final disinfection with NaClO. The WSP team have studied the DWSS with the aim to identify the hazardous events, hazards and risks by means of the application of a semi-quantitative risk matrix approach. The main results are reported in Table 1. In the first risk assessment (without the implementation of control measures adopted), 130 hazardous events and 148 hazards were detected.

As example, concerning the precipitation with $FeCl_3$, the coagulant dosage pump could be affected by a breaking event, involving high concentration of arsenic in distributed water, with a chemical contamination. Considering the historical data, this hazardous event and its related hazard happen once a year, so they are unlikely. Therefore, the risk rating is medium. Moreover, as concerns the water distribution network, biofilm erosion could affect pipes. In this case, microbial pathogens can be found in water and, therefore, the severity of consequences is maximum (microbial contamination). The historical data of biofilm monitoring in the distribution system show that this hazardous event and hazard are likely. Therefore, the risk rating is very high.

After this step, the current control measures were identified and validated, and risks were reassessed. In the treatment plant, in order to control the $FeCl_3$ dosing pump operation and thus the effectiveness of arsenic precipitation, in situ inspections are regularly carried out, but the pump periodic revision is not done. Therefore, the likelihood can not be reduced and the risk rating remains medium. In the water distribution network, to control biofilm formation in pipes, a periodical biofilm removal is carried out. Considering this control measure, the likelihood can be reduced from likely to rare, so that the risk becomes low.

So, new control measures were proposed with the aim to reduce the risks with medium, high and very high rating. In order to control $FeCl_3$ injection, the dosing pump could be connected to remote control that triggers alarms if the pump is not working. Moreover, jar test at laboratory scale can be performed to verify the effectiveness of the arsenic precipitation process. As concerns the distribution network the control measures proposed are the installation of rechlorinated points in the network and in situ inspections.

Table 1. WSP application: main results.

Process step	Hazardous event (hazard type)	R rating (before considering controls)	In place control measure	Validation	R rating (after considering controls)
Precipitation with $FeCl_3$	Dosage pump breaking (chemical)	Medium	• In situ inspection • Pump revision • Alarms	Effective Not effective Effective	Medium
Distribution network	Biofilm erosion (microbial)	Very high	Biofilm removal	Effective	Low
	Vandalism (chemical/physical/microbial)	High	No controls in place	Not effective	High

Risk score: low (<6); medium (6-9); high (10-15); very high (>15).

2) Case study 2: ranking wastwewater treatment options by assessing the impact on human health.

The main results of the monitoring campaign conducted on the studied WWTP can be summarized as follows: around 90% removal efficiency of the target EDCs (final NP concentration < 0.3 µg/L); reduction of the baseline toxicity; removal of the entire estrogenic influent load; not effective reduction of the mutagenic activity (details can be found in PAPA et al., 2016a).

Data gathered during the monitoring campaign and other previous works (PAPA *et al.*, 2013), were used for comparing the secondary and secondary+tertiary treatment options based on the impact on human health. This was estimated in terms of DALY, with reference to both air and water pollution, and then converted in an economic value (to be intended as a social cost). It was estimated that the impact related to water declines from around 6 €/PE/y in case no treatment is applied, down to about 0.5 €/PE/y in case tertiary ozonation is used.

On the other side, the air pollution generated by energy consumption accounts for 1.3 €/PE/y for the conventional secondary treatment, up to 1.7 €/PE/y, with final ozonation. As a whole, the use of tertiary ozonation improves the human health status by reducing the overall impact of about 20-25%, compared to the reference situation (conventional activated sludge treatment, alone).

3) Case study 3: An analysis of the risk posed by leachate from dumpsites in developing countries.

Figure 2 shows the area beyond which the risk can be considered admissible, i.e. the area beyond which people may build and use wells without the risks related to the presence of a dumpsite.
For all the cases, the area of risk is very large. For example, the carcinogenic risk for adults is nearly 6000 m long, and 4000 m long for a child.

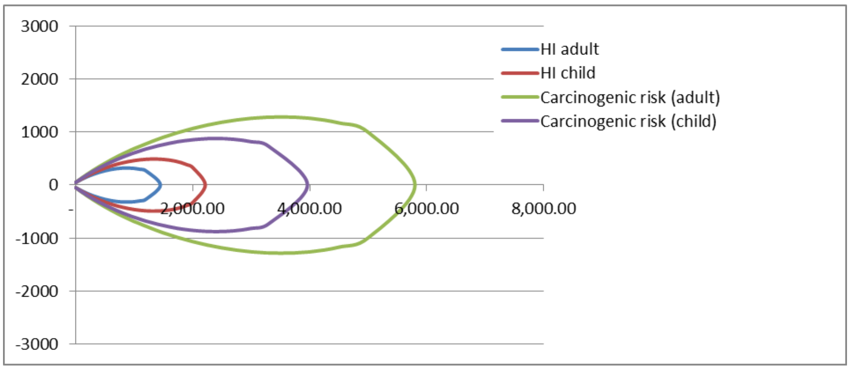

Figure 2. Estimated area of risk with regard to both carcinogenic and toxic (not carcinogenic) contaminants. The values along the axes are expressed in meters.

Table 2 presents the results of the sensitivity analysis. The outputs from various input values are compared with the respective "baseline" cases through the relative sensitivity coefficient (S) calculated as follows:

$$S=|(\Delta b/b)\times(a/\Delta a)| \qquad \text{equation (1)}$$

where a and b are baseline input and output values, Δa and Δb are input and output range, respectively.
The sensitivity analysis results indicate that model output "x" is very sensitive to the model input parameters $C_{gw,0}$ (concentration of contaminant in the leachate) and d_a (the depth of the groundwater).

Table 2. Sensitivity analysis for the proposed model

Input parameter	Value	Factor of input change from baseline	Model output x (m)	Factor of x difference from baseline	Relative sensitivity S
$C_{gw,0}$ [mg/l]	1.55 (baseline)	---	5,797.3	---	0.5783
	0.155	0.1	1,831.2	0.33	
	3.1	2	8,200.7	1.50	
d_{WT-D} [m]	10 (baseline)	---	5,797.3	---	0.1492
	5	0.5	6,693.6	1.22	
	40	4	3.666.5	0.67	
K_s [m/s]	10^{-8} (baseline)	---	5,797.3	---	0.0002
	10^{-10}	0.01	5,797.3	---	
	10^{-6}	1000	5,680.1	0.98	
d_a [m]	20 (baseline)	---	5,797.3	---	0.4712
	10	0.5	4,100.7	0.71	
	40	4	8,198.4	1.41	
L_{pr} [m^3/y]	3,000 (baseline)	---	5,797.3	---	0.0001
	1,000	0.33	5,795.0	0.9996	
	10,000	3.33	5,797.3	---	
A [m^2]	10,000 (baseline)	---	5,797.3	---	0.0384
	2,500	0.25	4,100.2	0.70	
	250,000	25	9,607.0	1.66	

CONCLUSION

The WSP proposal for Mortara was very useful not only as a risk mitigation approach, but also as a cost-effective tool for water suppliers. Furthermore, this approach will reduce public health risk, ensure a better compliance of water quality parameters with regulatory requirements, increase confidence of consumers and municipal authorities, and improve resource management due to intervention planning. Further, some new control measures are proposed by the WSP team within this work.

The coupled application of a battery of bioassays and of a model for a human health damage-oriented assessment revealed to be a successful strategy for the evaluation of tertiary treatment options. Indeed it resulted that, when a secondary biological process (activated sludge system) is equipped with a final ozonation stage, a reduction (around 20-25%) of the overall impact (on atmosphere and hydrosphere) can be achieved, thus moving in the direction of improving the human health protection.

Increasing quantities and the hazardousness of waste being disposed of in dumpsites in developing countries mean there are increasing risks posed to the environment as well as to the public health of people living in proximity to the sites (COLLIVIGNARELLI *et al.*, 2011). As consequence, there is a need for further studies that provide a holistic evaluation of the risk potential in order to minimize these risks.

The importance of the presented model is related to the fact that in developing countries dumpsites are common as well as the weakness of suitable tools to assure healthy conditions for nearby communities involved. The outputs from the model could inform more effective policies, enforcement, finance and suitable skills and competencies. The procedure followed can represent a first step in a risk analysis or help to evaluate the area of risk beyond which a community may build and use safety wells for drinking water.

REFERENCES

1. APAT. Criteri Metodologici per l'Applicazione Dell'Analisi Assoluta di Rischio Alle Discariche. Agenzia per la Protezione Dell'Ambiente e per i Servizi Tecnici (APAT), Rome, Italy, 2005. Available online: http://www.isprambiente.gov.it/it/temi/siti-contaminati/analisi-di-rischio (accessed on 13 June 2018).
2. BARTRAM, J.; CORRALES, L.; DAVISON, A.; DEERE, D.; DRURY, D.; GORDON, B., HOWARD, G., RINEHOLD, A., STEVENS, M. Water Safety Plan manual: step-by-step risk management for

drinking-water suppliers. Geneva: WHO – WORLD HEALTH ORGANIZATION, p. 108, 2009. ISBN 978 92 4 156263 8.

3. COLLIVIGNARELLI, C.; VACCARI, M.; DI BELLA, V.; GIARDINA, D. Techno-economic evaluation for the improvement of MSW collection in Somaliland and Puntland. Waste Manag. Res., v. 29, p. 521–531, mai. 2011.
4. DOMENICO, P.A. An analytical model for multidimensional transport of a decaying contaminant species. J. Hydrol., v. 91, p. 49–58, mai. 1987.
5. GOLLAPALLI, M.; KOTA, S.H. Methane emissions from a landfill in north-east India: Performance of various landfill gas emission models. Environmental Pollution, v. 234, p. 174–180, mar. 201
6. IHEDIOHA, J. N., UKOHA, P. O., EKERE, N. R. Ecological and human health risk assessment of heavy metal contamination in soil of a municipal solid waste dump in Uyo, Nigeria. Environ Geochem Health, v. 39, p. 497-515, 2017.
7. ISWA (International Solid Waste Association). State of the nation report: landfilling practices and regulation in different countries. ISWA, 6 p, 2012.
8. KUMARATHILAKA, P.; JAYAWARDHANA, Y.; BASNAYAKE, B.F.A.; MOWJOOD, M.I.M.; NAGAMORI, M.; SAITO, T.; KAWAMOTO, K.; VITHANAGE, M. Characterizing volatile organic compounds in leachate from Gohagoda municipal solid waste dumpsite, Sri Lanka. Ground Water. Sustain. Dev. 2016, v. 2–3, p. 1–6, 2016.
9. PAPA, M., ALFONSÍN, C., MOREIRA, M.T., BERTANZA, G. Ranking wastewater treatment trains based on their impacts and benefits on human health: a “Biological Assay and Disease” approach”. Journal of Cleaner Production, v. 113, p. 311-317, feb. 2016b.
10. PAPA, M., CERETTI, E., VIOLA, G.C.V., FERETTI, D., ZERBINI, I., MAZZOLENI, G., STEIMBERG, N., PEDRAZZANI, R., BERTANZA, G. The assessment of WWTP performance: towards a jigsaw puzzle evaluation? Chemosphere, v. 145, p. 291-300, feb. 2016a.
11. PAPA, M., PEDRAZZANI, R., BERTANZA, G. How green are environmental technologies? A new approach for a global evaluation: the case of WWTP effluents ozonation. Water Res. v. 47, p. 3679-3687, jul. 2013.
12. PRÜSS-USTÜN, A., WOLF, J., CORVALÁN, C., BOS, R., NEIRA, M Preventing disease through healthy environments - A global assessment of the burden of disease from environmental risks, World Health Organization, p. 1-176, 2016.
13. VACCARI, M., VINTI, G., TUDOR, T., (2018). An Analysis of the Risk Posed . Leachate from Dumpsites in Developing Countries. Environments v. 5 (9), 17 p., set. 2018.
14. WHO - WORLD HEALTH ORGANIZATION. Guidelines for Drinking-water Quality. 3rd ed. Geneva, 540 p., 2004. ISBN 92 4 154638 7.
15. ______. The global burden of disease: 2004 update. World Health Organization Publishing, Geneva, Switzerland, 2008. Available at www.who.int/evidence/bod (last viewed on 15 July 2015).
16. YAN, H.; COUSINS, I.T.; ZHANG, C.; ZHOU, Q. Perfluoroalkyl acids in municipal landfill from China: Occurrence, fate during leachate treatment and potential impact on groundwater. Sci. Total Environ. v. 524–525, p. 23–31, ago. 2015.